Alternative
Field Crops
Manual

University of Wisconsin–Extension,
Cooperative Extension
University of Minnesota
—Center for Alternative Plant &
Animal Products
—Minnesota Extension Service

Alternative Field Crops Manual

Introduction

This Alternative Field Crops Manual addresses the need for detailed information on the production of a number of agronomic crops adapted to the upper Midwest. Our intent is to provide county extension agents and others in educational roles a concise, uniform source of information on those field crops which may be considered as alternatives to traditional farm commodities.

The manual is a joint project between the University of Wisconsin Cooperative Extension Service, the University of Minnesota Extension Service and the Center for Alternative Plant and Animal Products. Extension specialists from both states have written or reviewed each chapter to insure accuracy and applicability of information and recommendations.

Inclusion of a crop in this notebook is for educational purposes only; no endorsement of any particular crop is implied. Individual growers should consider the following factors in determining whether a crop might be a viable alternative in their particular situation:

1. Market availability-Amount of demand for the product, market location and transportation to market.
2. Projected cost of production vs. projected yields and price.
3. Producer's resources-Land (suitable soil), irrigation capability, available labor, equipment, capital, and personal goals and interests.
4. Specific crop requirements and adaptation.

Further information may be available from: University of Wisconsin Cooperative or Extension Service, Department of Agronomy, Madison, WI 53706, Telephone (608)-262-1390, Center for Alternative Plant and Animal Products, 340 Alderman Hall, University of Minnesota, St. Paul, MN 55108, Telephone (612)-624-4217

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Adzuki Bean

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I. History:

The adzuki bean (*Vigna angularis*) has been grown and used for many centuries in the Orient. It was introduced to Japan from China about 1000 years ago and it is now the sixth largest crop and is a frequent subject in Japanese scientific publications. It is a cultigen not found in the wild and its center of origin is unknown but variously proposed to be China, India or Japan. Erect plant types are currently grown in northern provinces of Japan while the branching, vining types are cultivated in China, Manchuria and other warmer climate areas.

The major part of the Chinese crop is produced in the Yangtse River Valley. It also grows in south China, Korea, New Zealand, India, Taiwan, Thailand, and the Philippines. Its principal use throughout the Far East is as a confectionery item. It is cooked and combined with varying proportions of sugar, water, starch, plant gums, and other ingredients, and consumed as such or in combination with other foods. The single largest use of these so-called "ann" products is as fillings for bread (annpan), steamed breads or dumplings and sweet cakes. At least 50 other beans and legumes are also used to make these pastes, but the adzuki bean is the most prized, in large part due to its desirable red color, but also due to a delicate flavor and to the characteristic grainy texture of the pastes made from it.

II. Uses:

This crop is consumed directly as food, with little processing. Therefore, quality is important. Dark red color and a general plump, healthy appearance of seeds are the quality factors a buyer considers.

III. Growth Habits:

Adzuki bean is a legume. It germinates by epicotyl growth, leaving the cotyledons below the soil surface. They have an indeterminate growth habit which results in completely mature pods (1/8" diameter by 5" long), brownish in color, along with slightly yellow and completely green pods on each plant. Plants generally mature in 110 to 120 days after planting and are 18-25 inches tall.

IV. Environment Requirements:

A. Climate:

Adzuki bean has similar climatic requirements to soybean or drybean.

B. Soil:

Soil requirements for adzuki bean are similar to that of drybeans.

C. Seed Preparation and Germination:

Seed treatments for fungi, insects and bacteria are recommended.

V. Cultural Practices:

A. Seedbed Preparation:

A well prepared seedbed is advantageous to provide good soil to seed contact which aid in germination.

Table 1: Maintenance N, P_2O_5 and K_2O recommendations for adzukis.

	Nitrogen Soil Organic Matter (T/A)					
Grain Yield	<21	21–35	36–75	>75	Phosphate	Potash
bu/A	lb N/A				lb P_2O_5/A	lb K_2O/A
10–20	20	10	10	5	15	20
21–30	30	20	10	5	20	30
31–40	40	30	10	10	30	60

B. Seeding Date:

Adzukis are very slow to emerge, especially if the soils are cool (50° –55°F). Seedlings emerge in about 10–14 days when planted in late May. Earlier planted adzukis may take up to 20 days to emerge. Adzukis planted between May 11 and June 7 have yielded well at several Minnesota locations.

C. Method and Rate of Seeding:

Seeding rate should achieve 6 plants per foot of row in 30-inch row spacings. This seeding rate will achieve a plant population of approximately 105,000 plants per acre, (which is comparable to navy bean recommendations) and will require approximately 30 pounds of seed (25–35 pounds). Because of seed size and germination rate differences, growers should calculate rates based on their seed lot. Proper planting depth (1 1/2"), moist soil, and good seed-soil contact are required for uniform stands.

D. Fertility and Lime Requirements:

Legumes require neutral to alkaline soil for maximum N fixation by nodule bacteria. Soils with pH 5.8 to 6.4 have been used for adzuki production with few problems. Soils should be tested and, if necessary, limed to at least pH 6.0. Dolomitic limestone would need to be applied at least one year prior to adzuki production. Soils need to have medium to high soil test levels of P and K to ensure adequate fertility levels for maximum crop yield. In Wisconsin, these soil test levels are 31 to 60 lbs per acre and 221 to 300 lb K per acre depending on subsoil category. If necessary, soils should be amended with P_2O_5 and/or K_2O prior to seeding based on soil test results. Maintenance phosphorus and potassium requirements are very similar to other edible beans (i.e. navy) and fertilizer equivalent to crop nutrient removal should be applied annually in order to maintain adequate soil test levels. Table 1 lists the maintenance P_2O_5 and K_2O necessary for grain yields ranging from 10 to 40 bu per acre. Some nitrogen is necessary to ensure good nodulation even though adzukis are legumes that have the ability to fix nitrogen if proper inoculation (Inoculant EL, Nitragin Company, Milwaukee, WI 53209) has been applied to the seed prior to planting. Table 1 also gives recommended N rates based on both crop yield and soil organic matter content.

E. Variety Selection:

The most widely grown variety in the Upper Midwest is a Japanese import, "Takara" which was brought in from Japan in 1978. The variety "Minoka", a largeseeded adzuki bean, was released by the Minnesota Agricultural Experiment Station in 1980 but has not been widely grown.

F. Weed Control:

Adzuki beans are poor competitors against weeds because of early slow growth, so a combination of chemicals and cultivation are required.

1. Mechanical: Select fields with relatively light weed pressure to grow adzuki beans. Rotary hoe 7 to 10 days after planting to kill the first flush of weeds as they emerge. This should give a sufficient height difference between weeds and the crop to effectively use row cultivation. Delay the first cultivation until the primary leaves are fully developed. Cultivate a second time 10 to 20 days later, if needed.

2. Chemical: Treflan (3/4–1.0 qt/A) alone or in combination with Amiben (1 gal/A) as a preplant incorporated treatment has given the most consistent weed control. Amiben can also be applied alone as a preemergence treatment. Basagran (3/4 pt/A) is an approved broadleaf herbicide for postemergence use. Many of the other herbicides used on edible beans should not be used on adzuki beans.

G. Diseases and Their Control:

White mold (*Sclerotinia* sp.) and a bacterial stem rot (*Pseudomonas adzukicola*) have been problems in adzuki bean production fields in the past.

To help prevent problems with these and other diseases in adzukis a good rotation program (small grains and/or corn), use of disease-free seed, and a spray program should be implemented.

H. Insects and Other Predators and Their Control:

No information available.

I. Harvesting:

Adzukis mature later than some other edible beans. About 118 days is a typical maturity period. depending upon the growing season. Mid-September is a typical harvest date.

The indeterminant growth habit of the plant means that there will be completely mature pods (1/8" diameter by 5" long), brownish in color, along with slightly yellow and completely green pods on each plant. The stems may be slightly green with several green upper leaves present.

Some growers pull and windrow adzukis early in the morning to allow drydown, followed by combining later in the day. Others have direct combined the beans with grain headers or used row crop headers.

Shattering of pods is common, so care is needed to prevent large harvest losses. Selection of harvest maturity is also important. Delaying harvest until late in the season or late in the day will likely increase harvest losses. Slower speeds and opening the concaves to avoid splitting beans and damaging the seed is also necessary. The pods shatter very easily to release the seeds.

VI. Yield Potential and Performance Results:

Research plot yields of adzuki bean in Minnesota have ranged from 0 to 4,000 lb/a and averaged about 1400 lb/a. Yields have been the highest on the lighter soils under irrigation. The management required to produce good yields are similar to that used for other edible beans.

VII. Economics of Production and Markets:

Adzuki markets are limited and acreage is contracted in advance of planting. Quantity use of adzuki products are presently limited, but new markets are being developed domestically and overseas.

VIII. Information Sources:

- Adzuki Bean Cultural Information. 1987. L.L. Hardman. University of Minnesota Extension Service, St. Paul, MN.
- Varietal Trials of Farrn Crops. 1988. Report No. AD-MR-1953, Univ. of Minnesota Agric. Exp. Sta. St. Paul, MN.

Amaranth

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I. History:

Amaranth, an ancient crop originating in the Americas, can be used as a high-protein grain or as a leafy vegetable, and has potential as a forage crop. Grain amaranth species have been important in different parts of the world and at different times for several thousand years. The largest acreage grown was during the height of the Aztec civilization in Mexico in the 1400's. The past two centuries grain amaranth has been grown in scattered locations, including Mexico, Central America, India, Nepal, China, and Eastern Africa. Research on amaranth by U.S. agronomists began in the 1970's, so optimum production guidelines and uniform, adapted varieties have not yet been fully developed.

A few thousand acres of amaranth are commercially grown in the United States, and markets for that small acreage are fragile but developing each year. Acreage has increased during the 1980s. Growers are advised to begin with a few acres, and to have a contract or identify buyers before planting the crop.

II. Uses:

A. Food Uses:

Grain amaranth has been used for food by humans in a number of ways. The most common usage is to grind the grain into a flour for use in breads, noodles, pancakes, cereals, granola, cookies, or other flour-based products. The grain can be popped like popcorn or flaked like oatmeal. More than 40 products containing amaranth are currently on the market in the U.S.A.

B. Nutritional Value:

One of the reasons there has been recent interest in amaranth is because of its useful nutritional qualities. The grain has 12 to 17% protein, and is high in lysine, an essential amino acid in which cereal crops are low. Amaranth grown at Arlington, WI in 1978 had protein levels of 16.6 to 17.5%. The grain is high in fiber and low in saturated fats, factors which contribute to its use by the health food market. Recent studies have linked amaanth to reduction in cholesterol in laboratory animals.

C. Forage Uses:

Little is known about the production and utilization of amaranth as a forage. The leaves, stem and head are high in protein (15-24% on a dry matter basis). A Minnesota study (1 year) on amaranth forage indicated a yield potential of 4-5 tons/acre dry matter, with crude protein of the whole plant at 19% (late vegetative stage) to 11-12% (maturity) on a dry basis. A relative of grain amaranth, redroot pigweed, (*Amaranthus retroflexus*), has been shown to have 24% crude protein and 79% in vitro digestible dry matter. Pigweeds are known nitrate accumulators, and amaranth responds similarly. Vegetable amaranths, which are closely related, produced 30 to 60 tons/a of silage (80% moisture) on plots in Iowa. In areas where corn silage yields are low due to moisture limitations, grain amaranth may become a suitable silage alternative after further research.

III. Growth Habits:

The two species of grain amaranth commonly grown in the U.S. are *Amaranthus cruentus* and *Amaranthus hypochondriacus*. Grain amaranths are related to redroot pigweed, but are different species with different characteristics and have not become weeds in fields where they have been grown. The grain amaranths have large colorful seed heads and can produce over 1000 pounds of grain per acre in the upper Midwest, though a portion of this grain yield may be lost in harvesting.

Grain amaranth plants are about five to seven feet tall when mature, and are dicots (broadleaf) plants with thick, tough stems similar to sunflower. The tiny, lens-shaped seeds are one millimeter in diameter and usually white to cream-colored, while the seeds of the pigweed are dark-colored and lighter in weight.

IV. Environment Requirements:

A. Climate:

Amaranthus is a widely adapted genus, and can be grown throughout the Midwestern and Western U.S. Grain amaranth is reportedly drought-tolerant, similar to sorghum, provided there is sufficient moisture to establish the crop. Amaranth responds well to high sunlight and warm temperatures. Early season frost damage is not a problem because the crop is not sown until late May or early June. However, frost plays an important role in the harvest of the crop. Since amaranth is an annual crop native to the southern latitudes of North America, it does not mature completely in the upper Midwest's short growing season. A frost is usually necessary to kill the crop so that the plant material will be dry enough to harvest.

V. Cultural Practices:

A. Seedbed Preparation:

Seeds are very small, so it is important to have a fine, firm seedbed. Seedbed preparation can be done with a field cultivator or disk; followed by cultipacking or spiketooth harrow and planting, preferably using a planter with press wheels. Seeds should be planted no more than 1/2 inch deep, depending on soil texture and surface moisture at planting time. Heavy textured soils should be avoided. If crusting is a problem, rotary hoeing at a slow speed may be helpful. Poor emergence, as low as 50%, is not uncommon, Since seeds are shallow planted, there is potential for them to wash out on sloping ground.

B. Seeding Date:

The crop is usually sown in late May or early June when the soil temperature is at least 65°F, and after early weed flushes have been controlled.[1]

C. Method and Rate of Seeding:

An optimum plant population has not been established, but one-half to two pounds of seed per acre is considered suitable (approximately 600,000 seeds per pound). Row spacing should be based on the cultivator equipment available. A number of planter types have been used successfully to deal with the small seeds of amaranth. Approaches that have proven successful include: using a vegetable planter with a small plate appropriate for carrots or celery; installing special amaranth seed plates in a sugar beet planter; using the in-furrow insecticide application equipment as a planter; or using a standard grain drill. Grain drills are not recommended due to problems in controlling seeding rate and depth, but they can be used if the amaranth seeds are diluted with a "carrier" like ground corn. A mixture suitable for drilling consists of one-half pound of amaranth with four and one-half pounds of ground corn. Set the drill for a seeding rate of five pounds per acre.

D. Fertility and Lime Requirements:

Little data are currently available on the pH and fertility requirements of amaranth. Amaranth is adapted to soils that are slightly acidic to slightly basic (pH 6.5 to 7.5). Consideration of the pH requirement of rotational crops should also influence the lime recommendation for amaranth.

The fertility requirements of amaranth appear to be intermediate between small grains and corn and probably are similar to sunflower. Soil P and K should test in the medium to high range (30 to 75 lbs. P and 160 to 240 lbs. K per acre, depending on subsoil fertility group). Test the soil and apply any corrective P_2O_5 or K_2O recommended on the soil test report.[2]

Maintenance fertilizer equivalent- to crop removal should be applied to maintain soil test P and K levels. A crop yielding 1200 lbs/a grain will remove about 36 lbs of N, 7 lbs of P, and 6 lbs of K per acre and various amounts of calcium and magnesium and micronutricnts. However, amounts greater than those are needed to sustain high yield levels. Requirements are higher when amaranth is harvested for silage because virtually the entire above-ground portion is removed. For example, the total N uptake of the amaranth plant is about 90 lbs/a. Suggested maintenance recommendations are 75 lbs N, 25 lbs P_2O_5 and 40 lbs K_2O per acre. If soil organic matter exceeds 5%, apply 50 lbs N/A, if less than 1.5% organic matter, use 100 lbs N/A. Credits for a preceding legume crop and use of manure should be subtracted from these recommendations.

E. Variety Selection:

Uniform varieties of grain amaranth have not yet been fully developed. Available material consists of selected lines which vary in their uniformity and degree of adaption to temperate latitudes. Researchers at the Rodale Research Center in Pennsylvania and the USDA Plant Introduction Station at Ames, Iowa, have done significant work in developing amaranth varieties and cataloging germplasm. Rodale Research Center has distributed a number of lines including some that have been grown successfully in Minnesota (e.g. K343, K266, and K432). University of Minnesota trials'at Rosemount from 1977 to 1989 showed yields from 300 to 3800 lbs/a for the 20 lines tested. Amaranth seed is also available commercially (see Table 1).

Table 1: Sources of grain amaranth seed.[1]

American Amaranth, Inc., P.O. Box 196, Bricelyn, MN, 56014 (507-653-4377)

Terrance Cunningham, R.R. 1, Box 255 Twin Lakes, MN, 56089 (507-852-3465)

Johnny's Selected Seeds, Albion, ME, 049 10 (207-437-4301)

Nu-World Amaranth, Inc., P.O. Box 2202 Naperville, IL, 60540 (312-369-6819)

Calvin Oliverius, P.O. Box 25, Albin, WY, 82050 (307-246-3270)

Plants of the Southwest 1812 Second St., Santa Fe, NM 87501 (505-983-1548)

Soaring Eagle Seeds, P.O. Box 94, Shawmut, MT. 59078 (406-632-4528)

[1]This is a partial listing and does not imply endorsement of the seed quality.

F. Weed Control:

1. Mechanical: Since amaranth is not planted until late May or early June, many weeds will already have emerged. These early weeds must be controlled by tilling the field prior to planting. Grain amaranths grow slowly during the first several weeks after planting, so three or four cultivations may be needed during this period to control weeds. Once the amaranth plant is about a foot tall, it begins to grow rapidly and is very competitive with weeds. Two species of weeds which are especially competitive with amaranth are lambsquarter and pigweed. Fields with high populations of these weeds should not be used for amaranth production. Since grain amaranth seeds do not undergo dormancy, and because plant growth is not vigorous early in the season, it is unlikely that grain amaranth will be a weed problem in succeeding crops.

2. Chemical: No herbicides are labeled for use with amaranth.

G. Diseases and Their Control:

Researchers and growers have observed little in the way of major disease problems. Further problems may develop as the acreage of amaranth increases. Damping-off of young seedlings can be a problem under some conditions, caused by *Pythim* and *Rhizoctonia* and stem canker, caused by *Phorma* or *Rhizoctonia.*

H. Insects and Other Predators and Their Control:

Tarnished plant bug, flea beetle, and amaranth weevil, are potentially significant insect pests of amaranth. The insect most likely to affect yields is the tarnished plant bug, (*Lygus*), a sucking insect which often reaches high populations in the seed head during the critical seed fill stage. Flea beetles damage young leaf tissue. The adult amaranth weevil feeds on leaves, but the larval stage is more damaging because they bore into the central tissue of roots and occasionally stems, causing rotting and potentially lodging. It is currently unknown whether our insect control measures are cost-effective, but significant loss of yield and quality due to *Lygus* damage has been observed.

I. Harvesting:

Harvest is the most critical stage in grain amaranth production. Without careful harvest techniques, it is possible to lose or damage the majority of the seed. A killing frost must occur before harvest followed by a week of good drying weather (there are no approved desiccants for amaranth). If the stems and leaves are too wet, the seeds become sticky and adhere to the inside of the combine as well as the straw discharge. Shattering during the cutting process can also cause losses, so adjustments should be made to minimize shattering of the heads. When reel heads are used it may be helpful to remove several reel bats or raise the height of the reel. Row headers perform better than reel heads for combining amaranth. High cylinder speed can damage grain and reduce germination and popping volume. Conventional combines can be used if fitted with appropriately-sized separator screens.

J. Drying and Storage:

Grain handling and storage plans should be developed before harvest begins. It is important to clean the grain to remove plant and foreign material which will increase the chance of molding. Cleaning can be done using a 1/16 inch screen top, and a 1/23 inch screen, 22 × 22, or 24 × 24 wire mesh on the bottom. A gravity table can be used to separate particles of the same size but of different weight, such as the dark pigweed seeds. Maximum moisture for storing the grain is approximately 11%. Small amounts of grain can be dried by blowing air across the amaranth; heated air may be necessary at certain times. The optimum way to store the grain after cleaning and drying is in wooden storage bins or in heavy duty (4 or 5 ply) paper bags. University studies at Rosemount, Minnesota showed average test weight of 63 pounds per bushel.

VI. Yield Potential and Performance Results:

University of Minnesota trials at Rosemount conducted from 1977 to 1989 showed yields from 300 to 3800 lbs/a on hand-harvested plots. Realistic yields from combine-harvested plots range from 600-1500 lbs/a.

VII. Economics of Production and Markets:

Perhaps the greatest problem facing the development of amaranth as a crop is finding markets. The crop has only been grown commercially during the 1980's, and the markets are. still very small. The primary market for amaranth is the food industry, where it is used in 40-50 products. A farmer entering the market with grain from several hundred acres of amaranth could cause a surplus and drastically lower prices. For this reason amaranth should be grown only after identifying a market for the crop, and preferably after arranging a contract with a buyer.

Farmers have marketed their crop in a number of ways. Some sell small bags of the whole grain or flour mail-order to consumers. Many of these purchasers are allergic to wheat products. Other growers sell to local or regional health food stores or restaurants. There are also a few who buy grain from the farmers and market it to the larger health food companies. Companies that have developed grain amaranth products include Health Valley Natural Foods, Arrow Mills, Walnut Acres, Nu-World Amaranth, and American Amaranth, Inc.

VIII. Information Sources:

- Amaranth Grain Production Guide" produced by the Rodale Research Center (RD 1, Box 323, Kutztown, PA 19530) and the American Amaranth Institute (Box 216 Bricelyn, MN 56097).
- Amaranth - Modern Prospects for Ancient Crop". 1984. National Academy Press, Washington, D.C.
- Amaranth, Quinoa, Ragi Tef, and Niger: Tiny Seeds of Ancient History and Modern Interest" (1986) Minnesota Experiment Station Bulletin AD-SB-2949, St. Paul, MN.
- Growing Grain Amaranth As A Specialty Crop" by Robert L. Meyers and Daniel H. Putnam, Center for Alternative Crops & Products, Minnesota Extension Service, AG-FS-3458, 1988. University of Minnesota, St. Paul, MN.

Footnotes:

[1]Amaranth seedlings are very sensitive to frost; the crop should be sown after all danger of frost is past.

[2]Until further studies on amaranth fertility needs are completed, nitrogen recommendations for sunflower are reasonable approximations. Amaranth is very responsive to nitrogen application, but can lodge severely under high nitrogen soil conditions.

Broomcorn

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I. History:

Broomcorn (*Sorghum vulgare* var. *technicum*) is a type of sorghum that is used for making brooms and whiskbrooms. It differs from other sorghums in that it produces heads with fibrous seed branches that may be as much as 36 in. long.

Although the origin of broomcorn is obscure, sorghum apparently originated in central Africa. Production of this crop then spread to the Mediterranean, where people used long-branched sorghum panicles for making brooms in the Dark Ages. Broomcorn may have evolved as a result of repeated selection of seed from heads that had the longest panicle branches. The broomcorn plant was first described in Italy in the late 1500s. Benjamin Franklin is credited with introducing broomcorn to the United States in the early 1700s. Initially, broomcorn was grown only as a garden crop for use in the home. By 1834 commercial broomcorn production had spread to several states in the Northeast and started moving west. Illinois was the leading producer of broomcorn in the 1860s, but production of the crop in that state virtually ceased in 1967. Some production has occurred in Wisconsin since 1948.

Domestic broomcorn acreage is low because of the limited demand for the crop and its vast labor requirements, particularly for harvesting. In the early 1970s, approximately 100,000 acres of broomcorn were harvested in the United States annually, with the highest acreages in Oklahoma, Texas, New Mexico and Colorado. It is also produced in Illinois and Iowa. Half of the domestic needs for broomcorn are imported from Mexico.

II. Uses:

The long fibrous panicle of the broomcorn plant is used for making brooms. A ton of broomcorn brush makes 80 to 100 dozen brooms. High-quality broomcorn brush is pea-green in color and free from discolorations. The fibers should be straight, smooth, pliable, and approximately 20 in. long. Brush that is overripe, reddened, bleached, crooked, coarse or flat is considered poor quality.

The stalks are of very little value for forage. The mature seed is similar to oat in feed value.

III. Growth Habits:

Broomcorn is a coarse annual grass that grows 6 to 15 ft tall. It has woody stalks with dry pith and 8 to 15 nodes and leaves above the ground. The upper internode, or peduncle, is 8 to 18 in. long and topped by a series of closely compressed panicle nodes from which the fibers develop. The fibers, usually 12 to 24 in. long, are branched toward the tip, and the flowers and seeds are borne at the tips of the small branches. The seeds are brown, broadly boat-shaped and enclosed in tan, reddish tan or brown, pubescent glumes. The glumes generally remain on the mature seeds, and 30,000 seeds weigh approximately one pound.

Plants of standard varieties range from 6 to 15 ft in height; dwarf varieties range from 3 to 7 ft in height. Dwarf varieties usually produce one or more tillers, which also bear usable brush. Some dwarf varieties develop constrictions near the base of the peduncle, which provide a ready breaking point when the brush is pulled from the stalk.

IV. Environment Requirements:

A. Climate:

Broomcorn can be grown in practically every state. It will produce a fair quality of brush wherever the temperatures are high enough for com to grow well. Like other sorghums, it is relatively tolerant of heat, drought and poor culture. The best brush, however, is produced where the summers are warm and the soils are moist and fertile. Annual rainfall of 15 to 32 in. is adequate. Poor soils and extremely cool or dry weather result in inferior brush.

B. Soil:

Broomcorn does best in warm, fertile soils. Deep alluvial soils usually produce brush of higher yield and quality than shallower soils. The crop can be grown on rich bottom lands or sandy uplands.

V. Cultural Practices:

A. Seedbed Preparation:

In the Midwest, the land is usually plowed, double-disked and then harrowed prior to planting broomcorn.

B. Seeding Date:

Broomcorn is usually planted between May 1 and June 15.

C. Method and Rate of Seeding:

In humid regions, broomcorn is planted in 36 to 40 in. rows, with plants spaced 3 in. apart. A thinner stand (with plants 6 to 9 in. apart in the rows) is used in the drier western broomcorn districts. The quantity of seed required ranges from 2 to 4 lb/acre (60,000 to 100,000 seeds/acre).

D. Fertility and Lime Requirements:

Nutrient requirements for most sorghums include 60 to 120 lb/acre of nitrogen, depending on soil organic matter level, and 30 lb/acre each of phosphate (P_2O_5) and potash (K_2O) at medium soil test levels. Animal manure or a balanced commercial fertilizer can be applied. A soil pH of 6.0 to 6.5 may result in highest yields.

E. Variety Selection:

The varieties of broomcorn grown in the United States can be divided into three groups: Standard, Western Dwarf and Whisk Dwarf. Standard broomcorn varieties usually grow 6 to 15 ft tall. They bear a brush 16 to 36 in. long. The "handle" or stem of the brush is at least 8 in. long and is cut at harvest. Evergreen, Black Spanish (Black Jap) and California Golden are varieties of standard broomcorn.

Western Dwarf broomcorn varieties usually grow 4 to 7 ft. The brush (15 to 24 in. long) is weakly attached to the stalk and can be pulled or jerked off at harvest time without cutting. About one-half to two-thirds of the length of the brush is covered by the "boot," or upper leaf sheath, at harvest. The Western Dwarf broomcorn varieties, including Evergreen Dwarf, Scarborough and Black Spanish Dwarf, are grown in the semiarid western areas.

Whisk Dwarf broomcorn usually grows to a height of 2 1/2 to 4 ft and produces a fine slender brush about 12 to 18 in. in length. The stem is easily detached from the stalk, and the brush is harvested by pulling or jerking. Whisk Dwarf is used for making whisk brooms and for the insides of floor brooms. The only variety of Whisk Dwarf grown in this country is Jap or Whisk Dwarf.

F. Weed Control:

Weeds are controlled by cultivation until the broomcorn plants are large enough to compete with the weeds.

G. Diseases and Their Control:

All varieties of broomcorn appear to be susceptible to fungal smut (*Sphacelotheca sorghi*), which destroys the seed heads. Another disease, Sorghum rust (*Puccinia purpurea*), attacks the leaves of broomcorn but does not cause appreciable damage or loss.

Sorghum crops are subject to a number of other diseases that can be limiting, especially in wet climates. These include fungi that cause foliage blights and stalk rots. Rotations help reduce their severity and keep them under control.

H. Insects and Other Predators and Their Control:

No information available.

I. Harvesting:

Broomcorn brush turns from pale yellow to light green before maturity. It should be harvested when the entire brush is green from the tip down to the base of the peduncle. The fibers will be weak at the bottom if they are harvested while the lower ends are still yellow. The brush often begins to redden and become less flexible about 4 or 5 days after the proper stage for harvesting.

Tall standard broomcorn is "tabled" to allow some drying before it is removed from the field. The tabler walks backward between two rows and breaks the stalks diagonally across each other to form a "table" out of the two rows that is 2 to 3 ft high. The brush is then cut, pulled out of the boot, or leaf sheath, and placed on the "table" to dry for a short time (less than 24 hours). The brush is transferred to a curing shed.

The heads of dwarf varieties are jerked or pulled from the stalks and allowed to dry for a day in bunches on the ground or between the stalks before they are hauled from the field.

Broomcorn may be threshed either before or after curing. However, threshing before curing results in better quality brush because the fine branches are less likely to be knocked off when the brush is still moist and flexible.

J. Drying and Storage:

The highest quality broomcorn is cured in 4 to 6 in. layers on slats in sheds. Curing requires 10 to 20 days, after which the broomcorn is baled. Bales weigh about 330 pounds each.

When hauling, curing, threshing and baling, the brush must be handled in small bunches to keep the fibers straight and untangled. Because of the special care that is required, the operations of harvesting, curing, threshing and baling may take 90 to 130 man-hours per ton of shed-cured brush cut from tabled stalks.

VI. Yield Potential and Performance Results:

Normal broomcorn yields range from 300 to 600 lb/acre, or enough to make 150 to 350 brooms/acre.

VII. Economics of Production and Markets:

There is a very limited demand for broomcorn. It is advisable to identify a market before planting the crop.

VIII. Information Sources:

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Buckwheat

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I. History:

Buckwheat (*Fagopyrum sagittatum* Gilib) has been grown in America since colonial days, and the crop once was common on farms in the northeastern and northcentral United States. Production reached a peak in 1866 at which time the grain was a common livestock-feed and was in demand for making flour. By the mid 1960's the acreage had declined to about 50,000 acres. The leading buckwheat states are New York, Pennsylvania, Michigan, Wisconsin, Minnesota, and North Dakota. Canada has more buckwheat acreage than the United States.

Buckwheat enjoyed a resurgence of popularity in the mid 1970's that was brought on by the demand for commercially prepared breakfast cereal and by exports to Japan for making buckwheat noodles. This boom was due to the nutritional excellence of buckwheat. USDA-ARS analyses indicate that the grain has an amino acid composition nutritionally superior to all cereals, including oats. Buckwheat protein is particularly rich (6%) in the limiting amino acid lysine (Table 1).

II. Uses:

Until the recent increased interest in buckwheat for human food, about 75% of the grain produced was used for livestock and poultry, about 5-6% for seed, with the remainder milled into buckwheat flour. Between 5 and 10% of the seeded acreage was turned under for green manure. Several thousand acres were harvested green for extracting rutin. Today, the major use of buckwheat is for human food. The composition of buckwheat grain and its byproducts, are shown in Table 2. The amino acid concentrations, as reported by Robinson, are shown in Table 1.

Table 1: Average amino acid concentrations in buckwheat.[1]

Amino acid	In seed	In groat[2]	In protein
	%		
Glumtamic acid	1.99	2.72	18.02
Arginine	1.47	2.01	13.27

Aspartic acid	1.20	1.64	10.86
Valine	0.85	1.17	7.71
Leucine	0.75	1.02	6.75
Lysine	0.66	0.90	5.99
Glysine	0.61	0.83	5.52
Phenylalanine	0.46	0.63	4.17
Serine	0.46	0.62	4.12
Alanine	0.45	0.61	4.03
Threonine	0.43	0.58	3.87
Proline	0.41	0.55	3.66
Isoleucine	0.39	0.53	3.48
Tyrosine	0.23	0.32	2.12
Histidine	0.23	0.32	2.11
Cystine	0.18	0.25	1.66
Methionine	0.15	0.21	1.37
Tryptophan	0.14	0.19	1.29

[1]From Robinson, R.G., The Buckwheat crop in Minnesota, Agricutural Experiment Station Bulletin 539, 1980.
[2]Calculated from analyses of whole seed.

Table 2: Percent composition of buckwheat grain and buckwheat byproducts. [1]

Grain or by product	Moisture	Protein	Fat	Fiber	N-free extract	Ash
	%					
Whole grain	10.0	11.2	2.4	10.7	64.0	1.7
Flour, light	12.1	7.8	1.5	0.7	76.7	1.2
Flour, dark	11.7	15.0	2.8	1.1	67.7	1.7
Groats	10.6	11.2	2.4	0.6	73.7	1.5
Hulls	8.0	4.5	0.9	47.6	36.8	2.2
Middlings	10.7	27.2	7.0	11.4	39.1	4.6
Farina	12.0	2.7	0.4	0.4	83.0	0.5

[1]From Coe, M. R. Buckwheat milling and its by-products. USDA Circular 190. 1931.

A. Food for Humans:

Most of the buckwheat grain utilized as food for humans is marketed in the form of flour. The flour is generally dark colored due to presence of hull fragments not removed during the milling process. Buckwheat flour is used primarily for making buckwheat griddle cakes, and is more commonly marketed in the form of pancake mixes than as pure buckwheat flour. These prepared mixes may contain buckwheat mixed with wheat, corn, rice, or oat flours and a leavening agent. Buckwheat flour is never produced from tartary buckwheat because of a bitter taste that makes it undesirable as human food.

Some buckwheat grain is utilized in the form of groats (that part of the grain that is left after the hulls are removed from the kernels). The product may be marketed as whole groats, cracked groats, or as a coarse granular product. These products are used for breakfast food, porridge, and thickening materials for soups, gravies, and dressings.

Buckwheat may cause a rash on the skin of certain individuals, especially if it is eaten frequently or in large quantities.

Buckwheat flour and groats must be used fresh because their fat content is high and they soon become rancid. This poor keeping quality makes buckwheat products difficult to handle in the summer.

B. Feed for Livestock:

Buckwheat is a satisfactory partial substitute for other grains in feeding livestock. It has a lower feeding value than wheat, oats, barley, rye, or corn. The grain should be ground and mixed with at least two parts of corn, oats, or barley to one part buckwheat.

When fed continually or in large amounts to certain animals, buckwheat grain may cause a rash to appear on the skin. This rash is confined to the white-haired parts of the hide of the animal, and apparently occurs only when animals are exposed to light. The substances that produce the rash are in the buckwheat hulls.

Tartary buckwheat has a lower feeding value for livestock than the common varieties, but it was used extensively as an ingredient of scratch feeds for poultry. The small, smooth, rounded seed of tartary makes it more satisfactory for poultry than the larger and more angular seeds of common buckwheat.

Buckwheat middlings are rich in protein, fat, and minerals, and are considered a good feed for cattle when not fed in large amounts or as the only concentrate. They may also be used satisfactorily as a substitute for linseed meal in a ration consisting of tankage, linseed meal, and alfalfa hay. Buckwheat middlings apparently have no harmful effect on dairy cows or dairy products. They are not satisfactory for pigs when fed as the only concentrate, and are not palatable to pigs as are other ground grains.

Buckwheat hulls have little or no feeding value, but they contain most of the fiber of the seed. They are sometimes combined with middlings and sold as buckwheat feed or bran. They are also used as soil mulch and poultry litter in the U.S. and for pillow stuffing in Japan.

Buckwheat straw is sometimes used for feed when well preserved, but may cause digestive disturbances when fed in large amounts.

Buckwheat seed is an ingredient in commercial bird feed mixes and the seed is sometimes planted to provide feed and cover for wildlife.

C. Honey Crop:

With the exception of tartary, buckwheat is sometimes used as a honey crop. It has a long blooming period, especially in September when other sources of nectar are limited. The honey is dark in color, and has a strong flavor unpleasant to some persons but highly favored by others. Buckwheat was once an important honey crop in this country, especially in the Northeast where climatic conditions are most favorable to nectar flow. When buckwheat was commonly grown, it was one of the beekeepers' greatest sources of nectar, and the supply of buckwheat honey generally exceeded the demand. However, because of the decline of buckwheat as a grain crop, buckwheat honey now is so uncommon that it may command a price higher than that of almost any other honey.

Buckwheat nectar flow is favored by adequate moisture combined with clear, still days and cool nights. Under these conditions, an acre of buckwheat may support a hive of bees and yield up to 150 pounds of honey in a season. Reports are that it is not uncommon for a strong colony to glean 10 pounds of honey per day while foraging buckwheat. Although buckwheat is one of the most dependable and highest yielding honey plants, it normally yields nectar only during the morning and bees are unable to complete a full day of nectar collection. As a result, bees working buckwheat may not be very amiable to the beekeeper should he visit his hives in the afternoon.

Buckwheat may fill a special need for the beekeeper since the honey flow comes late in the season when other nectar is scarce. Thus, it may be possible to obtain a crop of buckwheat honey in an area where an earlier flow has been harvested from other sources. The variety Tokyo is reported to produce a lighter colored honey than most buckwheats.

D. Smother Crop:

Although modern weed control methods have reduced the need for smother crops, buckwheat may still be useful for this purpose. Buckwheat is a good competitor because it germinates rapidly, and the dense leaf canopy soon shades the soil. This rapid growth soon smothers most weeds.

Buckwheat has been cited as a useful crop for control of quackgrass in the northeastern states, but rapid and complete control should not be expected. A heavy crop of buckwheat should smother most of the quackgrass if the land has been previously cultivated to break up the quackgrass sod, and then fall-or early spring-plowed and disked or field cultivated occasionally until planting time.

Other weeds may be more effectively controlled by growing buckwheat. Scientists have reported that the crop can be used to eradicate Canada thistle, sowthistle, creeping jenny, leafy spurge, Russian knapweed and perennial peppergrass (Marshall and Pomeranz).

Because of buckwheat's early competitiveness, it is not useful as a companion crop for establishing legumes.

E. Green Manure Crop:

Buckwheat is a useful green manure crop. It can produce significant amounts of dry matter. Up to 3 tons of dry matter per acre has been obtained after 6 to 8 weeks of growth on relatively unproductive land under Pennsylvania conditions. When plowed under, the plant material decays rapidly, making nitrogen and mineral constituents available for the succeeding crop. The resulting humus improves physical condition and moisture-holding capacity of soil. Where a second crop of green manure is desired, rye may be drilled into the buckwheat stubble and plowed under in the spring. The rye frequently can be drilled into the buckwheat stubble without previous disking or plowing. Buckwheat green manure may also fit into fairly tight rotations such as when a crop is harvested prior to mid-July and a succeeding crop is not scheduled until fall. If volunteer buckwheat is harmful in the succeeding crop, then the green manure crop of buckwheat should be destroyed before a large number of seeds mature.

F. Milling Buckwheat:

A few mills still use old-fashioned stone burs to produce buckwheat flour, but the greater number use steel rolls. Some buckwheat flour is milled so finely and is so refined that it is as white as wheat flour. Usually, however, small particles of hull remain in the flour and give it a characteristic dark color. Flours are milled to meet. the protein and fiber specifications of the buyer.

One hundred pounds of clean, dry buckwheat yields 60 to 75 pounds of flour, 4 to 18 pounds of middlings, and 18 to 26 pounds of hulls. Not more than 52 pounds of pure white flour from 100 pounds of grain is obtained in milling. Buckwheat more than 1 year old is reported to make flour inferior to that made from freshly harvested grain. The middlings, composed mostly of the gem and the inner covering of the grain just beneath the hull, are used for feed.

III. Growth Habits:

Buckwheat has an indeterminate growth habit. Consequently the plant grows vegetatively and flowers until terminated by frost. There has been little effort to improve the crop through plant breeding since buckwheat is naturally cross-pollinated and cannot be inbred because of self-incompatibility. Therefore, buckwheat yields, unlike those of other crops, have remained relatively stable and thus have discouraged production. Flowers of cross-pollination species of buckwheat attract insects because of their secreted nectar. However, studies at Pennsylvania indicate that insect activity is not essential to get effective fertilization and seed set.

IV. Environment Requirements:

A. Climatic Requirements:

Buckwheat grows best where the climate is moist and cool. It can be grown rather far north and at high altitudes, because its growing period is short (10 to 12 weeks) and its heat requirements for development are low. The crop is extremely sensitive to unfavorable weather conditions and is killed quickly by freezing temperatures both in the spring and fall. High temperatures and dry weather at blooming time may cause blasting of flowers and prevent seed formation. Generally, buckwheat seeding is timed so that the plants will bloom and set seed when hot, dry weather is over. Often seeding is delayed until three months prior to the first killing frost in the fall.

B. Soil Requirements:

Buckwheat grows on a wide range of soil types and fertility levels. It produces a better crop than other grains on infertile, poorly drained soils if the climate is moist and cool. It is an efficient crop in extracting phosphorous of low availability from the soil. In addition, buckwheat tends to lodge badly on fertile soils. It is often better suited than most other grains on newly cleared land, on drained marsh land, or on other rough land with a high content of decaying vegetative matter.

Buckwheat has higher tolerance to soil acidity than any other grain crop. It is best suited to light to medium textured, well-drained soils such as sandy loams, loams and silt loams. It does not grow well in heavy, wet soils or in soils that contain high levels of limestone. It grows well where alfalfa or red clover would not. On soils high in nitrogen, lodging may occur and cause a reduction in yield. Once lodged, a buckwheat plant does not return upright. Crusting on clay soils may result in an unsatisfactory stand because of poor seedling emergence.

C. Seed Preparation and Germination:

Buckwheat will germinate at temperatures ranging from 45° to 105°F. Freshly harvested seed of some types may not germinate until after 30-60 days of drying and storage. The seed may retain its viability for several years, but seed that is no more than one year old is best to use for planting. Buckwheat plants will emerge from the soil 3-5 days after planting. The time required is influenced by depth of seeding and the temperature and moisture content of the soil.

V. Cultural Practices:

A. Crop Sequence and Rotation:

Serious diseases affecting other dicot field crops have not been important in buckwheat; therefore the volunteer plant problem is the main problem in crop sequences. Volunteer sunflower, rapeseed, mustard, and corn can be serious weeds in buckwheat planted before June 15. Volunteer buckwheat can be a problem in crops following buckwheat, but herbicides will control these in most crops.

B. Seedbed Preparation:

A firm seedbed is best for successful buckwheat production because of its relatively small seed size and its shallow root system. A firm seedbed facilitates absorption of nutrients essential for rapid growth, and tends to reduce losses from drought. If soil has been plowed for a previous crop which has failed, only disking or harrowing may be required. Rolling or cultipacking the seedbed just prior to seeding is sometimes helpful.

C. Seeding Date:

Buckwheat may be sown at any time after all danger of killing frost is past. Since the crop grows rapidly and matures in a short growing season, the most common practice is to seed the crop only 10-12 weeks before a killing frost is expected. For Wisconsin, seeding in mid-June is advised. For Minnesota, plantings in June in the north, before July 15 in the central, and before July 25 in the extreme southern part of the state may mature sufficiently before normal frost dates. The crop produces seed within one month after planting and continues to flower and produce seed until killing frosts occur.

Thin stands of buckwheat produce strong plants that branch and resist lodging on good land. Thick stands produce plants that are spindly and have short branches and poor seed set.

E. Fertilizer and Lime Requirements:

Buckwheat has a modest feeding capacity compared to most other grains, and if fertilizer is not applied, the removal of nutrients by a buckwheat crop may have a depressing effect on the yield of the following crop. Typical nutrient removals by the grain for a 1200 lb/a crop are 9 lb/a N, 3 lb/a P_2O_5 and 12 lb/a K_2O. However, in Minnesota, a 2000-pound yield of seed removed 40 pounds N, 20 of P_2O_5 and 13 pounds per acre of K_2O or about the same as a 2000 pound crop of sunflower seed. The crop grows well on acid soils and gives little response to liming above a pH of 5.0. It has about the same acid tolerances as oat and potatoes. Soils should be limed for the crops grown in rotation with buckwheat.

It is unlikely that buckwheat will respond to additional P or K at soil tests above 30 lb/a P or 300 lb/a K. Table 3 shows the recommended fertilizer rates for buckwheat yielding 30-50 bu/a for Wisconsin and Minnesota.

Table 3: Wisconsin and Minnesota recommended fertilizer applications for a goal of 30 to 50 bu/a buckwheat yield.

Soil Test	N[1]	P_2O_5	K_2O
	lb/a		
Very Low Or Low	30	60-80	60-90
Medium	30	30-40	30-60
High	30	15-20	15-30
Very High or Excessively High	30	0	0

[1]Recommended nitrogen rate ranges from 0 to 50 lb N/a depending on cropping history and organic matter level. If the previous crop was alfalfa, no nitrogen is recommended. If the previous crop was corn or small grains the recommended nitrogen rate is 50 lb N/a where soil organic matter is <2%, and 15 lbs N/a where the organic matter is 2-5%.

D. Method and Rate of Seeding:

The most satisfactory method of sowing buckwheat is with a grain drill that plants the seed one to two inches deep. Poor stands are likely when seedings are more than two inches deep.

A seeding rate of 36 to 72 pounds per acre or 16 seeds per square foot of clean, viable seed is sufficient. At least 48 pounds per acre should be used of large-seeded varieties such as Pennquad.

F. Variety Selection:

Because little breeding work has been done on buckwheat, there are only a handful of varieties that are grown in the United States. Dr. Harold Marshall, formerly with the USDA at Penn State University did much of the variety improvement work in the 1960's to 1980's. The tetraploid variety Pennquad was released by Dr. Marshall's program in 1966 and is still grown on some of the buckwheat acreage. Most of the available buckwheat varieties are diploids. Since buckwheat is cross pollinated, variety designations may not be valid except for Certified seed lots. Varieties that have been grown in the United States in the past 20 years include:

Mancan: Large-seeded diploid variety. Has low test weight but good market acceptability. Released by Agriculture Canada and licensed in 1974.

Manor: Large-seeded diploid variety. Has low test weight but good market acceptability. Released by Agriculture Canada and licensed in 1980. Production of certified seed is limited to Canada.

Pennquad: Very large-seeded tetraploid variety. Has good lodging resistance. The grain is especially well suited for milling because of its large, uniform size. Released by the Pennsylvania Agricultural Experiment Station in 1966.

Tempest: Small-seeded diploid variety with high test weight. Selected by Agriculture Canada from a Russian seedlot and licensed in 1971.

Tokyo: Small-seeded diploid type with high test weight. Developed by Agriculture Canada from a Japanese introduction.

Winsor Royal: Large-seeded diploid type with low test weight, but has good market acceptability. Released by Winsor Grain Company, Minneapolis, Minnesota, in 1982. Sale of seed is regulated by the U.S. Variety Protection Act.

Common: Seed lots tested under this name range from small to medium in seed size and often have medium to high test weight.

G. Weed Control:

1. Mechanical: The best means of controlling weeds is to destroy the young weed seedlings with tillage prior to planting buckwheat. Good, solid stands of buckwheat will compete with weeds which may germinate later.

2. Chemical: There are no herbicides registered for use on buckwheat in Wisconsin or Minnesota.

H. Diseases and Their Control:

Diseases are not a problem in buckwheat production, although a leaf spot caused by species of the fungus *Ramilaria* and a root rot caused by *Rhizoctonia* sometimes occur.

I. Insects and Other Predators and Their Control:

Wireworms and aphids may attack buckwheat, but do not cause serious losses. Japanese beetles are particularly fond of buckwheat flowers and may occasionally do considerable damage.

When birds are numerous, they may do considerable damage to buckwheat grain before the crop is ready for harvest. Deer and other wildlife may also damage buckwheat if the field is adjacent to a wooded area or other cover for wildlife. Rats and mice can be very destructive in buckwheat fields, especially when the plants have lodged.

J. Harvesting:

The best practice is to direct combine when the maximum number of seeds have matured (75% of seed brown or black) and the plants have lost most of their leaves. When immature plants are harvested, green seeds and moist fragments of the plants may cause difficulties in storing the grain. However, considerable grain loss from shattering may occur if the crop is left standing, especially after a killing frost.

Cylinder speed (about 650 RPM) and cylinder concave clearance (1/8-1/2 in.) of the combine should be set to prevent excessive cracking and breaking of the grain. Losses and broken kernels should be checked to refine combine adjustments.

Proper selection of the sieves and adjustment of the chaffer and air settings are also important to insure minimal losses. Sieve openings of 1/4 to 3/8 in. are suggested.

K. Drying and Storage:

Grain harvested with a combine may contain green plant fragments and require careful drying for safe storage. Drying of buckwheat grain prior to cleaning facilitates the removal of plant fragments and immature seeds. Seed should be dried prior to storage if its moisture percentage exceeds 16. With the use of a grain drier, buckwheat can be harvested at a much higher moisture content, thus minimizing the loss due to shattering. Market grades have been established for buckwheat and discounts are common if the seed doesn't meet the grade standards.

VI. Yield Potential and Performance Results:

Buckwheat yields in Wisconsin and Minnesota typically range from 500 to 2,000 pounds/acre. With good management and favorable weather, buckwheat should yield 1,200 to 1,600 pounds/acre in a cool, moist climate that is common in northern Wisconsin or Minnesota. No yield trials have been conducted in Wisconsin in recent years. Performance of three buckwheat varieties in 23 tests in Minnesota from 1982 through 1987 is summarized in Table 4.

Table 4: Performance of buckwheats in Minnesota tests, 1992-87.

Variety	Yield (lbs/a)	Test Weight (lb/bu)	Days to first bloom	Height (in)	No. of seeds per lb
Mancan	1003	44	32	40	15,770
Manor	1070	44	32	40	16,256
Winsor Royal	1124	44	32	40	15,230

VII. Economics of Production and Markets:

The profitability of growing buckwheat today is quite variable. Buckwheat has not been grown extensively in recent years because other crops were more profitable. Before planting buckwheat, growers are urged to ask themselves the following questions:

1. Where will I purchase good quality seed? 2. What will be the seed price? 3. For what purpose will I raise the crop? - for feeding to livestock on my own farm? - to sell as a cash crop? - to be used personally for food? - to be left for wild game feed? 4. If I plan to sell, is there a buyer in the area? What price will I receive if I sell? Are there quality requirements? 5. If I plan to use it for food, how will I process it?

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Annual Canarygrass

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I. History:

Annual Canarygrass (*Phalaris canariensis* L.) or canaryseed is a grain crop with production practices and a life cycle similar to that of spring wheat or oat. The plant is native to the Mediterranean regions, and is grown on large acreages in the Middle East, Europe, and Argentina, with some production in the northern Red River Valley of North Dakota and Minnesota, U.S.A., and the western provinces of Canada. Production in these latter areas has periodically had significant effects on world production and markets. Commercial production in the U.S. developed after World War 11 in MN and ND, and shifted into Manitoba and later Saskatchewan. In 1987, over 180,000 acres of canarygrass were produced in Western Canada, 85% in Saskatchewan. Less than 3,000 acres annually have been contracted in Minnesota and North Dakota in recent years. It is grown under contract as a specialty crop in these regions, and is used primarily as birdfeed hence the name "canarygrass." The largest consumers are Japan and other countries of East Asia and Europe.

II. Uses:

The primary market for canarygrass is currently birdfeed, but other uses, including human food have been proposed. As a birdfood, the florets are sold and the birds dehull the florets before consumption. It is widely recognized as a superior canary-feed.

Annual Canarygrass seed is similar to oat in mineral composition. The caryopsis is higher in ash, oil, and phosphorus but lower in fiber than concentrations common in corn, pea, or fieldbean. Canarygrass caryopses have higher concentrations of all eight essential amino acids than does wheat or corn, and are higher in sulfur-containing amino acids than pea or fieldbean. In spite of this encouraging nutritional profile, the value of canarygrass in human food has not been adequately explored.

III. Growth Habits:

Annual canarygrass (a grain crop) is often confused with reed canarygrass (*Phalaris arundinacea* L.) which is a perennial forage crop and wild grass. Although heads of both crops are panicles, annual canarygrass heads are spike-like and resemble club wheat. Most cultivars tiller profusely and lodge when soil fertility and moisture is plentiful. The compact, oval-shaped panicles retain seed firmly so that shattering losses are usually small. The plant grows 36 in. high, heads in approximately 65 days, and matures in 104 to 107 days (similar to spring wheat).

IV. Environment Requirements:

A. Climate:

Regions with long, warm days and cool nights, such as the Northern Red River Valley in Minnesota, North Dakota, and Manitoba are well suited for canarygrass. It is generally considered a cool season crop with areas of adaptation similar to hard red spring wheat. Canarygrass has shown sensitivity to high temperatures which are common in May and June, and yields are substantially reduced under these conditions. It is more sensitive to heat and less drought tolerant than wheat.

B. Soils:

Canarygrass will grow on many types of soils but has performed well on heavier, clay loam soils of medium-high fertility. Canary seed requires ample moisture to obtain maximum yields, and so does more poorly on sandier soils. Some growers in Alberta have found canarygrass more tolerant of saline soils than wheat.

V. Cultural Practices:

A. Soil Preparation:

Tillage influences canarygrass stand and yield. Grain yields have been higher and weed control better with moldboard plowing rather than chisel plowing or rototilling.

B. Seeding Date:

Canarygrass is planted very early in the spring, as early as the ground can be worked. This corresponds to late March or early April in southern Minnesota or central Wisconsin, or early May in more northern locations. Yields are lower with later sowings.

C. Method and Rate of Sowing:

Plant canarygrass in 4 to 7 in. rows with a grain drill. Studies conducted at several locations in Minnesota indicate that seeding rates above 1,500,000 seeds/acre are needed for adequate stands, but very little yield increase occurred with densities greater than this (Figure 1). Current recommended seeding rates in the Upper Midwest are 30 lb/acre viable seeds or 40 seeds/ft^2 (1,742,000 seeds/acre). Plant seeds 1/2 to 1 1/2 in. deep, depending upon moisture conditions. A bushel of seed weighs 50 pounds.

D. Fertility:

In Minnesota research, canarygrass shows no response to nitrogen-fertilizers on the rich soils of the Red River Valley (Figure 2). Lodging is often a problem at higher nitrogen levels. On poorer soils, N is more likely to be limiting. Research conducted in Saskatchewan indicated top yields were obtained with the addition of 45 to 67 lb of N/acre. The seed and straw yields of canarygrass are below those of other spring sown cereals, and so nutrient uptake is likely to be somewhat less.

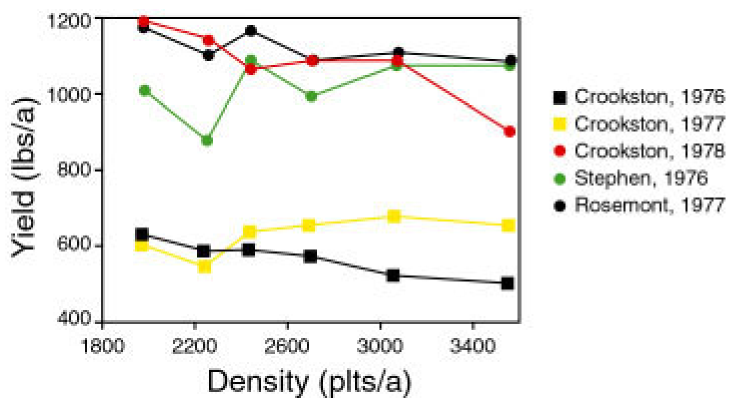

Figure 1. Effect of plant density on seed yield of annual canarygrass.
Data courtesy of Dr. R.G. Robinson, University of Minnesota.

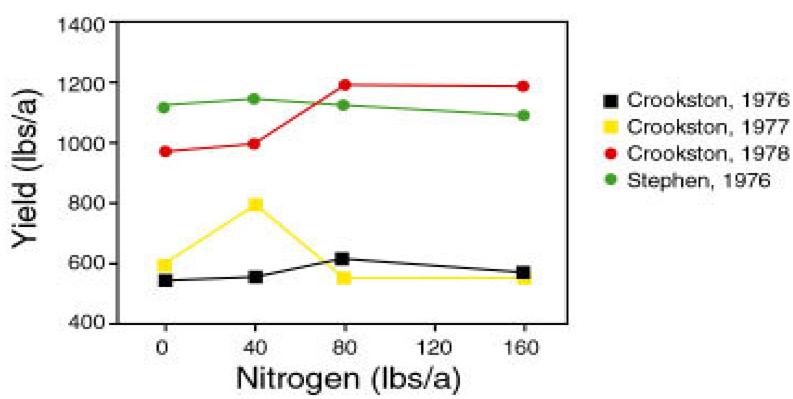

Figure 2. Effect of nitrogen fertilizer (Urea) on annual canarygrass seed yield.
Data courtesy of Dr. Robert G. Robinson, University of Minnesota.

Annual canarygrass is likely to respond to fertility similarly to reed canarygrass or spring-sown cereals in most soil situations. Nitrogen recommendations for soils with a range of organic matter are shown in Table 1.

Table 1: Nitrogen recommendations for annual canarygrass for a yield goal of 1000 to 1200 lb/acre.

Soil Organic Matter Content
%

<2	2-4.9	5.0-10	>10
amt. of N to apply, lb/acre			
50	20	10	0

On high organic matter soils or on soils following a legume or fallow, no nitrogen is recommended.

Soil test recommendations for phosphorus and potassium would be similar to other medium demand field crops (Demand level 4), see UWEX Publication A2809, and are shown in Table 2.

Table 2: Phosphate (P_2O_5) and potash (K_2O) recommendations for annual canarygrass.

Soil Test Interpretation				
Very low	Low	Medium	High	Excessively high
lb P_2O_5/acre to apply				
45	40	30	15	0
lb K_2O /acre to apply				
90	80	60	30	0

E. Variety Selection:

Many lines of canarygrass have been tested in northern Minnesota for yield, adaptation and agronomic characteristics. Three varieties currently recommended are Alden, Keet and Elias. Yields and characteristics are provided on Tables 3 and 4. Elias and Keet are higher yielding than Alden, and have better lodging resistance.

Table 3: Yields of annual canarygrass varieties at four Minnesota locations.

Variety	Crookston 1979-85	Stephen 1979-84	Rosemount 1979-84	Becker[1] 1982-84	Average 22 trials
	lbs/acre				
Alden	1516	1162	1081	910	1218
Elias	1810	1554	1224	918	1459
Keet	1660	1318	1142	925	1325
Checks 2	1454	1026	919	736	1093
LSD	128	127	99	80	25

[1]Irrigated.

Table 4: Characteristics of annual canarygrass varieties in Minnesota.

Variety	Planting to heading (days)	Planting to maturity (days)	Lodging (score[1])	Height (in)	Seeds (no./lb)	Test weight (lb/bu)
Alden	66	107	3.9	36	60,500	48
Elias	64	106	2.6	36	58,200	51
Keet	63	104	2.8	35	61,300	49
Checks[2]	64	107	3.9	34	56,000	49

[1] 1= erect, 9 = flat.
[2] 1984-85 data of progeny of old seedlots and varieties.

Variety Descriptions:

Alden—Medium yield, medium maturity and height. Poor lodging resistance. Medium size seed of medium test weight. Developed cooperatively by Minnesota Agricultural Experiment Station and Minn-Dak Growers Association. Released in 1973.

Elias—High yield, medium maturity and height. Fair lodging resistance. Medium size seed of very high test weight. Released by Minnesota Agricultural Experiment Station in 1983.

Keet—High yield, early, medium height. Fair lodging resistance. Medium size seed of high test weight. Released by Minnesota Agricultural Experiment Station in 1979.

F. Weed Control:

Canary seed is very susceptible to Treflan and Eptam damage, and so fields treated the previous year with these herbicides should be avoided. There are currently no herbicides for annual canarygrass registered in the U.S., and so cultural practices for weed control are required.

G. Diseases and Insects:

To date, insects, and diseases have not been a major problem in annual canarygrass production. Aphids are occasionally a problem during seed fill. Several pesticides have been registered in Canada for this purpose.

H. Harvesting:

Maturity occurs when the kernels are hard and the head has turned white-beige in color. The panicle of annual canarygrass resists shattering and so allow the crop to fully mature before harvest. Straight combining is the preferred harvest method but swathing just prior to combining is also effective.

Dehulling the seed is undesirable, and may result in dockage, and so a cylinder speed of 500 to 750 rpm is recommended. Combine clearance of 5 to 9mm (front) and 3 to 5mm (rear) is recommended and a low wind speed (similar to flax) should be used. The dust from canarygrass is irritating, especially on hot days, and dust masks may be required.

VI. Yield Potential and Performance Results:

Yield potential of canarygrass at four locations in Minnesota is provided in Table 3. Yields tend to decline at southern Minnesota locations and with hot weather conditions.

VII. Economics of Production and Markets:

Production costs are less than for spring wheat primarily because of reduced fertilizer and herbicide costs. Recent prices paid for annual canarygrass seed have ranged from 8 to 9 cents/pound. In Minnesota, several markets exist in the northwestern part of the state and in Minneapolis. Northern Sales in Winnepeg, Canada and Min-Dak Growers, Inc. Grand Forks, ND also contract or purchase annual canarygrass seed. Several area and local markets exist in other states, but should be identified before planting the crop.

VIII. Information Sources:

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- Minnesota Registered and Certified Seed Directory. 1990. Minnesota Crop Improvement Association, 1900 Hendron Avenue, St. Paul, MN 55108.
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- G.W. Rehm, C.J. Rosen, J.F. Moncreif, W.E. Fenster and J. Grava. Agricultural Bulletin 0519. Minnesota Extension Service, University of Minnesota. 36 p.
- Soil Test Recommendations: UWEX Publication A2809. University of Wisconsin-Extension.

References to pesticide products in this publication are for your convenience and are not an endorsement of one product over other similar products. You are responsible for using pesticides according to the manufacturer's current label directions. Follow directions *exactly to protect the environment and people from pesticide exposure. Failure to do so violates the law.*

Canola (Rapeseed)

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I. History:

Canola is a name applied to edible oilseed rape. This plant belongs to the mustard family along with 3,000 other species. Close relatives of this crop have been cultivated for food since the earliest recordings of man. Rapeseed has been important to Europe since the 13th century as a source of food and oil for fuel. Rapeseed production became popular in North America during World War II as a source of lubricants. Its oil has the property of adhering well to moist metal, making it an ideal lubricant for marine engines.

The name "canola" was registered in 1979 by the Western Canadian Oilseed Crushers Association to describe "double-low" varieties. Double low indicates that the processed oil contains less than 2% erucic acid and the meal less than 3 mg/g of glucosinolates. Erucic acid is a fatty acid that has been related to heart disease. Glucosinolates have breakdown products that are toxic to animals. Both characteristics make rapeseed products poor candidates for animal consumption.

In the early 1960s, Canadian plant breeders isolated single lines free of erucic acid and began programs to develop double low varieties.

Today annual worldwide production of canola is approximately 7.5 million tons on 4 million acres. Canada accounts for 15% of the world production and the European Economic Community for nearly 17%. The United States produces less than 1% of the world production. Minnesota and North Dakota are the major U.S. production states with about 20,000 acres. Canola ranks 5th in production among the world's oilseed crops following soybeans, sunflowers, peanuts and cottonseed.

II. Uses:

A. Oil and Protein:

Like soybean, canola contains both high oil content as well as high protein content. It contains about 40% oil and 23% protein compared to 20 and 40%, respectively, for soybean. Like soybean, when the oil is crushed out, it leaves a high quality, high protein (37%) feed concentrate which is highly palatable to livestock. Commercial varieties of canola were developed from two species; *Brassica napus* (Argentine type) and *Brassica* *campestris* (Polish type). Both species of canola produce seed that is high in polyunsaturated fatty acids (oleic, linoleic, and linolenic).

B. Forages:

Another potential for canola is as an annual forage. Historically, it was used as a forage for field-raised swine and poultry. Canola can produce 1.0 to 2.0 tons of dry matter per acre in a single season. A study conducted in Kansas found winter rapeseed forage to have crude protein of 21-33%, compared to 24% for winter wheat foliage.

III. Growth Habits:

Both fall and spring seeded types of canola are available. Canola growth is characterized by six main growth stages. Much of the management of this crop is related to the length of time and plant characteristics within each of these stages. Stage 0 is preemergence. The germinating seedling may take from 4 to 10 days to emerge. During this time it is susceptible to many soil borne pathogens. In Canada, seed protectant fungicides are often used on spring types, however effective materials have not been registered for use in the U.S. Speed of emergence depends on soil temperature and moisture, seed soil contact, and depth of planting. Stage I is the seedling stage where the very young plant has just emerged from the soil. Cotyledons are pushed through the soil surface by an active hypocotyl. At this stage, the seedling is still vulnerable to many soil pathogens, and to flea beetle infestation. Both pests are detrimental to stand establishment. Since the early canola crop is a poor competitor, it is extremely important to get a good stand.

Stage 2 is the rosette stage characterized by an increasing leaf area index. Spring canola will remain in this vegetative stage for several weeks. Winter canola also stays in this stage for several weeks in the spring. Near the end of Stage 2, the crop is nearing its maximum leaf area index and at that point is a much better competitor. Increasing day length and temperatures initiate bolting and the beginning of Stage 3, the bud stage. The plants reach their maximum leaf area index at this time along with 30 to 60% of its total dry matter. A large accumulation of foliage is required to provide adequate sugars during flowering and pod fill.

Flowering begins Stage 4 and continues for 14 to 21 days. Three to five flowers open per day and 40 to 55% of the flowers that open will develop pods. Ripening, or Stage 5, begins when the petals fall from the last formed flower on the main stem. Pod fill is complete 35 to 45 days after flower initiation, and the seeds contain about 40% moisture at this point. The crop is considered ripe and ready for swathing when 30 to 40% of the seed from pods on the main stem have turned color. Spring varieties of *B. napus* mature 74 to 140 days after seeding and *B. campestris* in 66 to 111 days.

IV. Environment Requirements:

A. Climate:

Canola is widely adapted, particularly to the cool extremes of the temperate zones.[1] Minimum temperatures for growth have been reported to be near 32°F. The crop will germinate and emerge with soil temperatures at 41°F but the optimum is 50°F. Winter annual varieties are grown where adequate snow covers or mild winters are common. The crop has been produced successfully in Michigan without benefit of snow cover. Planting date has a dramatic effect on survival however.

B. Soil:

Canola does best on medium textured, well drained soils. The crop is tolerant of a soil pH as low as 5.5 and saline conditions. Because of its tolerance to salinity, canola has been used as the first crop on newly drained dikes in the Netherlands. Canola requires approximately 16 to 18 inches of water through its growing season, with 8 to 8.3 inches used by annual varieties in July near flower and pod fill.

V. Cultural Practices:

A. Seedbed Preparation:

Stand establishment is very important with canola because of its lack of early competitiveness. Seeding into a smooth, firm seedbed helps maintain a uniform seeding depth and even emergence. Seedbed preparation is usually done with a shallow (4-5 inch) tillage operation. Recent research, however, has shown some success establishing canola with reduced tillage.

B. Seeding Date:

Canola can be seeded in either the fall or the spring depending on the type of variety. Fall dates need to be timed to achieve about 6 true leaves and good root reserves before a killing frost. Planting between August 15 and September 1 should accomplish this in most areas of Wisconsin and Minnesota.[2] Spring planting should begin as early as soil is dry and weather permits. Like spring small grains, spring canola generally yields the best with early planting. At Arlington, WI canola seeded the last week of April averaged 1325 lb/a compared to 1150 lb/a when seeded three weeks later on May 20.

C. Method and Rate of Seeding:

Canola is usually seeded with the small seed attachment of a grain drill to a depth of 1/2 to 1 inch. Rows should be spaced 7 inches or less. Research has shown highest yields with 3-inch row spacings. Canola should be seeded at 4-5 lb/a if drilled and 7-8 lb/a if broadcast depending on seed size and soil texture. Stands should be around 6-8 plants per square foot for highest yields. Canola stands of this density can withstand up to a 2/3 kill before reseeding is more profitable than maintaining the existing crop.

D. Fertility and Lime Requirements:

Little information is available on the responsiveness of canola to lime applications or soil pH. Most current canola production areas tend to be on soils which are slightly acid to alkaline, however this does not mean that more acid soils necessarily need to be limed to these levels.

Some states recommend that P and K should be applied on the basis of soil test recommendations for winter wheat. Table 1 shows the nutrient removals for typical wheat, barley and canola yields. For Wisconsin and Minnesota this means that when soil tests are in the medium range about 20-30 lbs Of P_2O_5 and 20 lbs of K_2O should be applied per acre. At lower soil tests these rates should be increased. Because canola is sensitive to direct seed contact with fertilizer, applications should be banded at least 2 inches to the side and below the seed or broadcast.

Table 1: Spring canola vs. other crops in usage of various macro nutrients.

Crop and Yield Level	Crop Part	Nutrients Removed (lbs./A)			
		N	P	K	S
Wheat at 40 bu./A	Seed	60	24	16	4
	Straw	25	5	48	6
	Total	85	29	64	10
Barley at 60 bu./A	Seed	60	22	20	5
	Straw	30	8	67	6
	Total	90	30	87	11
Canola at 35 bu./A	Seed	66	32	16	12
	Straw	39	14	67	9
	Total	105	46	83	21

Canola responds well to nitrogen fertilizer, with optimum yields occurring around 80-100 lbs N/acre. For spring canola, it should be broadcast and incorporated at seeding time along with the P and K. For winter canola, nitrogen may be best applied as a split application using starter nitrogen application of about 10-20 lbs/acre, followed by the remainder in the spring prior to regrowth.

As shown in Table 1, canola is a heavy user of sulfur. Soils most likely to respond to S additions are light colored, sandy soils, in northwestern Wisconsin and northern Minnesota which have not been manured within the past two years.

E. Variety Selection:

There are several varieties of oilseed rape available particularly from Canadian sources. Recently released varieties which meet the qualifications to be called canola are:

Andor—Released by University of Alberta in 1981 with distribution rights to Can-Alta Seeds Ltd., Red Deer, Alberta.

Global—Developed by Svalof A. B., Plant Breeding Station, Sweden. Distributed by Bonis and Company Ltd., Lindsay, Ontario, Canada.

Hyola 70—Hybrid developed by Contiseed Ltd. (Canada) to be marketed in U.S. in 1988, by Contiseed, Huron, SD.

OAC Triton—Tolerant of triazine (Sencor, Lexone, atrazine, etc.) herbicides. Originated by University of Guelph, Ontario. Licensed in 1984.

Regent—Originated by University of Manitoba. Licensed in 1977.

Topas—Reported to have moderate resistance to Sclerotinia. Developed by Svalof A. B., Plant Breeding Station, Sweden. Distributed by Bonis and Company Ltd., Lindsay, Ontario, Canada.

Tower—Originated by University of Manitoba. Licensed in 1974.

Tribute—Tolerant of triazine herbicides (Sencor, Lexone, atrazine, etc.). Better oil quality than OAC Triton but much lower seed yield than Westar. Originated by Agriculture Canada, Saskatoon, and University of Guelph, Ontario. Licensed in 1985.

Westar—Originated by Agriculture Canada, Saskatoon. Licensed in 1982. Production of certified seed limited to Canada.

Candle—Originated by Agriculture Canada, Saskatoon. Licensed in 1977.

Tobin—Originated by Agriculture Canada, Saskatoon. Licensed in 1981. Production of certified seed limited to Canada.

Characteristics of spring seeded canola varieties in Minnesota tests are shown in Table 2. (from Varietal Trials of Farm Crops-Minnesota Report 24)

Table 2: Characteristics of spring canola in Minnesota.

Crop and Variety	Oil (%)	Test Weight (lbs/bu)	Seeds (1,000/lb)	Days from planting to		Lodging (score)	Height (in)
				bloom	maturity		
Brassica napus							
Andor	42	50	137	51	98	0.9	35
Hyola 70	40	43	250	55	88	1.1	34

Global	41	51	133	59	99	2.2	39
OAC Triton	41	51	116	56	100	2.1	30
Topas	43	51	156	58	98	1.2	39
Tribute	35	49	152	55	88	0.8	31
Westar	42	51	123	52	93	0.9	35
Brassica campestris							
Tobin	41	52	197	43	89	4.0	30

F. Weed Control:

The best weed control practices are tillage, establishment of a good stand, and weed control in previous crops. Cruciferous weeds (wild radish, wild mustard, pennycress and shepherd's purse) are nearly impossible to control in the crop.

1. **Cultural:** As with small grains, the weed control in canola is primarily from the crop itself. Follow all recommended cultural practices to assure a dense vigorous crop that competes well with weeds. Select fields with minimal weed pressure and try to avoid those with weeds in the mustard family.
2. **Mechanical** control measures cannot be used in canola. A rotary hoe would kill many crop plants and row cultivation is not feasible because of the narrow row spacing.
3. **Chemical:** Treflan is the only herbicide registered in the United states for use in canola. Treflan and Poast are registered in Canada. Treflan is applied preplant incorporated and gives good annual grass control, but misses ragweed, mustard, and lady's thumb smartweed. Poast is used for postemergence control of annual grasses, quackgrass and volunteer cereals.

G. Diseases and their Control:

White mold (*Sclerotinia* stem rot) can be a serious disease after flowering in seasons with cool, moist growing conditions. Infection occurs when dropped petals contact the stem and spores germinate on the dead petals. Bleached stem lesions occur around the initial infection, then white mold and black fungal bodies grow inside and outside the stem. Sudden wilting and premature dying of individual plants are usually the first noticeable symptoms. Since white mold is a problem in several other crops, its occurrence in canola must be carefully monitored. Avoid planting canola following such crops as soybeans and dry edible beans or sunflower.

H. Insects and Other Predators and their Control:

Many insects may infest canola at various stages of its growth. Probably the greatest problem is caused by the flea beetle, a shiny black beetle about 10 to 15 mm long which attacks canola particularly at emergence, although it can be a problem later as well. Hot, sunny weather promotes feeding damage. Most growers control flea beetles with a granular insecticide mixed with the seed, but other seed-applied formulations and postemergence insecticides are also available. Seed-applied insecticides provide protection for about half as long as the granular materials. Flea beetle has not been a problem with winter canola types.

Diamondback moth larvae can be a problem in dry years. The larvae are pale yellow to light green, 11 to 13 mm in length, and frequently hang by a spun thread. Larvae eat flowers and young pods, and peel older tissue. Seeds under peeled pods often fail to develop properly. Spraying with one of the recommended insecticides can be justified in situations where there are over 20 larvae per plant.[3]

I. Harvesting:

Timely harvest of canola is critical to prevent shattering. When pods first begin to yellow, the crop needs to be checked on a 3 to 4 day schedule. Harvest maturity can only be determined by observing the color of the seed. In canola that stands well, 30 to 40% of the seed on the main stem needs to be brownish-red in color prior to swathing. This corresponds to about 30 to 35% seed moisture. Canola does have a tendency to lodge, particularly with over-fertilization of susceptible varieties. In severely lodged canola, swathing should be done when 40 to 50% of the seed in exposed pods has turned color.

Shattering can account for significant crop losses, therefore harvesting must not be delayed. Canola should be cut high on the stem and lightly pushed into the stubble with a windrower to prevent blowing. The crop is combined when it has dried to near 10% moisture. Direct combining with the use of a desiccant is possible in canola that is standing well, but determining application time is difficult and field losses are higher. The cylinder speed should be set at 450-1000 RPM and the cylinder concave clearance at 3/16 to 1/2 inch. Losses should be evaluated for further refinement of these adjustments. Canola that is to be stored for six months or more must be dried to near 8% moisture.

J. Drying and Storage:

Rapeseed must be handled and stored carefully. Tight storage bins are required. Seed can sweat in storage even at 9 to 20% moisture content. Inspection is required to prevent heating and spoilage in the bin. The small seed restricts air flow, so thin layers are necessary for drying wet seed. If much straw is present a scalper should be used to clean the crop.

VI. Yield Potential and Performance Results:

Yields of canola in the upper Midwest have been extremely variable in recent studies. In Minnesota, yields have ranged from 150 to 2500 lb/a with oil ranging from 39 to 47%. A test weight of 52 lb/bu is generally used for canola.

Studies conducted at several locations in Wisconsin have found yields of spring types ranging from 250 to 2300 lb/a, while winter types frequently have not survived the Wisconsin winters. Recent Wisconsin yields are summarized in Table 3 and Minnesota yields in Table 4.

Table 3: Yield of spring and fall seeded canola varieties in Wisconsin.

Variety	Arlington	Marshfield	Hancock	Ashland	Spooner	Sturgeon Bay
Spring Seeded						
Years:	1985-87	1985	1985	1985-86	1985	1985-86
No. tests:	5	1	1	2	1	2
	yield (lb/a)					
Varieties						
Westar	1485	1248	1577	826	1731	1846
Topas	1099	1248	2096	1111	2269	1849
Global	1243	1549	2201	970	1993	1848
Fall Seeded						
Years:	1986	1986	1986	1986		1986-87
No. tests:	I	I	1	1		2
Variety						
Jupiter	1422	645	938	1325		1746

Table 4: Seed yield of spring canola in Minnesota.

Crop & Variety	Roseau 1981-2, 84-5, 89	Crookston 1985	Morris 1989	Rosemont 1979-83, 87	Waseca 1987-88	Lamberton 1987	Grand Rapids 1988-89
	lbs/A						
Brassica napus							
Hyola 40	1465[1]	---	1945	569[1]	151	1087	1030
Global	1638[2]	1051	884	518[1]	188	665	918
OAC	1097[3]	954	1029	593[1]	179	510	335

Triton							
Topas	1294[2]	1058	1368	612[1]			
Westar	2065[3]	1377	1391	634[2]	281	1220	1381
Brassica campestris							
Tobin	1145[3]	876	---	1161[3]	273	920	697[1]

[1]One year data,
[2]Two year data,
[3]Three year data

VII. Economics of Production and Markets:

Canola is sometimes marketed on a contract basis. No standard grading system exists in the U.S., (although standards are being developed and may be in place by 1990), but primary grades used in Canada are generally followed by buyers.

Table 5 compares the costs of producing soybean, another oilseed crop, and those of canola. "Fixed costs" assume that such things as equipment, time investment, interest rates, etc. are the same for both crops. However, even with these costs being equal, the direct costs of canola production are higher. Most of the additional expense comes from increased fertilizer and pesticide inputs. Transportation costs to the market have not been included. For most areas of Wisconsin and Minnesota these costs are likely to be much higher for canola than for soybean considering the lack of available canola markets.

Potential returns of canola at $.10/lb with those of soybean at $5.50/bu are compared in Table 6. From this information, it is apparent that canola must yield higher than any of the varieties have in the recent Minnesota and Wisconsin evaluations to be economical.

Table 5: Canola production costs compared to soybean.

Expense	Cost/Acre	
	Soybean	Canola
Fixed costs	152.00	152.00
Variable costs		
Seed	$15.00	$14.00
Inoculurn	0.50	0.00
Fertilizer	16.80	34.00
Herbicide	15.00	6.00
Insecticide	0.00	1.50

Subtotal	$47.30	$55.50
Total Cost	$199.30	$207.50

Table 6: Potential returns with soybean at $S.50 per bushel and canola at $0.10 per pound.

Production Level	Soybean Yield (bu./A)	Profit	Canola Yield (lbs./A)	Profit
Breakeven	36	$0.00	2,075	$ 0.00
Good Yield	50	75.70	2,800	72.70
High Yield	70	185.70	3,600	152.50

Canola may be more adapted and competitive in the extreme northern portion of the Midwest where soybean yields are lower. With proper management, canola may be a potentially profitable crop for these areas.

VIII. Information Sources:

- Canola Production HandbooL 1989. Cooperative Extension Service Bulletin, C-706. Kansas State
- University. Manhattan, KS.
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- Winter Rapeseed Cultural Information. 1986. L. L Hardman. Dept. of Agronomy & Plant Genetics, Univ. of Minn. St. Paul, MN.
- Varietal trials of Farm Crops. Minnesota Report 24. Univ. of Minn. Ag. Exp. Sta., St. Paul, MN.

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Footnotes:

[1]Canola is sensitive to high temperatures, especially during flowering. Yields decline from northern to southern Minnesota, largely due to heat stress.

[2]In Minnesota, fall seeding should take place between Aug. 1 and Sept. 20. Winterkill of fall-seeded canola is likely if there is insufficient snow cover. (In 1989, 5 of 6 locations of winter canola were winter-killed).

[3]Check with authorities about temporary labels for your state, as there are currently no insecticides for canola that have a national EPA label.

Chickpea (garbanzo bean)

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I. History:

Chickpea (*Cicer arietinum* L.) is an ancient crop that has been grown in India, the Middle East and parts of Africa for many years. It may have been grown in Turkey nearly 7,400 years ago. Much of the world's chickpea supply (80 to 90%) comes from India where poor soil, use of unimproved varieties and low rainfall results in yields averaging about 700 lb/acre.

Most of the chickpea acreage in the United States (15,000 acres) is in California (8,000 acres) but certain areas of eastern Washington, parts of Idaho and Montana are now growing this crop successfully. This acreage has been increasing to provide chickpea supplies which formerly came from Mexico, which cut back chickpea production in favor of pinto bean.

II. Uses:

Chickpea is consumed as a dry pulse crop or as a green vegetable with the former use being most common. Seeds average about 20% protein, 5% fat and 55% carbohydrate.

Seeds are sold in markets either dry or canned. Common uses in United States are in soups, vegetable combinations, or as a component of fresh salads in restaurant salad bars.

Some livestock feeding trials have been conducted and these show chickpea to be a good source of protein for feeds, except that the amino acids methionine and cystine are deficient.

III. Growth Habits:

Plants are multiple branched, spreading growth habit annuals ranging from 8 to 40 in. tall. Some chickpea varieties have compound leaves (8 to 20 leaflets) and some have simple leaves, which are pubescent (hairy) in appearance. Chickpea leaves exude malic and oxalic acids.

Kabuli (large seeded = 800 seeds/lb) varieties are generally taller than the desi (small-seeded = 1,500 seeds/lb) varieties.

Because of its deep tap root system, chickpea can withstand drought conditions by extracting water from deeper in the soil profile.

Flowers (self-pollinated) which are borne in groups of two or three are 1/2 to 1 in. long and come in purple, white, pink or blue color depending upon variety. Each flower produces a short, pubescent pod which is 3/4 to 2 in. Long and which appears to be inflated. One or two seeds (1/2 to 1 in. diameter) are present in each pod. The seeds come with either rough or smooth surfaces and can be creme, yellow, brown, black or green in color. There is a definite groove visible between the cotyledons about two-thirds of the way around the seed, with a beak-like structure present.

IV. Environment Requirements:

A. Climate:

Chickpea is a cool season annual crop performing optimally in 70° to 80°F daytime temperatures and 64° to 70°F night temperatures. They produce good yields in drier conditions because of their deep tap root. Heavier rainfall seasons (over 30 in. annually) show reduced yields due to disease outbreaks and stem lodging problems from the excessive vegetative growth. Areas with lighter, well distributed rainfall patterns have produced the highest yield and quality chickpea seed.

B. Soil:

Chickpea does best on fertile sandy, loam soils with good internal drainage. Good drainage is necessary because even short periods of flooded or waterlogged fields reduce growth and increases susceptibility to root and stem rots.

C. Seed Preparation and Germination:

Good quality certified chickpea seed should always be used. This seed should be high in germination percentage (over 85%), free of damage, and free of weed seeds. Good quality seed does not need to be treated with an insecticide or fungicide, but if you have had past problems with Pythium or Rhizoctonia rots in your fields you may need to treat your seed prior to planting.

Plan to purchase the special strain of nitrogen fixing bacteria required for chickpea if you are planting this crop for the first time in a field. It can be purchased in peat or granular form, the latter type must be used if your seed is fungicide treated. Follow instructions supplied with your inoculant to ensure its proper use.

V. Cultural Practice:

A. Seedbed Preparation:

A firm, smooth seedbed with most of the previous crop residue incorporated is best. This will allow proper depth of planting as well as good seed-soil contact, which is essential for rapid germination and emergence. If moisture is short keep deep preplan" tillage to a minimum to prevent excessive drying in the top 2 to 3 in. of soil.

B. Seeding Date:

Chickpea is a cool season species and is frost tolerant as seedlings so seeds should be planted in early to mid-April when the small grains are planted in the Upper Midwest. Later planting dates result in shorter plants, less yield and late maturity of late formed flowers and pods. Flower and pod abortion rates increase if flowering and pod set coincide with the hottest and driest weather pattern. More research is needed in this area using currently available varieties.

C. Method and Rate of Seeding:

Chickpeas can be planted at row spacing between 6 in. and 40 in. South Dakota research showed a yield of 2936 lb/acre in 6 in. rows with only 1900 lb/acre yield production in 36 in. rows. Both row spacings had excellent weed control, and a plant population near the recommended rate of 140,000 live seeds planted per acre. Because seed size varies widely, this planting rate in pounds of seed per acre could vary from 75 to 150 lb/acre. Seeds dropped per foot for 6 in. rows should be about 2; for 15 in. rows 4 or 5 and for 36 in. rows about 10.

Seeds should be planted 1 in. to 2 in. deep using a drill or planter which can deliver the chickpea seed without damage. Good seed soil contact should be ensured with a press wheel if possible.

Because of the high cost of seed and variation in germination rates you should carefully calibrate your equipment to achieve the proper plant population.

D. Fertility and Lime Requirements:

Fertility requirements for chickpea in Minnesota and Wisconsin are not well known, but the crop will likely require the amounts of phosphorus, potassium and certain micronutrients which are recommended for other pulse or legume crops in this area. Any fertilizer application should be based on soil test level, previous crop and expected yield level. Soil should be limed to a pH of 6.0 unless a crop with a higher pH requirement is grown in the rotation. Phosphate and potash recommendations based on soil test values are given in Table 1.

If roots can be nodulated with the proper strain of Rhizobium, nitrogen fertilizer will not be necessary. Some growers may wish to provide 15 to 30 lbs of nitrogen as a broadcast treatment to enhance early seedling development.

E. Variety Selection:

Specific recent information on chickpea variety performance in Minnesota and Wisconsin is not available. Much variety development and testing has been done in recent years at the USDA-ARS and Washington State University research laboratories at Pullman, Washington; and Idaho Agricultural Experiment Station at Moscow, Idaho and this information is available. During the 1982–84 growing seasons agronomic scientists at South Dakota State University in Brookings tested a large number of lines from the germplasm collections of the International Center for Agricultural Research in Dry Areas (ICARDA) at Aleppo, Syria. The five highest yielding lines were from Syria, Turkey and Spain and were well adapted to South Dakota conditions.

Table 1: Phosphate and potash recommendations for chickpeas (2000 to 4000 lb/acre).

Subsoil fert. group*	Soil test interpretation					
	Very low	Low	Optimum	High	Very high	Excessively high[1]
	lbs P_2O_5/acre					
A, B, C	50	45	30	15	--	0
D, E, X	45	40	30	15	--	0
O	55	50	30	15	--	0
	lbs K_2O/acre					
A, B, D	120	110	90	45	20	0
C	125	115	90	45	20	0
E, O	110	105	90	45	20	0

[1]A small amount of starter fertilizer is recommended for cold soils.
*For a description of subsoil fertility groups, see UWEX publication A2809, Soil test recommendations for field, vegetable and fruit crops. Revised, 1990.

Growers should consider maturity, growth habit, seed size and color pattern as well as yield when selecting a variety to grow. Currently large seeded, lighter colored seed types are preferred for soup and salad bar uses. For the latest information on new varieties and seed available contact your local extension office or crop consultant or write to the Universities discussed above.

F. Weed Control:

1. Mechanical: Chickpea is not very competitive with weeds so they should be planted only on fields which have few if any major weed problems, especially perennial weeds such as quackgrass and Canada thistle.

Rotary hoeing and/or field cultivating in wider row spacings should be used as necessary to control weed populations in chickpea. Early weed competition is more damaging to yield than later emerging weeds. Avoid extensive damage to plants and cultivate when leaves and stems are dry to reduce spread of disease organisms.

2. Chemical: The herbicide metholachlor (Dual) can be applied as a preplant incorporated or preemergence treatment. It gives excellent annual grass and fair to good annual broadleaf control. A rotary hoe could be used in chickpea in the same manner as with soybean. Row cultivation is not practical due to the narrow row spacing.

If annual grasses or quackgrass are abundant after the crop emerges, a postemergence application of sethoxydim (Poast) should be considered. Treat when the grasses are 4 to 6 in. tall. A 1 pt/acre rate controls most annual grasses; check the label and select the rate appropriate for your weed species. Always use 1 qt/acre of Dash or a crop oil concentrate when Poast is applied.

Chickpea has been grouped on some herbicide labels with other dry pod harvested crops such as field bean or adzuki bean. This could allow use of herbicides cleared in those crops to be used on chickpea. Read labels carefully and seek clarification from the company involved before using any herbicide on your chickpea crop. Be sure to ask a company representative, your extension agent or crop consultant for the most recent information and follow the label directions exactly. Because chickpea is a lesser grown crop in Wisconsin and Minnesota, label clearance from other states may not apply.

G. Diseases and Their Control:

Ascochyta blight, Rhizoctonia root rot, Pythium rot, Fusarium wilt, white mold, bacterial blight and certain viruses are possible disease problems in production fields of chickpea. These are typical diseases which affect other pulse or legume crops and they are accentuated by periods of high rainfall, high humidity and high temperatures.

These are best controlled by using good quality seed, proper crop rotations, proper tillage practices to bury diseased residue and disease resistant varieties if available.

Contact your extension agent or crop consultant for identification of disease organisms, threshold value determinations and control or management suggestions.

H. Insects and Other Predators and Their Control:

Because chickpea leaves, stems and pods are heavily pubescent with glandular hairs that secrete malic and oxidic acid, they suffer little direct damage from aphids and other insects. Several viral diseases (transmitted by aphids) have occasionally been reported in chickpea fields in Washington and Idaho. Seedcorn maggot and wireworms might be expected to cause problems early in the season by attacking the germinating seed and destroying the growing point.

If a serious insect problem develops in a field, consult your local Extension office or crop consultant for information about threshold value determinations and recommendations for control.

I. Harvesting:

Chickpea can be harvested direct or swathed prior to combining depending upon uniformity of maturity and weed problems. About 1 week of good drying weather is required in the swath.

Chickpea can be swathed when the plants are yellowing and the pods are their mature color. This should be done when the plants are slightly damp to facilitate forming the swath without yield loss. When the vines, pods and seeds in the windrow are dry enough (seed moisture about 13%) the swath can be combined. Seed color is important (buyers prefer a yellowish-creme color) so greenish and brown seeds are generally unacceptable. Slight bleaching does occur in the swath. About 1% immature color seed is allowed before deductions are implemented.

Adjust the combine screen size, cylinder speed, concave clearance and air flow carefully to maintain a quality seed with little physical damage or excessive trash.

J. Drying and Storage:

Moisture content should be around 10 to 12% to prevent insect and or disease outbreaks in storage. Because of their relatively large seed size, chickpea can be dried slightly with ambient temperature air flow through thin layers in a regular storage bin.

Storage system should be carefully fumigated before storing chickpea and all storage areas should be monitored regularly to identify potential problems early.

VI. Yield Potential and Performance Results:

Research plot data in Washington and Idaho report yields from 1000 to 3500 lb/acre. Similarly managed test plots in South Dakota reported yields of 1700 to 2500 lb/acre. Growers could likely expect yields of 1800 lb/acre under good field and management conditions.

No current data is available for Minnesota and Wisconsin chickpea yields, either from research or production fields.

VII. Economics of Production and Markets:

Chickpeas can be marketed under contract or sold to brokerage firms at quoted prices. Small seeds, damaged seeds, foreign material, and off color in the seed lot will reduce price.

The outlook for chickpea in both domestic and export markets is bright. In 1980, California produced only 25% of the nation's annual requirement of about 17,000 metric tons. Foreign market demand is also good because many countries which use chickpea have shifted acreage to cereal crop production.

As with all specialty crops, growers should locate markets, delivery points and negotiate a suitable price before committing major acreage to this crop.

VIII. Information Sources:

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Comfrey

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I. History:

Comfrey has been cultivated since about 400 BC as a healing herb. The word comfrey, derived from the Latin word for "grow together", reflects the early uses of this plant. Greeks and Romans used comfrey to stop heavy bleeding, treat bronchial problems, and heal wounds and broken bones. Poultices were made for external wounds and tea was consumed for internal ailments.

Comfrey (*Symphytum* spp.) is native to Europe and Asia. Although comfrey has been used as a food crop, and as a forage crop, in the past 20 years scientific studies reported that comfrey may be carcinogenic, since it appeared to cause liver damage and cancerous tumors in rats. Comfrey-pepsin capsules, which are sold as a digestive aid in herbal and health-food stores in the USA, have been analyzed and found to contain pyrrolizidine alkaloids. These alkaloids cause liver damage in people and are a potential carcinogen. Huxtable et al. (1986) cited cases of hepatic veno-occlusive disease that were produced by using these capsules. These reports have temporarily restricted development of comfrey as a food crop.

Three plant species in the genus *Symphytum* are relevant to the crop known as comfrey. Wild or common comfrey, *Symphytum officinale* L., is native to England and extends throughout most of Europe into Central Asia and Western Siberia. Prickly or rough comfrey [*S. asperum* Lepechin (*S. asperrimum* Donn)], named for its bristly or hairy leaves, was brought to Britain from Russia about 1800. Quaker, Russian, or blue comfrey [*S.* × *uplandicum* Nyman (*S. peregrinum* Lebed.)] originated as a natural hybrid of *S. officinale* L. and *S. asperum* Lepechin. This hybrid was called Russian or Caucasian comfrey in reference to its country of origin. Cuttings of this hybrid were shipped to Canada in 1954 and it was named Quaker comfrey, after the religion of Henry Doubleday, the British researcher responsible for promoting comfrey as a food and forage. The majority of comfrey grown in the United States can be traced to this introduction.

II. Uses:

Prickly comfrey was evaluated for its value as a forage by the USDA and numerous state experiment stations more than 80 years ago. Comtrey yielded less than some common forage crops and its high water content of 85 to 90%, in comparison to 75 to 80% for alfalfa, made forage preservation difficult. The extensive hairs on comfrey leaves restricts its use as a forage. Fresh leaves are eaten by pigs, sheep, and poultry, but are frequently unpalatable to cattle and rabbits. Cattle and rabbits will eat the wilted forage. Horses, goats, chinchillas, and caged birds are also fed this forage. In a grazing trial in St. Paul, MN, comfrey was judged to be poorly palatable in comparison with several other plant species. This is probably due to the presence of hairs which wilting alleviates.

Wild comfrey was brought to America by English immigrants for medicinal uses. The allantoin content of comfrey, especially in the root, has resulted in its use in folk medicine for healing wounds, sores, burns, swollen tissue, and broken bones. Allantoin, found in milk of nursing mothers and the fetal allantois, appeared to affect the rate of cell multiplication. Wounds and burns seemed to heal faster when allantoin was applied due to a possible increase in number of white blood cells. Comfrey has been reported to promote healthy skin with its mucilage content that moisturizes and soothes, while the allantoin promotes cell proliferation.

The allantoin applied to external wounds is either a 0.4% solution or a 2% ointment. An effective allantoin formulation is difficult to prepare from comfrey due to the low and variable content of this substance. Hart (1976) reported that dried comfrey leaves contain 0.1 to 1.6% allantoin while dried roots have 0.4 to 1.5%. Since fresh leaves are 85% water, they could not contain more than 0.2% allantoin. It would require anywhere from 8 oz to 8 lb of dried comfrey leaves per quart of water to produce a 0.4% solution that would be effective.

Comfrey produces large amounts of foliage from late May until hard frosts in October or November. This crop has been used as a salad green and potherb because it was considered a good source of protein and a rare plant-derived source of vitamin B_{12}. Vitamin B_{12} is produced usually by soil bacteria and fungi or in the small intestines of some animals. Humans usually obtain this vitamin from eggs, dairy products, and meat. However, a study on the nutritional value of comfrey conducted in Australia in 1983 found that you would need to eat more than 4 lb/day of fresh comfrey to obtain the minimum daily requirement of B_{12}. Eating such large amounts of comfrey, a poor source of vitamin B_{12}, is inadvisable due to the potential health hazards.

Protein content of comfrey dry matter (15 to 30%) is about as high as legumes. Robinson (1983) reported specific amino acid and mineral content of comfrey. Hart (1976) mentioned that comfrey has lower amounts of eight amino acids that are essential for humans than turnip greens or spinach, but more than cabbage. Comfrey, like most green vegetables, is deficient in methionine and is also low in phenylalanine. Three ounces of dried turnip greens or spinach, in comparison to 20 oz of dried comfrey, supply adults with the total daily requirement of all essential amino acids, except for methionine. Comfrey also tends to have high ash content.

III. Growth Habit:

Comfrey is a herbaceous perennial plant with short, thick, tuberous roots, a deep and expansive root system: Comfrey begins growth in early-April and by early May compact clusters of young leaves are visible in the crown of the old plant. Within a few weeks, the leaf blades with long petioles have grown to over 12 in. high. Basal leaves are large, lance-shaped, stalked, and coarsely hairy. The stem elongates rapidly and reaches a height of over 3 ft. Upper leaves do not have long petioles and are attached closely to the stem.

Flowering starts in late May or early June and continues until fall. Leaves on flowering, erect stems are sessile or decurrent, and decrease in size up the stem. The bell-shaped flowers with pedicels are in terminal cymes or one-sided clusters. Flowers of common comfrey are usually creamy yellow, but white, red, or purple types have been found in Europe. Prickly comfrey has pink and blue flowers while Quaker comfrey has blue, purple, or red-purple flowers. Seed production is rare, and crops are usually established from root cuttings and crown divisions. Vegetative growth does not cease with the start of flowering, and the plant will add new stems continuously during the growing season. The plant will grow rapidly after harvest and flower again. Comfrey crowns and roots are very winterhardy in northern Midwestern environments.

IV. Environment Requirements:

A. Climate:

Comfrey produces the highest yields in full sunlight and under cooler conditions. Unlike annual crops, the leaves do not readily wilt during extended periods of drought due to its deep root system. This crop is also very frost resistant.

B. Soil:

Comfrey is adaptable to many soils, but prefers moist, fertile soils. Thin soils over rock will give a poor crop, but on light sands and loams, this crop will be productive if adequate nutrients are present.

C. Seed Preparation and Germination:

Comfrey is propagated from root cuttings, crown divisions, and transplants. Production during the first year is greatest for a crop started from transplants and lowest for one using root cuttings. After the first year, comfrey yields the same regardless of propagation method. Root cuttings are the least expensive method of propagation, and consequently, are used most often. Root cuttings are usually 1 1/2 to 6 in. long and 1/4 to 3/4 in. in diameter. Smaller cuttings will also generate plants, but plants from longer cuttings emerge and establish more quickly. Wilted cuttings should be soaked in cold water until they become firm before planting. Root cuttings develop buds about 3 to 6 weeks after planting, while crown divisions emerge in about 10 days. Prickly comfrey is propagated by seed in the Soviet Union.

V. Cultural Practices:

Comfrey plantings should last indefinitely (more than 20 yrs) if proper weed control and soil fertility are maintained.

A. Seedbed Preparation:

Till the soil so that it is free of perennial and annual weeds, and is level prior to planting. When an area is to be replanted with a different crop, repeated tillage is usually used to remove the comfrey plants. Deep moldboard plowing should be done in September or October, and then followed by tillage with a field cultivator, which will expose roots to the drying and freezing conditions of winter. Herbicides could be used in removing the old plants. Glyphosate was sprayed in June at Rosemount, MN and killed stems and leaves. However, plants grew again from the roots to produce a full stand by September.

B. Planting Date:

The best time to plant is in April, or as early as the soil can be tilled, but the crop can be planted throughout the growing season. A small crop can be anticipated the first year if it is planted early in the season. However, the most efficient use of the land usually occurs when comfrey is planted after the harvest of small grain or other early season crops. Root cuttings should be planted before September, while transplants or crown divisions can be planted as late as early October. Planting late in season has the advantage that the land can be summer fallowed to kill weeds. Plants must be established and grow before winter in order to produce a high yield the following year.

C. Method and Density of Planting:

Root cuttings should be laid flat and covered with soil. The cuttings should be planted at a depth of 2 to 4 in. according to soil texture and expected soil moisture. A 4-in. depth is commonly used, but 2 in. is adequate with irrigation. Very small cuttings should not be planted as deeply as the longer cuttings. Young transplants should be planted upright with the crowns about 2 in. deep. Comfrey is planted in a checkerboard arrangement in rows that are 3 to 4 ft apart to permit cross cultivation for effective weed control. Closer row spacing, such as 30 in., may produce higher yields but the cost of cuttings will be greater.

D. Fertility Requirements:

Comfrey is a high-protein forage that, unlike legumes, obtains all of its nitrogen from the soil. Older plantings with leaves showing a lighter green color will usually require broadcasting or sidedressing of nitrogen ferrilizer. Recommended rates vary from 40 to 100 lb N/acre depending on soil organic matter. Barnyard manwe is an excellent nutrient sowce for comfrey. Productive comfrey, like silage corn, removes relatively large amounts of potassium, phosphorus, and calciwm from the soil. Comfrey productivity is not very sensitive to soil pH, but highest yields occur on soils with a pH of 6.0 to 7.0. Soils testing in the medium range should receive about 25 lb P_2O_5 and 120 lb K_2O/acre.

E. Variety Selection:

All commercial plantings in the United States appear to be derived from cuttings of the Bocking Mixture cultivar. This cultivar was imported from England into Canada in 1954 and subsequently arrived in the USA. This cultivar is a mixture of several clones that differ slightly in plant vigor and general morphology.

F. Weed Control:

1. Mechanical: Comfrey is an excellent weed competitor due to its rapid and dense growth. Weeds may become established between comfrey plants under a multiple-cut harvesting regime. As a result, two cultivations per year are often required. Rototilling between plants is an effective method for destroying weeds.

2. Chemical: Comfrey has usually been grown without herbicides. No herbicides are labeled for use on this crop in the Upper Midwest.

G. Diseases and Control:

Diseases have not been a serious problem with comfrey in the United States. Comfrey rust fungus (*Melampsorella symphyti*) overwinters in roots and reduces yield of old plantings in Great Britain. This disease problem has not spread to the United States due to plant quarantine regulations on the importation of roots or plants.

H. Insects and Other Predators:

Insects have not been reported to be a problem with comfrey in the United States.

I. Harvesting:

When comfrey is wilted or ensiled after cutting, cattle and rabbits will eat it, since this practice collapses the leaf hairs. Leaf hairs of comfrey are apparently not a problem when cattle are fed green chop that is harvested daily.

J. Drying and Storage:

Drying comfrey for use as a medicinal herb or clean hay is not easy for mechanized farms since at least three days of dry weather are required to cure it in a windrow, and the leaves may get dirty when laying on the soil. The medicinal herb or clean hay can be made by drying leaves by spreading them out in open areas. The comfrey may turn a dark color, but it is still acceptable to livestock as a forage.

Comfrey must be cut and allowed to wilt for a minimum of 24 hrs when used as silage. Additives such as molasses or grain are sometimes helpful, and mixing up to 25% comfrey with small grain or corn forage serves as an economical method to make high quality silage.

VI. Yield Potential and Performance Results:

More than half of the annual yield in Minnesota trials was produced in the first two cuttings during June and July (Table 1). Chinese researchers found that the greatest annual yields were obtained from three cuttings, which start at full bloom in mid-June. Comfrey yields are frequently reported on a fresh-weight basis, which exaggerates the yield potential of the crop due to its high moisture content. Comfrey forage averaged about 89% moisture in Minnesota trials (Table 1). Moisture content of comfrey forage is higher than in some legume and grass forages. For example, alfalfa cut in early bloom has 80% moisture and winter rye has 75 to 85% moisture when harvested between the tillering and boot stages.

Annual dry-weight yields in Minnesota ranged from about l 1/2 to 6 t/acre for four or five cuttings. However, on a fresh-weight basis, the same yields ranged from 13 to 61 t/acre. The low yields in 1979 and 1980 from the 1979 planting, compared to the higher yield obtained in 1980 from the 1979 planting that was not harvested in 1979, indicates that the crop plants need time to accumulate root reserves before intensive harvesting begins.

Quaker comfrey may produce forage yields almost as high as those of alfalfa or orchardgrass when planted at the optimal spacing and rate of fertility. Hart (1976) compiled a table of comparative yields for comfrey and other forages that showed comfrey is not better than other forages (Table 2). Robinson observed that comfrey was high in crude protein (21 to 31%), which increased from the first to last harvest. Research trials conducted by USDA scientists (Hart et al., 1981) found crude protein contents that ranged from 13 to 17% for comfrey and 16 to 17% for alfalfa. However, they also observed that except at the highest nitrogen rate, its digestibility was usually somewhat lower than those for alfalfa, orchardgrass, and other forages.

Table 1. Moisture percentages and dry-matter yields of comfrey at Rosemount, Minnesota, 1979–1981.

	Year Harvested		
Planting Date	1979	1980	1981
	Moisture (%)		
April 28, 1975	92	87	88
October 14, 1977	90	88	88
April 23, 1979	89	87	88

April 23, 1979	--	88	90
	Yield (lb. dry matter/acre)		
April 28, 1975	5,340	8,650	9,485
October 14, 1977	12,140	7,950	9,485
April 23, 1979	2,720	6,240	9,480
April 23, 1979	-	10,210	8,110

Source: R G. Robinson, 1983. University of Minnesota, St. Paul, MN.

Table 2. Dry-matter yields of comfrey and other forage crops in different areas of the world.

Location	Years of Data	Crop	Yield (Ton/acre)
California	2	Alfalfa	12.0
		Comfrey	10.7
Oregon	5	Alfalfa	7.6
		Comfrey	5.0
Wisconsin	1	Red Clover	4.0
		Comfrey	3.2
England	2	Timothy	4.0
		Comfrey	3.1
Germany	2	Alfalfa	5.3
		Comfrey	3.6
USSR	4	Alfalfa	4.5
		Red Clover + Timothy	4.1
		Corn	3.2
		Comfrey	2.0
Kenya	2	Alfalfa	1.9
		Comfrey	1.7

Source: R H. Hart, 1976, Crops and Soils 29(1):12-14

VII. Economics of Production and Markets:

Comfrey has some disadvantages compared with other forage crops. Comfrey reguires the addition of nitrogen fertilizer to produce a high yield and protein content, while alfalfa produces high yields and protein content without addition of nitrogen fertilizer. Alfalfa and other forages can be established more cheaply than comfrey, since it is usually planted as root cuttings, especially at the close spacing needed for maximum yield. Comfrey, like other perennials, may be difficult to eradicate in order to plant other crops. The high moisture content and unpalatability for some livestock species make utilization of comfrey as a feed difficult. The presence of toxic alkaloids is also a problem. Advantages of comfrey are that it is very winterhardy in northern environments and could stabilize soil on erodible lands. It also produces fresh forage at a time of the year (spring, fall) when forage may be short from other sources.

Controversy about the safety of comfrey for internal use continues. Occasional use of comfrey for variety in one's diet and medicinal purposes will probably continue. Nonetheless, comfrey should no longer be considered a crop that can be consumed by humans or animals with complete safety.

It should be noted that consumption of comfrey is usually at lower levels than in toxicity research. Studies need to be conducted that involve the normal or low intake of comfrey for a proper evaluation of the health hazard to people or farm animals. Comfrey can be used externally as a medicinal herb for the allantoin content and as a crop for composting, mulching, or green manuring.

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for one product over other similar products is implied by the Minnesota and Wisconsin Extension Services.

Cowpea

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I. History:

Cowpea (*Vigna unguiculata* L. Walp.), an annual legume, is also commonly referred to as southern pea, blackeye pea, crowder pea, lubia, niebe, coupe or frijole. Cowpea originated in Africa and is widely grown in Africa, Latin America, Southeast Asia and in the southern United States. It is chiefly used as a grain crop, for animal fodder, or as a vegetable. The history of cowpea dates to ancient West African cereal farming, 5 to 6 thousand years ago, where it was closely associated with the cultivation of sorghum and pearl millet.

Wordwide cowpea production has increased dramatically in the last 25 years. United States production of dry cowpea has declined from 3/4 million acres to a few thousand over the same period. The blackeyed cowpea type is grown primarily in California and is marketed as California blackeyed peas.

II. Uses:

Cowpea seed is a nutritious component in the human diet, as well as a nutritious livestock feed. Nutrient content of cowpea seed is summarized in Table 1.

Table 1. Nutrient content of mature cowpea seed (average of eight varieties).

Protein	24.8%
Fat	1.9%
Fiber	6.3%
Carbohydrate	63.6%
Thiamine	0.00074%
Riboflavin	0.00042%
Niacin	0.00281%

[1]From Bressani R. Chap. 28 in Cowpea Research, Production and Utilization, Wiley and Sons.

The protein in cowpea seed is rich in the amino acids, lysine and tryptophan, compared to cereal grains; however, it is deficient in methionine and cystine when compared to animal proteins. Therefore, cowpea seed is valued as a nutritional supplement to cereals and an extender of animal proteins.

Cowpea can be used at all stages of growth as a vegetable crop. The tender green leaves are an important food source in Africa and are prepared as a pot herb, like spinach. Immature snapped pods are used in the same way as snapbeans, often being mixed with other foods. Green cowpea seeds are boiled as a fresh vegetable, or may be canned or frozen. Dry mature seeds are also suitable for boiling and canning.

In many areas of the world, the cowpea is the only available high quality legume hay for livestock feed. Digestibility and yield of certain cultivars have been shown to be comparable to alfalfa. Cowpea may be used green or as dry fodder. It also is used as a green manure crop, a nitrogen fixing crop, or for erosion control. Similar to other grain legumes, cowpea contains trypsin inhibitors which limit protein utilization.

III. Growth Habits:

Cowpea is a warm-season, annual, herbaceous legume. Plant types are often categorized as erect, semi-erect, prostrate (trailing), or climbing. There is much variability within the species. Growth habit ranges from indeterminate to fairly determinate with the non-vining types tending to be more determinate. Cowpea generally is strongly taprooted. Root depth has been measured at 95 in. 8 weeks after seeding.

Cowpea seed ranges in size from the very small wild types up to nearly 14 in. long and the number of seeds per pounds range from 1600 to 4300. Seed shape is a major characteristic correlated with seed development in the pod. Seeds develop a kidney shape if not restricted within the pod. When seed growth is restricted by the pod the seed becomes progressively more globular.

The seed coat can be either smooth or wrinkled and of various colors including white, cream, green, buff, red, brown, and black. Seed may also be speckled. mottled, or blotchy. Many are also referred to as "eyed" (blackeye, pinkeye purple hull, etc.) where the white colored hilum is surrounded by another color.

Emergence is epigeal (similar to common bean, and lupin) where the cotyledons emerge from the ground during germination. This type of emergence makes cowpea more susceptible to seedling injury, since the plant does not regenerate buds below the cotyledonary node.

The trifoliolate leaves develop alternately. Leaves are smooth, dull to shiny, and rarely pubescent. Commonly, the terminal leaflet is longer and larger than the lateral leaflets. There is a wide range in leaf size and shape.

Cowpea generally is day neutral. Flowers are borne in multiple racemes on 8 to 20 in. flower stalks (peduncles) that arise from the leaf axil. Two or three pods per peduncle are common and often four or more pods are carried on a single peduncle. The presence of these long peduncles is a distinguishing feature of cowpea and this characteristic also facilitates harvest. The open display of flowers above the foliage and the presence of floral nectaries contribute to the attraction of insects. Cowpea primarily is self pollinating.

Cowpea pods are smooth, 6 to 10 in. long, cylindrical and generally somewhat curved. As the seeds approach the green-mature stage for use as a vegetable, pod color may be distinctive, most commonly green. yellow or purple. As the seeds dry, pod color of the green and yellow types becomes tan or brown.

IV. Environment Requirements:

A. Climate:

Cowpea is a warm-season crop well adapted to many areas of the humid tropics and temperate zones. It tolerates heat and dry conditions, but is intolerant of frost. Germination is rapid at temperatures above 65°F; colder temperatures slow germination.

Cowpeas are grown under both irrigated and non-irrigated regimes. The crop responds positively to irrigation but will also produce well under dryland conditions. Cowpea is more drought resistant than common bean. Drought resistance is one reason that cowpea is such an important crop in many underdeveloped parts of the world. If irrigation is used, more vegetative growth and some delay in maturity may result. Application rates should insure that the crop is not overwatered, especially in more northern latitudes, as this will suppress growth by lowering soil temperatures. The most critical moisture requiring period is just prior to and during bloom.

B. Soil:

Cowpea performs well on a wide variety of soils and soil conditions, but performs best on well-drained sandy loams or sandy soils where soil pH is in the range of 5.5 to 6.5.

V. Cultural Practices:

A. Seedbed Preparation:

Soils should be cultivated deeply enough to insure that no barrier to penetration of the soil by the taproot (such as a hardpan) exists. Cowpea may be adversely affected by soil crusting under certain soil and environmental conditions.

B. Seeding Date:

Cowpea should not be planted until soil temperatures are consistently above 65°F and soil moisture is adequate for germination and growth. Seeds will decay in cool, wet soils. In the Minnesota-Wisconsin area, optimum seeding dates usually correspond to those for fieldbean (May 15-30).

C. Method and Rate of Seeding:

Traditionally, cowpea in the United States has been seeded in rows spaced 30 to 36 in. apart with seeds spaced 2 to 4 in. in the row. Recently, higher plant populations achieved by using narrow rows 12 to 20 in. have been used in commercial plantings. For forage purposes, the crop may be seeded in rows or broadcast (solid-seeded). Seed should be planted 1 to 1 1/2 in. deep and good seed-soil contact is important. The amount of seed to sow per acre depends on seed weight, germination percentage, and plant spacing. Recommended field seeding rates range from 18 to 22 lb/acre for viney, indeterminate types to 40 to 50 lbs for large-seeded determinate types. Optimum plant spacing depends on vine type. Highly determinate types may be planted 2 to 3 in. apart. Viney indeterminate types require more space, and a final stand with 8 to 9 in. between plants in 30 in. rows is considered to be a minimally acceptable population.

D. Fertility and Lime Requirements:

Cowpea, like all legumes, forms a symbiotic relationship with a specific soil bacterium (*Rhizobium* spp.). *Rhizobium* makes atmospheric nitrogen available to the plant by a process called nitrogen fixation. Fixation occurs in root nodules of the plant and the bacteria utilize sugars produced by the plant. Although cowpea *Rhizobium* is normally widespread, seed inoculation with *Rhizobium* specific to cowpea would be beneficial in areas where it is not present. Always use *Rhizobium* of the cowpea type.

Excess nitrogen (N) promotes lush vegetative growth, delays maturity, may reduce seed yield and may suppress nitrogen fixation. The plant will perform well under low N conditions due to a high capacity for N fixation. A starter N rate of around 27 lb/acre is sometimes required for early plant development on low-N soils.

A soil test is the best way to determine soil nutrient levels. In general, at least 27 lb P/acre and 40 lb K/acre are. recommended on soils of medium fertility but individual soils will vary in fertilizer requirements. Band fertilizer 3 to 4 in. deep and 2 to 3 in. away from the seed, or broadcast and disc in all fertilizer, including nitrogen, before planting.

E. Variety Selection:

The International Institute for Tropical Agriculture (IITA) in lbadan, Nigeria is the center for world-wide collection and testing of cowpea germplasm. The Institute has developed high yielding, short season, multiple disease-resistant varieties that are ready for harvest in 60 days. Several of the U.S. State Agricultural Experiment Stations conduct cowpea variety development programs. Cowpea researchers at the University of Minnesota have released two extra-early-maturing varieties, MN 13 and MN 150 (Table 3). Crude protein and digestibility of the whole plant are reported to be similar to alfalfa with yields ranging from 1.3 to 1.8 ton/acre after 60 days of growth.

Table 2. Dry-matter yields of cowpea cultivars and breeding Hues grown under two plant populations in 1981 and 1992 at Becker and Waseca, Minnesota.[1]

Cultivar	Plant Population (1000 plants/acre)			
	53		106	
	1981	1982	1981	1982
	(lb/acre)			
Colossus	3000	2580	2968	2525
MN139	1746	-	2402	-
Au704	2475	-	3659	-
Calif. Blackeye #5	2745	2483	3775	3312
Alabama Giant Blackeye	2215	-	3165	-
Freezegreen	1753	-	1996	-
MN150	-	1598	-	2050
LSD 5%	442	NS	442	NS

[1]From Marsh, D.B., L. Wawa. and G. C. Martin, HortScience 22(2~241-243.

Cowpeas have been grouped into the following market classes based on seed type and color:

Black eye and purple eye—The immature pods shell easily because the hull (pod wall) is pliable and the seeds come out of the pod clean and free. The shelled peas are attractive, mild flavored and suitable for processing. The white hilum is surrounded by black, pink, or light-red.

Brown eye—Pods vary in color from green to lavender and have a wide range of lengths. The immature seeds, when cooked, are a medium to dark brown color, very tender, and have a delicate flavor.

Crowder—Seeds are closely crowded in the pods and tend to be globular in shape.

Cream—Seeds of these types are generally cream colored and have no noticeable "eye" (the hilum is inconspicuous).

Clay—These are generally older varieties that are medium to dark brown in color and kidney shaped. They are no longer commonly grown.

White acre—The peas are kidney shaped with a blunt end. This type is a semi-crowder, generally tan in color and somewhat small. Pods are quite stiff.

Table 3. Days to harvest, seed type, seed yield-, and canopy size of cowpea cultivars on an irrigated sandy loam, Becker, Minn., 1993.

Entry	Days to harvest	Seed type	Seed yield[1] (lb/acre)	Weight of 100-seed (g)	Canopy ht (in.)	Canopy width (in.)
MN 13	96	Holstein	2001	15.7	22	18
MN 150	96	Calico	1951	15.0	25	21
Calhoun P. Hull	116	Calico	1783	17.0	21	45+
Colossus	116	Brown	1640	28.4	19	33
Pinkeye P. Hull	116	Blackeye	1152	16.9	15	45+
Mississippi Silver[2]	-	Brown	-	-	22	45+
Texas Cream 82		Cream			17	45+
Calif Blackeye #5[2]		Blackeve			22	59+

[1]Yield is dry seed average weights of 3 single row, 20 ft. plots for each entry. Rows were spaced 30 in. apart. Pods were air-dried for 2 months before threshing and weighing.
[2]These cultivars did not reach pod and seed maturity before Frost.

F. Weed Control:

Adequate weed control is necessary for good growth and high yields.

1. Mechanical: Use of the rotary hoe and row cultivator in cowpea is similar to that of soybean. One or two rotary hoeings followed by timely cultivation should be done when no herbicides are used. One or more cultivations should also be done when herbicides are used.

2. Chemical: The term " cowpea" is not found on most herbicide labels. Rather, the crop is referred to as blackeyed peas, southern peas, pinkeyed peas or crowder peas. Farmers planning on producing cowpeas should check with their State Agricultural Extension Service for advice on chemical weed control.

G. Diseases and their Control:

Root rot and damping off are caused by three different fungi. Symptoms vary and include rapid death of young succulent plants, discoloration of taproots, longitudinal cracks of the stems, stunting, wilting and poor yields. Complete control of root rot and damping off is difficult, and no variety of cowpea is resistant to root rot. Persistent damp weather prior to development of the first true leaf and also the crowding of seedlings due to poor seed spacing may increase damping off. The following control practices help reduce losses from these diseases:

Fungal and viral diseases can be reduced by:

- treating high quality seed with fungicides labeled for cowpeas.
- applying cowpea-labeled fungicides in the furrow.
- avoiding throwing soil against plant steins during cultivation.
- a four or five year rotation with other crops.
- seeding into warm, well-prepared soils.
- planting certified seed of resistant varieties.
- controlling weeds.
- the removal of virus-affected plants.

Southern blight is caused by a fungus that attacks roots and stems of cowpeas. The occurrence of southern blight is not restricted to the South. The first visible symptom of southern blight is a progressive, yellowing and wilting of the foliage beginning on the lower leaves. The plant dies within a few days after the rust symptoms appear. A brownish vascular discoloration inside die stem may extend several inches above the soil line. During warm, moist conditions, the coarse, white mycelium of the fungus makes characteristic fan-shaped patterns of growth on the stem at the soil line. In this white-mat of the fungus, numerous smooth, round, light-tan to dark-brown mustard seed-like bodies called sclerotia are formed. In addition to the cultural practices listed above, bury previous crop debris and the sclerotia, at least 6 in. deep as far ahead of planting as possible.

Several viruses can attack cowpea. A characteristic symptom of the mosaic virus disease is an intermixing of light and dark-brown areas. Mottled areas are irregular in outline and may follow the main veins. Infected leaves are generally smaller than healthy ones, and often there is a slight puckering and curling of leaf edges. Infected plants usually are more dwarfed and bushy and yields are reduced. Mosaic diseases can also result in malformed pods. Plants infected during seedling stages may be barren and fail to produce. The best way to prevent large yield losses from virus diseases is to grow tolerant varieties.

Fusarium wilt usually causes the lower leaves on one side of the plant to turn yellow. Infected plants usually are stunted and wilted as the organism develops in the food and water conducting tissues. Brick red tissue can be observed in the stem when it is split lengthwise. The best control of Fusarium wilt is the use of resistant varieties. When resistant varieties are not used, it is important that root-knot nematode control practices be followed since nematodes increase plant susceptibility to Fusarium wilt.

H. Insects and Other Predators and Their Control:

Root-knot nematodes cause the root to appear knotted and galled. Above ground nematode symptoms appear as nutrient deficiencies, with stunting and often wilting because the root system is incapable of absorbing adequate amounts of water and nutrients. Do not confuse nematode root symptoms with the nodules of nitrogen fixing bacteria. Nodules are attached to sides of roots, and galls are within the roots. Root-knot nematodes can also be harmful to the cowpea because root injuries make the plants much more susceptible to attack by Fusarium wilt. In addition to detecting the presence of nematodes by observing galled roots, they can be detected by a soil test for nematodes. If nematodes are present certain practices help reduce nematode populations. These practices include crop rotation, fallowing, sanitation, weed control, and planting resistant varieties.

Cowpea curculio is a small weevil that causes blister-like spots on the surface of the pod. These spots result from adults puncturing the pod to feed on or to lay eggs. Punctures from feeding result in small malformed peas, and the results of egg laying are many legless grubs that destroy developing peas.

Aphids are small, green, soft-bodied insects that feed by piercing the plant tissue and withdrawing plant juices. Infestations of this pest develop on leaves and the fruiting stems. Their feeding, especially on the fruiting stem reduces the amount of plant nutrients available for pod and pea development. Infested foliage turns yellow and dies. Aphids excrete large quantities of a sugary substance called honey dew which supports the growth of sooty mold. Sooty mold, a fungus, is dark in color, which reduces the amount of sunlight that reaches the leaf. Mild damp weather favors development of aphid populations.

Green stink bugs cause damage by puncturing the pods and feeding on developing peas. In the Southern States, the lesser cornstalk borer and possibly other borers may be a problem, especially where cowpeas border fields of maturing corn or sorghum. Lesser cornstalk borer damage may be significantly reduced by clean cultivation at least two weeks prior to planting. In more northerly areas, some damage may be experienced from the European corn borer.

I. Harvesting:

Cowpea can be harvested at three different stages of maturity: green snaps, green-mature, and dry. Depending on temperature, fresh-market (green-mature) peas are ready for harvest 16 to 17 days after bloom (60 to 90 days after planting). Harvest date for green snap pods is normally specified by the processor. Mechanical harvest requires the use of a snap bean or green pea harvester. Most domestic cowpea production is mechanically harvested, however, hand harvested cowpeas suffer less damage and the harvest season may continue over a 1 to 3 week period. One person can hand harvest 12 to 20 bushels of cowpea pods per day. Cowpea pods are packed, 25 pounds net, in bushel hampers or mesh bags (not burlap sacks).

Mature green cowpeas are normally harvested mechanically by some type of mobile viner. Dry cowpeas may be windrowed to facilitate drying or straight combined using a small grain or soybean combine.

J. Drying and Storage:

Harvested green cowpeas will "heat" resulting in spoilage unless kept cool. Post-harvest, provide shade and adequate ventilation is necessary on the way to the cooler. Cowpeas cooled below 45¡F may show chilling injury.

Dry cowpea seed is cleaned, graded, fumigated and packed in small plastic bags for sale to consumers.

VI. Yield Potential and Performance Results:

Cowpea yield information from warmer climates, where the crop has been grown successfully, does not necessarily indicate a performance level that might be realized in the Upper Midwest. A comparison between Wisconsin-Minnesota-adapted and southern types is shown in Table 3. Seed yield potential under dryland and irrigated conditions for Minnesota compared with other crops is indicated in Table 4. These data indicate that other grain legumes such as soybean and common dry edible bean may outyield cowpea (for dry seed yield) under many conditions in the Upper Midwest, therefore the price of cowpea should be greater to compete in these crops. However, cowpea may be valued as an annual forage crop in these regions.

Table 4. Seed yield and characteristics of four cowpea selections compared with navybean, soybean, and adzuki bean at Rosemont and Becker, MN. 1984-85.

Cultivar	Days to Maturity	Height in.	Lodging (1-9)	Leaf retention (%)	Wt 100 seed (g)	Seed yield				
						Irrigated		Dryland		Average of 4 trials
						Becker 1984 (lb/acre)	Becker 1985 (lb/acre)	Becker 1995 (lb/acre)	Rosemont 1995	
82E9	117	17	1.5	28	17.9	1797	2192	1570	1352	1725
MN 1	110	16	2.8	16	10.8	2077	1609	1107	1392	1546
MN 7	112	16	2.9	16	10.7	2163	1791	1149	1673	1694
MN 9	110	15	1.8	is	11.4	2054	1685	1056	1553	1587

Fleetwood navybean	105	-		57	19.1	2907	3640	958	1657	2366
Evans soybean	128	-		0		3164	2499	2730	2910	2826
Takam adzuki	124	26	3.7	13	11.1	2929	4095	2378	1772	2794

[1]Data courtesy of R. O. Robinson, University of Minnesota Experiment Station.

Average yield data for cowpea grown in Texas, 1978 and 1979 respectively, showed significant variability, ranging from 625 and 1400 lb/acre for green cowpeas and 570 and 1000 lb/acre for dry seed.

Grading standards for mature-green cowpeas require that pods of similar varieties should be fairly well formed and filled, neither overmature nor excessively young. Pods should be free from decay, worm holes, scars, discoloration, wilting, dirt, or other material. U.S. No. 1 grade requires that 95% of the pods be at least 5 in. long. U.S. Commercial grade has no minimum length.

VII. Economics of Production and Markets:

An Upper Midwest market for fresh green or dry cowpeas has yet to be developed. Dry cowpea production are likely to incur costs similar to the costs of dry edible bean production. Fresh green cowpea requires a specialized pea harvester, therefore, growers may need a contractual relationship with a processor/harvester for those services. Small acreages of cowpea may be hand harvested and may find a niche in a specialty/gourmet market. Hand harvesting for a fresh green cowpea market will require substantially greater labor and management inputs. Prospective growers need to investigate potential markets prior to planting. The distance to market, availability of labor and short term storage along with vagaries of the market and of the grower's individual situation should be considered.

VIII. Information Sources:

- Commercial Production of Southern Peas in Mississippi 1986. Extension Service of Mississippi State University Publication 1535. Mississippi State University.
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Fababean

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I. History:

Fababean is an annual legume known botanically as *Vicia faba* L. The crop is known by many names, most of which refer to a particular subgroup rather than the whole species. Common names for fababean include the large-seeded broadbeans or windsorbeans (*Vicia faba* var. *major*), horsebeans (*Vicia Faba* var. *equina*), and the small, round-oval seeded tickbean or pigeon bean (*Vicia faba* var. minor). The varieties grown in Manitoba are small to medium in seed size and belong to the minor and equina group. Fababeans are a versatile speciality crop that has proven itself to many Manitoba, Canada farmers in the past 15 years. In 1988 there was over 122,000 acres of fababeans produced in Manitoba.

II. Uses:

A. Livestock Feed:

The fababean does not possess any components toxic to animal or man. It is possible to feed the bean to all types of livestock or poultry provided it is cracked or crushed. No further processing is required. Canadian research showed no significant difference in milk production when cows were fed grain rations containing either fababeans or soybean meal as the protein supplement. Studies indicate that the dry matter digestibility of fababeans is somewhat lower than soybean meal and solubility of the protein is also lower in fababeans as compared to soybean meal. The fiber is higher and fat lower in fababeans versus soybean meal. The fababean is about 25% protein, and is higher in energy than soybean (Table 1). Most results suggest that substituting two parts of fababean for one part soybean and one part cereal grain gives equal or better rates of gain.

Table 1: Comparative nutrient content of fababean, barley and soybean meal.

	Fababean	Barley grain	Soybean meal
	% dry matter		
Crude protein	27.0	11.0	45.0

Digestible protein	22.6	8.8	41.8
Calcium	0.15	0.08	0.37
Phosphorus	0.50	0.35	0.67
Lysine	1.5	0.4	3.3
Methionine-cystine	0.5	0.2	1.6

B. Forage/Silage:

Fababean plants make high quality silage. Swathing should take place when the lowest seed pods begin blackening. The swath should be left to wilt for one to three days.

In a three-year experiment in Rosemont, MN, horsebeans sown at 180 lbs/a produced 4,370 lbs/a of dry forage containing 10.5% protein. A mixture of 60 lbs horsebeans and 64 lbs oats produced 5,613 lbs/a of dry forage containing 10.1% protein. This and other data suggest that an oat/fababean mixture for silage might be superior in production of protein per acre than oats alone.

C. Human Food:

The seed coat of fababean requires more chewing than that of the common baked bean varieties used in the United States, but the seed can be baked after it is softened in water. The large broadbean seeds are often preferred; the seed coats are often removed by hand before eating. Skinned beans are cooked, salted, and used for sandwich filling in North Africa. In Egypt and other Mid-Eastern countries, fababean is eaten as a staple food by many strata of the society, and the increasing population of Middle-Eastern people in the U.S. may be a potential market for fababeans.

III. Growth Habits:

Fababeans are small-seeded relatives of the garden broad bean. The plant flowers profusely but only a small proportion of the flowers produce pods. The fababean is very cold hardy, but cannot take excessive heat during flowering. As fababeans mature, the lower leaves darken and drop, pods turn black and dry progressively up the stem. Fababeans tend to shatter if left standing until maturity.

IV. Environment Requirements:

This annual legume grows best under cool, moist conditions. Hot, dry weather is injurious to the crop, so early planting is important. Medium textured soils are ideally suited for fababean production since the, crop requires a good moisture supply for optimum yields. Fababeans do not tolerate standing water.

Fababeans are slow (20+ days) to emerge and seeds must be in constant contact with moisture until seedlings are well established. The time from seeding to harvest ranges from 80 to 120 days. Fababeans are capable of fixing atmospheric nitrogen, which results in increased residual soil nitrogen for use by subsequent crops. Fababeans should be grown only once every four years in the same field to avoid a build-up of soil-borne diseases. Their susceptibility to diseases which are common in rapeseed and in sunflower limits their place in a crop rotation with other specialty crops.

V. Cultural Practices:

A. Seedbed Preparation:

For best results a good seedbed should be prepared, to insure good soil to seed contact. Since fababeans are slow emergers, time spent in preparing a good seedbed will help reduce problems with fababean and with early weed control.

B. Seeding Date:

Plant early in April if weather and soil conditions permit.[1] Yields are reduced significantly when planting is delayed to late May. Fababeans grow best under cool moist conditions; the seedlings are frost tolerant, but cannot tolerate heat during flowering. They are a legume and must be inoculated with specific inoculant to promote nitrogen fixation.

C. Method and Rate of Seeding:

Fababeans, which can be grown as a cultivated row crop or as a non-cultivated narrow-row crop like small grains, respond favorably to narrow row spacing. Yields in 7-inch rows were 4200 lb/a, in 14-inch rows 3000 and in 28-inch rows 2000 lb/a in a 2-year study conducted in Upper Michigan; similar results were found in a Minnesota study. In a study ranging from 80 to 300 lb/a, the optimum seeding rate was 160 lb/a when planted in 7-inch rows. Although high rates of sowing and narrow rows tend to produce higher yields, seed cost is an important restriction to optimum seeding rate. Planting depth is critical, since the hard, dry seed takes longer to absorb water and germinate than does common bean. Deep planting (2.5-4.0 inches) is necessary to get the seed below the surface so it doesn't dry out.

D. Fertility and Lime Requirements:

Legumes require neutral to alkaline soil for maximum N fixation by nodule bacteria. Soils should be tested and, if necessary, limed to at least pH 6.0. bolomitic limestone would need to be applied at least one year prior to fababean production.

Soils need to have P and K soil test levels in the medium to high range to ensure adequate fertility levels for maximum crop yields. These soil test levels are at least 11 ppm P and

81 ppm K depending on subsoil category. Soils should be tested and, if necessary, amended with P_2O_5 and/or K_2O prior to seeding.

Nutrients equivalent to crop removal should be applied annually in order to maintain adequate soil test levels. Fababean is similar in growth requirements and yields to canning peas. Therefore maintenance P_2O_5 and K_2O fertilizer in Table 2 is based on that necessary for canning peas planted in 7-inch rows. If top growth is removed for silage, higher applications are needed. Some N may be needed to ensure a good start since fababean is a shallow rooted annual legume planted very early. Table 2 also gives recommended N rates dependent on both crop yield and soil organic matter content.

Table 2: Annual nitrogen, phosphate, and potash recommendations for fababean.

Grain yield	Nitrogen		Phosphate	Potash
	Soil organic matter %			
	Low (≤=5)	High (≥=5)		
lb/A	lb N/A		lb P_2O_5/A	lb K_2O/A
1000-2500	15	5	10	20
2500-4000	25	10	15	30
4000-6000	35	15	20	40

E. Variety Selection:

The fababean variety "Outlook" was developed at the Univ. of Saskachewan, Saskatoon and licensed by Agric. Canada in 1981, and has performed well in Minnesota trials. "Petite" tickbean, a small-seeded fababean, was released by the Minnesota Agricultural Experiment Station in 1976; and "Minnesota" horsebean was released by the Minnesota Agricultural Experiment Station in 1968. Fababean varieties recommended for Manitoba are: Ackerperle, Aladin, Herz Freya, Outlook and Pegasus. One source of seed is the Manitoba Pool Elevators, Pembina & Perimeter, Winnipeg, Man. R3T 2E7.

F. Weed Control:

1. **Cultural and Mechanical:** Fababeans are poor competitors with weeds, particularly in the seedling stage. This makes integrated weed control essential for successful crop production. Select fields with light weed pressure. Do the primary tillage several weeks before planting and kill emerged weeds with shallow tillage just ahead of planting. Consider rotary hoeing fields 7 to 10 days after planting and use a row cultivator if rows are 20 inches or more apart.
2. **Chemical:** At the present time no herbicides are labeled for use on fababeans in Wisconsin or Minnesota.

G. Diseases and their Control:

No information available.

H. Insects and Other Predators and their Control:

Leaf hoppers and gray blister beetles have damaged trials in Minnesota. Black aphids can attack plants occasionally, but these are usually confined to a few plants, while plants a few feet away are not affected. Bean beetles will occasionally lay eggs in the flowers or young pods and the larvae bore into the young seeds as they pupate. The economic impact of these pests in Minnesota and Wisconsin is largely unknown and insecticides are not currently cleared for use on fababeans in the U.S.A.

I. Harvesting:

Swathing should begin when the lowest two bunches of pods begin blackening or when most seed easily detaches from the hilum. At this stage the moisture content of the beans is from 35 to 45%. Swathing in this moisture range provides the highest bulk density and 1000-kernel weight. The high moisture content requires a fairly long drying period in the swath, so it is advisable to lay a fairly light swath. Swathing fababeans is usually not difficult. In severely lodged crops, a pickup reel is quite effective. Low cylinder speeds of 300 to 500 revolutions per minute are recommended to minimize bean splitting and cracking, although the seed resists splitting and injury more than common bean.

J. Drying and Storage:

Rapid drying at high temperatures often causes stress cracks. The maximum moisture content for a "straight grade" of fababeans is 16%.

VI. Yield Potential and Performance Results:

Seed yields at Minnesota Agricultural Experiment Stations have averaged 1521 lbs/a in dryland (12 year/location average) and 2261 lbs/a under irrigation (6 year/location average). Much higher and lower yields have been observed on individual plots, crude protein percentage has ranged from 27 to 32%.

VII. Economics of Production and Markets:

Although the seed is used as a human food in other parts of the world (Europe, North Africa, Middle East), the markets for this use in the United States are negligible. The primary use in North America is as an animal feed, and as such, the cash market is poorly developed. The primary markets will include farmers or local feed dealers, and for use on-farm in animal production systems.

VIII. Information Sources:

- "Fababean Production and Use in Manitoba", Manitoba Agriculture. 1981.
- "Growing and Using Fababeans" Publication 1540, Information Services, Agriculture Canada, Ottawa K1A 0C7. 1975.
- "Fababeans for Farm Animals", Manitoba Department of Agriculture or Univ. of Manitoba, Department of Agriculture. 1974.
- "The Faba Bean (*Vicia faba* L.)", by P. D. Hebblethwaite. 1983.
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- Small Fababean. 1987. Terry Gompert. Crop Production News. Vol. VII, No. 29. University of Nebraska. Lincoln, NE.
- Fababeans. 1982. E. S. Oplinger. Field Crops 32.0 UWEX. Madison, WI 53706.
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Footnotes:

[1]Fababeans should be planted as early as possible in the spring. One Canadian study showed a 1% yield reduction for each day planting delay in April, and a 2% reduction after April.

Fieldbean

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I. History:

The common or fieldbean (*Phaseolus vulgaris* L.) could have been domesticated independently in Central and South America. Fossilized seed material has been found in Central America and Peru which dates to 7,000 years ago. By the time European explorers arrived in the New World fieldbeans were an important food staple. Today fieldbeans (Pinto, Navy, Kidney) are the most widely cultivated species of *Phaseolus* and, in terms of tons of crop produced per year, they are the second most important legume in the world (soybeans are first). They are now widely grown in Mexico, Central America and the Caribbean, South America, Asia and to a lesser extent in Africa.

Fieldbean acreage in the United States is concentrated in Michigan, North Dakota, Minnesota, Idaho, Colorado, Nebraska with limited acreage in several other states including Wisconsin.

Grower interest in fieldbean in the United States is largely affected by market prices and proximity of buying stations or processing facilities. In the rest of the world fieldbeans are a major source of protein in the diet of subsistence farmers. The nine major pulse (grain legume) crops, in order of acreage world wide are: drybean (fieldbean, adzuki, mung), chickpea, fieldpea, cowpea, fababean, pigeon pea, vetch, lentil and lupine.

II. Uses:

Fieldbeans are specific types of *Phaseolus* which are harvested as mature dry seeds, as opposed to snapbeans which are harvested when pods are green and the seeds are succulent for use as a fresh vegetable. They require minimal processing between production field and consumer, so they must be intact and free of blemishes as well as pesticide residue when presented for sale. Excellent quality is equally important to yield in realizing maximum economic return.

Fieldbean seeds contain 22% protein, 2% fat, 61% carbohydrate (includes 5% fiber) as well as adequate levels of all vitamins and minerals.

There is an inverse relationship between per capita income level and consumption of legumes such as fieldbean. For example Brazilians consume about 70 grams of beans per day while United States consumers only use about 16 grams per day.

Fieldbeans are used in soups, chili dishes, baked bean and casserole recipes, refried bean paste, fresh salads and can be purchased in dried or previously canned and cooked products.

Beans which do not meet human food quality standards can be utilized for livestock. Large amounts of splits, culls and poor quality lots of fieldbeans are used in this manner. They must be incorporated into the ration based on actual nutrient content.

Bean seeds contain an inhibitor which prevents the trypsin enzyme from digesting protein in the digestive tract of non-ruminant animals. Heat treatment using a commercial roaster or extruder, or some type of cooking can denature this inhibitor.

The following table shows the nutrient composition of three market classes of fieldbeans compared to soybeans. Note that they are much lower in protein and fat, a fact which must be taken into account when substituting them for soybean meal in a diet or ration.

Table 1: Nutrient composition of various classes of fieldbeans compared to soybeans.

Constituent	Pinto	Navy	Kidney	Soybean
	% composition[1]			
Crude protein	23.00	23.00	23.00	38.00
TDN	68.00	79.00	78.00	88.00
Fat	1.20	1.40	1.20	18.00
Calcium	0.13	0.15	---	0.25
Phosphorus	0.46	0.57	---	0.59
Fiber	4.10	4.20	4.10	5.00

[1]Values on air dry basis (88 to 90 % dry matter); F.B. Morrison, *Feeds and Feeding* 22nd edition, the Morrison Publishing Company, Ithaca, N.Y., 1957.

III. Growth Habit:

Fieldbeans are warm season annual legumes with upright or bush as well as vine type or indeterminate growth habit. The first true leaf formed after the cotyledons emerge from the soil is simple or unifoliate and all subsequent leaves are compound (with three leaflets).

Small flowers (self-pollinated) are produced in clusters at various nodes on the plant and may be either white or lavender in color. Mature pod color, seed color and seed size or shape varies depending upon market class and/or variety.

The crop requires between 85 and 120 days from planting to maturity depending on variety. The first half of this period is vegetative development and the latter half is reproductive. In vine types there is an overlap of the two periods because continued vegetative growth occurs after flowering begins. Flowering continues for 2 to 3 weeks so there can be new pods, half developed pods and fully developed pods as well as newly opened flowers present on many plants in early August. Pods are initially green changing to light brown or tan as they mature. Each pod can contain 2 to 4 seeds depending upon variety.

The U.S.D.A. Marketing Service assigns beans to market classes, many of which can be grown in Minnesota and Wisconsin. A brief description of each market class is provided in the following paragraphs. For specific details on the varietal performance of beans within each class, see the most recent edition of *Varietal Trials of Farm Crops*, Miscellaneous Report 24, Agricultural Experiment Station, University of Minnesota or similar references from other universities or private companies.

Black Turtle: Plants of this class have short vines and produce dark black seeds with a white hilum.

Cranberry: Both bush and vine type varieties are available. Seed is similar to pinto except that the seed surface is pink with scattered reddish markings.

Great Northern: These plants have a viny, indeterminate growth and produce large flattened white seeds that compete with navys for dry package sales. Great northerns are not used for canned beans because the seeds soften and deteriorate during cooking.

Kidney: Plants of this class are upright, bush types that mature slightly later than navy or pinto. The seeds are large and flat with a distinct dark red coloration. Kidney seeds crack easily, and harvesting damage is a common cause of dockage or rejection at the buying station. Most kidney beans are canned and cooked as whole beans or as a component in canned chili products.

Navy: Both short vine and bush varieties are available, but Minnesota and Wisconsin growers utilize bush varieties to produce good quality white beans. Careful management is necessary to produce the blemish-free seeds which bring the highest price. Navys are used in canned pork and bean products or as bagged dry beans for boiling and baking purposes.

Pink: Plants of this class have indeterminate vines and are more susceptible to halo blight than pintos. Seeds of the pink class are medium sized and uniformly rosy redbrown at harvest. These beans are used interchangeably with small reds in canned bean products such as chili.

Pinto: These varieties generally have a prostrate vine type growth and produce a flattened buff-colored seed with scattered brown splashes on the surface. Pintos are used directly as baking beans or in a canned product. Refried bean paste is another use. Because of the mottled seed coat, weathering and disease spots do not reduce market quality as much as with white seeds.

Small Red: Small acreages of these short, vine type plants are grown in Minnesota. Seed of small red varieties are medium sized and uniformly red with a white hilum. Market competitors for small reds are the pinto, cranberry, and pink classes. Production of good quality small red beans is difficult in humid climates because of rust and blight disease problems.

Small White: It is possible to produce these beans in Minnesota and Wisconsin. The seed resembles that of navy beans. The recommended variety has a short vine growth habit, and mature seed is difficult to tell from the slightly larger navy beans. Small whites and navy beans are used for the same commercial purposes.

IV. Environment Requirements:

A. Climate:

Fieldbeans are a warm season crop which performs best in temperatures ranging from 80°F highs to 50 to 60°F lows during the growing season. High temperature and moisture stress during the flower and pod setting period results in abortion of large numbers of blossoms and developing pods.

Growing season of 14 to 20 in. rainfall are best. Low relative humidity is best because bacterial and fungal disease problems are lessened. Light rainfall as crop nears maturity is best to facilitate maturity. Most types of fieldbeans require a frost free growing season of 85 to 120 days between mid-May and mid-September for best yield performance.

B. Soil:

Fieldbeans perform best on fertile sandy loam soils with good internal or tile drainage and moderate organic matter content. Soils that can be temporarily flooded, easily compacted, or which crust over regularly in early spring are not suitable for fieldbean production. These conditions result in plant death or restricted root system development.

Good water holding capacity in the upper 5 ft is essential, otherwise sprinkler irrigation will be required for best yield performance.

Soils with a pH between 5.8 to 6.5 are best. A soil pH above 7.2 can result in chlorosis problems due to iron and zinc deficiencies in certain varieties and/or market classes.

C. Seed Preparation and Germination:

Selecting high quality fieldbean seed for planting is essential. Germination percentage, physical appearance, varietal purity, and freedom from disease are the principal quality considerations. Bag labels usually provide information a grower needs about each seed lot; be sure to read these labels carefully. All states have a certification system to help ensure the availability of high quality seed and most use the following categories:

Breeder seed is controlled by the originator or owner of the variety and is used to produce foundation seed as the first step in the multiplication process.

Foundation seed is produced from breeder seed under the control of the designated seed certification agency in each state. **White** tags are used to identify bags of this seed.

Registered seed is produced from foundation seed and is carefully managed to maintain its genetic purity. Higher standards for field culture, seed cleaning, and storage are required of growers who produce registered seed. **Purple** tags are used to identify this seed.

Certified seed is produced from registered or foundation seed and, under certain conditions, from other certified seed. Good standards of field culture, cleaning, and storage are required of growers of certified seed. This class of seed is most commonly used by growers for commercial planting and is identified with **blue** tags. In Minnesota, fields being considered for certification require two field inspections as well as laboratory evaluations to ensure quality and purity.

States differ on standards and testing procedures for certification of edible beans. Because Idaho provides much of the seed, producers should understand three additional categories that are used in that state:

Seed labeled with a **green** tag indicates that a field inspection has been done by the Idaho Department of Agriculture (IDA) to check tor blight symptoms. No varietal purity is guaranteed, nor are laboratory tests for seed-borne blight organisms conducted on such seed lots.

Seed labeled with a **yellow** tag by the IDA is intended for use only in Idaho. Yellow-tagged seed is reported to be blight-free based on a laboratory serological test. Yellow tags are issued for pinto, pink, great northern, small red, and lima beans. The Idaho Crop Improvement Association also issues yellow tags for seed lots in the certification system that fail to qualify for blue tags because of low germination or large numbers of split seeds.

Affidavit seed is not a part of the seed certification system, but this category is used by some companies for seed of known variety or purity. Quality of the seed lot is based on the word of the seed conditioner of dealer. No minimum standards exist for this type of seed.

Certification of seed does not guarantee freedom from seed-borne disease problems, but it does insure the best quality seed possible with the inspection and testing procedures currently being used.

Fieldbean seeds are routinely treated with a fungicide, insecticide, and bactericide to control root rot and damping off organisms, insects, and to kill bacterial blight organisms on the seed surface.

V. Cultural Practices:

A. Seedbed Preparation:

The soil should be tilled to remove weeds and prepare a seedbed which will provide a good seed soil contact. Fall plowing is recommended to prepare this seedbed on heavier soils in order to allow secondary tillage in the spring which can break up clods and incorporate remaining residue. If moisture is short, keep spring tillage to a minimum to prevent excessive drying of the top few inches of soil.

B. Seeding Date:

The highest yields result from plantings between May 15 and 26. Seed should be planted when the soil temperature reaches 50°F at a 3 in. depth, but after the danger of late spring frosts has passed. Growers should plant beans as early in each season as possible for maximum yield.

Certain plant or seed characteristics are affected by planting date, including days to emerge, first bud date, and date of maturity. Beans planted on May 15 take twice as long to emerge as beans planted on June 5.

Planting in mid-May results in slightly delayed flower bud development compared to later plantings, but it also results in higher yield. Early plantings permit flowering and pod set early in July, when the probability of adverse weather is lower. Later plantings are subject to high temperatures and lower soil moisture during reproductive periods, which cause shedding of flowers and developing pods. Early planting also allows completion of growth and maturity in late August. Harvest can then be completed before the wetter September weather comes.

C. Method and Rate of Seeding:

Recommended planting rates for fieldbeans depend on plant growth habit, seed size, germination rate, and experience of the grower, Table 2.

Table 2: Fieldbean planting rate recommendations.

Class	Seeds/lb (number)	Rate (lb/acre)	Rate (seeds/acre)

Black Turtle	2300	45	105,000
Cranberry	1000	85	105,000
Great Northern	1000	100	105,000
Kidney	900	90-115	105,000
Navy (30 in. rows)	2500	30	105,000
(6 in. rows)		60	105,000
Pink	1700	60	105,000
Pinto	1300	60-80	105,000
Small Red	1400	75	78,000
Small White	3000	35	78,000

Experienced growers have produced excellent yields of most of these classes using lower populations than these values, but because of the wide range of conditions which a crop might encounter, these values should be used until you can do the job well.

All bean types showed 10 to 15% yield decreases at row spacings wider than 30 in. and 18 to 32% yield increases for narrower row widths. Because beans in narrow rows outyield those in wide, growers should consider narrow rows for erect or bush types.

Consistent yield increases are obtained for both pinto and navy beans in the narrowest row spacings in both dryland and irrigated plots. Narrow rows can increase the possibility of foliar and stem disease problems because the plant canopy is dense.

Normal planting depths of 1 to 2 in. may sometimes be exceeded to place seed in moist soil for rapid germination, but maximum planting depth should not exceed 2.5 in.

Carefully planned crop rotations are necessary in bean production, and rotations should be a minimum of 2 years, but 3 and 4 year cycles are best. Crops such as corn, wheat, oats, barley, and flax should precede beans because bean diseases do not build up in those crops. Effective herbicides for controlling annual and perennial weeds are available in those grain crops, thereby reducing weed competition in dry beans.

D. Fertility and Lime Requirement:

Fieldbeans require good fertility to achieve high yields. Yields are generally highest when fertility is supplied to the alternate crops in the rotation rather than as direct additions to the current crop.

Soil scientists recommend a fertility program based on yield expectation, nitrate nitrogen soil test levels, previous crop in rotation, and soil organic matter level either singly or in combination. Recommended Nitrogen for fieldbeans is N (lbs/acre) = expected yield/50 to 2.5 (% soil O.M.). Adjustments can be made for a previous legume crop and manure applications. The following tables indicate the Minnesota recommendations for phosphorus, potassium and zinc requirements of fieldbeans.

Effective nodulation by nitrogen-fixing bacteria (*Rhizobium phaseoli*) *is* difficult to achieve in certain soil types and under certain environmental conditions. Yield increases have been reported following inoculation on fields in which nodule development was poor in previous crops. If nodule development is poor, growers should consider application of a commercially available inoculant at planting time. Inoculants come in moist, peat form, or in slightly drier granular form. Moist types are added directly to the seed. Granular types can be applied in furrow and still achieve satisfactory results. All types of inoculants should be fresh and stored in a cool, moist environment until placed in the soil at planting. Low humidities and high temperatures inactivate the live bacteria in the inoculant.

Other nutrients should be added as needed, according to soil test results. Fieldbeans will generally show yield responses to applied fertilizer if the soil tests are low to medium, but they rarely respond to fertilizer when test values are in the higher range.

When fertilizer is required, one choice is to broadcast and plow or disc it down. Row application can be done as long as the fertilizer does not come in direct contact with the developing seedling roots. A 2 in. by 2 in. placement is common; with such placement, the developing root system gradually grows into the fertilizer supply.

Table 3: Phosphorus (P) and potassium (K) recommendations for fieldbean.

Expected yield	Phosphorus (P) soil test (lb/acre)[1]				Potassium (K) soil test (lb/acre)[1]			
	0-10	11-20	21-30	30+	0-100	101-200	201-300	300+
(lb/acre)	P_2O_5 to apply[2] (lb/acre)				K_2O to apply[2] (lb/acre)			
3000 or more	80	60	40	0	120	90	50	0
2500-2900	70	50	40	0	100	70	40	0
2000-2400	60	40	30	0	80	50	30	0
1500-1900	50	30	30	0	70	40	0	0
1400 or less	40	30	0	0	60	30	0	0

[1] For soil P and K reports in ppm. (ppm × 2 = lb/acre).
[2]Recommended rates are for total amount to apply-broadcast + row. Low rates may be row-applied.

Table 4: Zinc recommendations for field corn, sweet corn, grain sorghum, and fieldbeans.

Zinc soil test (ppm)	Relative level	Amount of zinc to apply (lb/acre)		Possibility of yield increase from zinc application
		zinc	zinc sulfate	
Less than 0.5	Low	10 to 15	28 to 42	Highly possible
0.5 to 1.0	Medium	5 to 10	14 to 28	Possible
More than 1.0	High	0	0	Unlikely

Other crops: Zinc response has not been observed on other crops in Minnesota. If zinc test is low (less than 0.5 ppm) apply zinc on trial basis only at 5 to 10 lb/acre of actual zinc.

Micronutrient deficiencies occur on certain soil types or in certain pH ranges. If a soil or tissue test indicates a deficiency, additions are likely to raise yields. Fieldbeans have a relatively high requirement for manganese. Well-drained, high pH soils, especially organic soils, are often low in this element.

Soils with high soluble salt values (as measured by electrical conductivity) are not good choices for edible bean production and should be planted to crops that are more tolerant.

E. Variety Selection:

New fieldbean varieties are constantly being developed by breeders at public universities and private companies. Hundreds of these varieties have been evaluated in the performance testing programs conducted by the University of Minnesota, North Dakota State University, as well as private bean companies and crop consulting firms. These test results usually provide data on disease and insect resistance, maturity, yield, seed quality and size, growth habit, as well as possible special characteristics such as cookability or flavor tests. The results of these tests are available from the Extension Service or from the field agronomists employed by the bean companies. They are also featured in a late winter issue of 'Bean Talk' published by the Northwest Bean Growers Association R.R. 3, Box 102, Frozee, MN 56544.

Good yielding disease resistant varieties adapted to this area are available in all the market classes described earlier in this chapter. Growers should check with the company to whom they plan to sell their production to see if they have a variety preference. This is important because canners and processors are often very particular about the specific color, size and shape of the beans they use in their products.

F. Weed Control:

Fieldbeans compete poorly with weeds and should be planted on fields with a carefully planned weed control program. Perennial weeds, both grass and broadleaf, are severe problems in edible bean fields, since annuals can be controlled with preplant or preemergence chemicals or cultivation.

A weed control program for most growers should be a combination of chemical and mechanical methods.

1. **Mechanical:** Mechanical cultivation should only be, used during the early growth period (first 5 to 6 Weeks) All cultivation should be completed before bloom, because the roots begin to spread into the row middles and can be damaged by late cultivation. Cultivation after the canopy has closed spreads disease. The best weed control program eliminates weeds early, before canopy closure, preventing competition with the beans for nutrients, light and water.
2. **Chemical:** Factors to consider in making chemical choices are: crops planted before and after beans in the rotation, weed species present, weather conditions at application time, and rates required. A selection of preplant incorporated, preemergence, and postemergence herbicides is available for use on drybeans. Several states including Minnesota (AG-BU-3157) and Wisconsin (A2350) have extension publications with herbicide recommendations for drybeans. Before making any decision on a chemical, growers should have the following information on each field: soil texture, percentage organic matter, weeds expected, and soil pH. The chemical and proper rate can then be matched to the field conditions, weed species, and bean type.

G. Diseases and Their Control:

Fieldbeans are susceptible to several diseases that can limit yield. Some of these diseases can accumulate in the soil of a field until beans cannot be grown. Detailed information on the major diseases of fieldbeans are described in *Edible Bean Diseases and Disorder Identification*, North Central Regional Extension Publication 159. Common blight, white mold, rust, halo blight, Rhizoctonia, Pseudomonas brown spot, Fusarium, Bean common mosaic, Pythium (damping off), and Anthracnose are the diseases which can attack fieldbean.

The following field management procedures can help reduce disease in edible bean fields:

1. Refuse remaining in a field after combining should be buried by tillage to promote its decay and reduce spread of disease organisms to other fields or farms.
2. Proper weed control during the growing season is important because some disease organisms can infect weeds growing in the field. White mold, for example, can infect ragweed and increase white mold problems in a field.
3. Use only disease-free seed to prevent introduction of bacterial blights, anthracnose, and common bean mosaic which are seed-borne.
4. Use disease resistant varieties.

Chemicals applied to dry beans are called protectants because they protect the seed or plant from initial disease infections or reduce disease spread. These chemicals establish a protective blanket on the surface of the seed or plant (surface protectant), or by absorption into the plant (systemic fungicide), which prevents infection by specific pathogens.

Timing of these protectant sprays is critical. Spray applied at later stages of plant growth are less likely to show economic returns but do prevent the further development of the disease.

The use of systemic fungicides offers the potential for improved disease control. Once absorbed by the plant tissue they are less subject to weathering and are often active against newly established infections. Careful monitoring of crop and weather conditions can lead to the accurate timing of applications, improved disease control and significant reduction in fungicide use. An important limitation in use of systemic fungicides is the selection of fungal strains that are resistant to specific systemic fungicides. This risk can be substantially reduced by combining systemic and protected fungicides or alternating treatments between different fungicides.

H. Insects and Other Predators and Their Control:

The fieldbean crop in Minnesota and Wisconsin has generally been free of serious insect problems, although several different species of insects are encountered in fields. Occasionally one or more of these insects can become abundant enough to cause yield loss. It is important, therefore, to be aware of insect pests so they can be controlled before major losses occur. For some pests, chemical treatment, along with crop rotations, can be used to reduce the damage.

A list of common fieldbean insects in Table 5 should assist you with field evaluations. Only the most common ones are included. Other less obvious problems can appear which will require the services of a professional consultant or extension agent to ascertain which insect species is causing the problem.

Table 5: Possible fieldbean insect problems.

When	Where	What
At emergence	Evidence of poor stand, wilting seedlings or cutoff plants	White grubs Wireworms Seedcorn maggot Cutworms
During: early seedling grow	On leaves	Bean thrips (not common in Minnesota) Slugs
Late season plants	On leaves, flowers and pods	Green cloverworm Bean leaf beetle larvae Leafhopper Two-spotted spider mite

		(rarely in Minnesota) Aphids Plant bugs
During storage or during cleaning	Seed	Plant bugs Bean weevils

Aways read product labels and consult with extension specialists and custom applicators when you have questions.

Insecticides on fieldbeans must be applied carefully because minimal processing of the crop occurs between the grower's field and the consumer's product. Strict adherence to label restrictions will help avoid problems in selling the crop.

I. Harvesting:

Fieldbeans are usually harvested with puller-cutters, followed by windrowing and combining. A puller-cutter has heavy, V-shaped blades that move just below the soil surface, cutting off or uprooting the plants and turning them over into windrows. This process is best done early in the morning when the plants are damp to minimize shattering.

After sufficient time in the windrow for drydown, combining is done using slow cylinder speeds to prevent seed damage. The combine should be kept at full capacity by using large windrows or faster ground speeds to move plant material into the threshing mechanism and prevent damage to seed. Periodic adjustments in the cylinder-concave clearances are necessary to prevent seed cracking if moisture content of the beans changes during combining.

Bean ladders or belt conveyors should be used to move beans, especially when seed is dry. If augers have to be used, they should be run full to reduce damage. Fieldbeans vary in susceptibility to damage. The various classes and their damage sensitivity are:

Class	Damage sensitivity rating
Red kidney	High
Black turtle	High
Small red	Medium
Great northern	Medium
Navy	Medium

Small white	Low
Pink	Low
Pinto	Low

Adapted varieties of navy, dry red and kidney beans have a determinate growth habit (bush), so the beans are more uniform in maturity. Some growers combine navys directly, but this method can result in large losses if the combine is not equipped with a floating cutter bar and automatic header control. Direct combining also causes considerable seed damage if the concave clearances are not carefully adjusted. Direct combining reduces machinery costs and field time and reduces the risk of quality and yield loss during rainy periods.

Pinto beans have an indeterminate growth habit (vines) and generally are pulled when most pods are yellow and seeds have visible streaks. Immature beans continue to dry in the windrow. Pintos are generally ready to combine after 4 to 10 days in the windrow. Beans with moistures as high as 18% are safe to combine, with safe short-term storage moistures being 16.5% and longer term storage 15.5% moisture or less.

J. Drying and Storage:

When prices are low, growers store the crop until prices improve. A storage facility for a crop that is used directly by humans without further processing must be protected from water; from contamination by other crops, chemicals, or odor; from rodents; from insects; from fungi; from fire; and from temperature extremes.

Mold development on beans in storage is influenced by the temperature of the beans and by the relative humidity of the air in the spaces. For all grains, 75% relative humidity in these spaces will provide safe storage, if normal temperatures are maintained. For fieldbeans, 75% relative humidity occurs at bean moisture contents of 16 to 16.5%.

In Minnesota and Wisconsin, bean quality can be easily maintained at low temperatures (35 to 55°F) in storage shortly after harvest if bin aeration is provided. These low temperatures slow mold development. A small aeration fan 0 to 14 horsepower) and a 12 in. diameter perforated duct can aerate up to 3,000 hundredweight of beans.

If beans need to be dried prior to storage, two methods can be used:

In-Storage Drying With Unheated Air: The bin must have a perforated floor and a fan capable of delivering at least 5 cubic ft per minute per hundredweight of beans in storage. The fan must be run continuously until the beans at the top are dry. The fan will provide about 2°F temperature increase, which will lower the relative humidity of the spaces in the bin. With these air-flow rates and the cool weather normally present after harvest, you can maintain beans in good marketable condition.

Heated-Air Dryers: High air-flow heated dryers (batch, continuous flow, or batch-in-bin) can be used if temperatures are lowered to prevent seed damage.

Dryer operating temperatures depend on air flow, bean moisture content and the weather. It is best to start with small temperature increases (2 to 5°F over ambient temperature) to determine the specific operating temperature to use in each situation.

VI. Yield Potential and Performance Results:

Yields in Minnesota average between 1,200 and 2,000 lbs/acre for the most commonly grown classes, although research plot yields and fields of certain top growers have exceeded 3,500 lbs/acre. Most of the bean acreage in Minnesota and Wisconsin is devoted to pinto, navy and dark red kidney classes, but smaller acreages of great northern, pink, small red, black turtle, cranberry, adzuki and swedish brown classes have been grown.

On nonirrigated soils in northwest Minnesota, fieldbeans are included in a small grain rotation because of high cash return. Fieldbeans are used in rotations in central and north-central Minnesota where soybeans do not show increased yield from irrigation and in central and west-central Wisconsin where irrigation is available. They are not widely grown in the major soybean areas of southern Minnesota and Wisconsin because they have not been competitive with cash returns from soybeans.

Bean production requires a greater attention to field management than do some of the other commonly grown field crops. Since beans are a special use crop, market demand is variable.

The advantage of growing several different types of fieldbeans each year is that each class may have a different price in the market. Such diversity can allow a producer to stabilize income. Local markets have not been developed for some of the lesser grown types so you should obtain a contract or a written price quote before planting.

VII. Economics of Production and Markets:

Farmers often sign contracts with bean brokers, processors or canners for a portion of their anticipated production prior to planting. These contracts often specify variety and/or market class, moisture content, physical quality and delivery point as well as price per pound. The quantity contracted is often about one-half of the anticipated yield/acre so that cash costs, etc. can be recovered if the actual yields fall below anticipated values. These contracts can have "act of God" clauses which release the grower if drought, hail, or insect problems reduce yields significantly.

Prices paid for fieldbean vary widely from year to year and prices for each market class varies depending upon supply and demand. Prices, at harvest, have ranged from seven cents to fifty-three cents per pound in recent years. Preplant contracts during the recent production years varied between sixteen and twenty-five cents per pound.

Tables 6 and 7 provide some typical cash, overhead and total costs of production under dryland conditions or under irrigation in Minnesota and Wisconsin. Cash costs include fertilizer, pesticide, seed, fuel costs, etc. while overhead includes depreciation on equipment, labor, property taxes, land interest charges, insurance, etc.

Minnesota studies estimate that the average cost to grow a pound of fieldbeans is somewhere between fifteen and eighteen cents. Farmers should calculate their own cost of production in order to ascertain the yield level needed to make a profit. A per pound price calculation will allow you to obtain the contract price which will provide you the greatest profit.

Table 6: Fieldbean costs of production (Navy, Pinto, Kidney).

	$/acre	
	Dryland	Irrigated
Cash costs	112	125
Overhead costs	M	la
Total	233	320

Table 7: Returns over cost of production at 100%, 7S%, 50% of listed yield (Beans at 0.23/lb).

Yield level	Dryland yield (1600 lb/acre)		Irrigated yield (2100 lb/acre)	
	Cash	Total	Cash	Total
100%	$223	$112	$335	$160
75%	$147	$26	$237	$42
50%	$136	$ 15	$117	$78

VIII. Information Sources:

- Cultural and Chemical Weed Control in Field Crops. AG-BU-3157. Minnesota Extension Service. University of Minnesota.
- Dry Bean Production Handbook. A-602 (Revised). Cooperative Extension Service. North Dakota State University, Fargo.
- Edible Bean Disease and Disorder Identification. North Central Regional Extension Pub. 159. Minnesota Extension Service. Univ. of Minnesota and University of Wisconsin-Extension.

- Recognition and Management of Dry Bean Production Problems. North Central Regional Extension Publication 198. Minnesota Extension Service. Univ. of Minnesota and University of Wisconsin-Extension.
- Varietal Trials of Farm Crops. Miscellaneous Report No. 24. Minnesota Agricultural Experiment Station. University of Minnesota. St. Paul, MN.
- Commercial Navy and Red Kidney Bean Production. A2349. University of Wisconsin-Extension. Madison, WI.
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Dry Field Pea

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I. History:

Field pea (*Pisum sativum* L.), a native of Southwest Asia, was among the first crops cultivated by man. Wild field pea can still be found in Afghanistan, Iran and Ethiopia. This crop has been long grown in the United States and historically, field pea was one of Wisconsin's best paying cash crops. In 1909, 78,000 acres were planted and part of eastern and northeastern Wisconsin led the country in field pea production. As market prices declined, partly the result of less costly imported field pea, production declined. Today, the countries leading in field pea production include the Soviet Union, China, India, Canada, and the United States. In the United States the largest acreages of field pea are in Washington, Idaho, Oregon, Minnesota and North Dakota. Plantings of dry field pea in 1989 in the United States was estimated to be over 30,000 acres and in Canada over 450,000 acres. Cultivation of field pea has lead to a gradual separation of types: those grown for vegetable use, those grown for seed and fodder, and the edible podded types which have evolved most recently.

II. Uses:

Over half the domestic field pea production goes to the dry pea market or for planting seed used by growers of fresh garden, frozen or canning field pea. The smooth, green- and yellow-seeded varieties are used for human consumption as dry split field pea. Field pea have high levels of the essential amino acids, lysine and tryptophan, which are usually low in cereal grains. Consequently, field pea can supplement the low amount of protein present in food and feed processed from cereal grains. Field pea are used as protein concentrates for livestock and are popular pigeon feeds. Field pea flour is valued not only as a vegetable protein source but also, in part, due to its unique functional properties. The use of vegetable proteins as functional ingredients in the food industry is increasing and special attention has been given to the use of field pea because they are already an accepted part of the human diet throughout the world. The viscosity of slurried pea flours makes them useful in aqueous food systems.

Field pea also contain proteases, tannins, and lectins, etc. which may reduce livestock feed gain when present at too high a concentration in a diet. However, it has been shown that partial or complete replacement of soybean meal with pea screenings (in a barley diet for hogs) did not reduce growth rate or efficiency of feed conversion. Field pea may be grown as a forage crop, for hay, pasturage or silage. Field pea grown in a mixture with oat, barley or triticale yields more dry matter per acre than a straight pea culture and the field pea stand more erect which makes the crop easier to harvest. Protein content and feeding value of the forage is increased-by the addition of peas to the seeding mixture. A mixture of 2/3 field pea and 1/3 oat can be seeded with alfalfa or clover as a companion crop. The highly populated stand reduces weed competition, allows for one or two alfalfa cuttings following the pealage harvest. Harvest is recommended when field pea is in full bloom and oat is beginning to head. In southern states, field pea is grown as a fall-sown cover and green manure crop. As a green manure crop, field pea returns approximately 25 lb/acre of nitrogen (N) to the soil. The cream-colored varieties commonly grown in Minnesota and Wisconsin are used for feed or as seed for forage production. The tender shoots of field pea may be cut and used as salad greens. A considerable proportion of field pea is exported, primarily to Europe.

III. Growth Habit:

Field pea is an annual herbaceous plant and the stems grow to a length of 2 to 4 ft. A leaf consists of one to three pairs of leaflets with a terminal, branched tendril. Leaves are pale green with a whitish bloom on the surface. At maturity, the plant is a prostrate vine.

Field pea is of the indeterminate (climbing) type or determinate (bush or dwarf) type. Flowers are borne on racemes arising in the axils of the leaves and are highly self-pollinated. In most varieties, the blossoms are reddish-purple or white. Pods are about three in. long and contain four to nine seeds. Seed may have a green, yellow or cream colored seed coat and are classified as such.

IV. Environment Requirements:

A. Climate:

A cool growing season is necessary for optimum field pea production (a mean temperature of 55° to 65°F). Hot weather during flowering causes the flowers to blast which results in reduced seed set. Field pea seedlings can withstand considerable frost exposure without damage. If frost injury does occur and the main shoot is killed, new shoots will originate from nodes below the soil surface. In the Pacific Northwest, winter varieties of field pea are planted in September. However, these varieties cannot survive winter temperatures common to Minnesota and Wisconsin.

In the Upper Midwest, field pea is a spring annual with a maturity of 95 to 100 days. Field pea requires the same length of growing season as wheat and is normally harvested in August. On average, it requires 60 days from planting until bloom, and 100 days to mature the dry seed. In temperate climates, where winters are severe, the crop is usually planted in the spring. Where there are little or no frosts, planting occurs in the late fall and early winter. Because high temperature during blossoming results in reduced seed set, production of field pea as a summer annual in the United States is limited to the northern states. In the tropics and subtropics, field pea is planted at high elevations where the temperatures remain cool. The moisture requirement for field pea is similar to that for cereal grains. Good rains and/or early irrigation, and no rain during pod fill and ripening is ideal. Field pea has been grown successfully throughout the Upper Midwest, particularly in the northern tier of states.

B. Soil:

Field pea can be grown on a wide range of soil types, from light sandy loams to heavy clays, but in any soil there must be good drainage as field pea does not tolerate soggy or water-soaked conditions. The soil pH optimum is 5.5 to 6.5.

C. Seed Preparation and Germination:

Field pea is capable of utilizing bacterially fixed atmospheric nitrogen. The specific bacterial association for nitrogen fixation in field pea and lentils is with the bacterium *Rhizobium leguminosarium.* If field pea is to be grown in a field for the first time, or have not been grown recently, inoculation of the seed with the proper *Rhizobium,* prior to planting, may increase nodulation. Inoculation may also be beneficial if the soil pH is below 5.7. Once inoculated, seed should be kept out of direct sunlight and planted as soon as possible because the inoculant will die if subjected to sunlight or drying. Seed treatments with a fungicide may harm the inoculant so it is important to first check the seed treatment label. Field trials have shown that the seed treatment fungicides, Thirarn and Captan, do not significantly affect nodulation.

Pea seed germination rate increases with increasing temperature, but at temperatures greater than 64°F, the percentage of seeds germinating decreases (Table 1). The percentage of seedlings that emerge is dependent not only on germination, but on the soil environment. Seed and soil-borne pathogens may have a major effect on emergence. An extensive amount of research has been conducted on different seed treatments and treatment methods. Seed treatment with the fungicide, Baytan, can significantly improve emergence. Fungicide labels should be checked to see if a particular fungicide can be used on field pea.

Table 1. Emergence of field pea seeds at different soil temperatures:

Soil Temperature (°F)	41	50	59	68	77	86	95
Percent Normal Seedlings	89	94	93	93	94	89	0
Days to Emergence	36	14	9	7	6	6	--

Source: Harrington and Minge (1954).

V. Cultural Practices:

A. Seedbed Preparation:

Field pea grows best when planted into a seedbed with a minimum amount of residue on the soil surface. In order to obtain good soil contact with the seed, seedbeds should be firm and well worked. Avoid seedbeds with large clods and do not work the soil too fine, or subsequent soil crusting following rains could cause emergence problems.

Fall plowing is recommended (unless erosion is a problem) to permit early spring planting. Cultivating the soil prior to planting aids in weed control and helps warm the soil.

B. Seeding Date:

Being a cool season crop, field pea cannot tolerate hot weather or drought stress during flowering, thus seeding early is important. Seeding should be as early in the spring as feasible provided soil temperature in the upper inch is over 40°F. In Minnesota and Wisconsin this ranges from mid-March to mid-April.

C. Method and Rate of Seeding:

Seed field pea with a grain drill 1 to 2 1/2 in. deep in rows 6 to 7 in. apart. Care must be taken to properly adjust the grain drill to prevent cracking the seed (cracked seed will not germinate).

Rate of seeding depends on the variety to be planted. Large-seeded varieties, such as Century should be seeded at a rate of 190 lb/acre. On average, a stand count of nine plants/sq ft is desirable. Field pea is not a strong competitor, therefore, poor germination or sowing at less than recommended rates may result in severe weed problems.

D. Fertility and Lime Requirements:

Well nodulated field pea does not require much added nitrogen. However, field pea grown on soils with less than 20 lb available nitrogen may benefit from 20 to 40 lb of nitrogen applied at seeding (Table 2). Over-application of nitrogen is usually not profitable and may suppress nitrogen fixation. Nitrogen fixation experiments utilizing a determinate field pea variety revealed no effect on early pod development, maximum growth rate or on maximum leaf area by the addition of starter N (NO_3) at 22 or 45 lblacre. N_2 fixation in field pea increased during preflowering and flowering to a maximum of 9 lb/acre/day at 9 to 10 weeks after seedling emergence. The total accumulation of fixed N in field pea supplied with, zero fertilizer N was 203 lb/acre.

Phosphorous and potassium are required by field pea in relatively large amounts and they should be added as required on the basis of soil test results (Table 2). Fertilizer may be broadcast in the spring during seedbed preparation or banded with the seed. Care must be taken to prevent direct contact between the seed and fertilizer because germinating field pea are extremely sensitive to high salt concentrations.

Sulphur is also required at a relatively high level to ensure adequate nitrogen fixation. Sulphur should be added on the basis of soil test recommendations. Application of lime is recommended on fields with a soil pH of 5.2 or lower.

Table 2. Fertilizer recommendations for field pea.[1]

Nitrogen (N)			Phosphorus (P)		Potassium (K)	
Previous Crop	Organic Matter		Soil Test P	Apply (P_2O_5)	Soil Test (K)	Apply (K_2O)
	low	high	lbs/A		lbs/A	
Corn, Potatoes, Sugarbeets	40	20	0-10	100	0-100	100
Small Grain, Soybeans	20	0	11-20	75	101-150	75
Alfalfa, Clover, Black Fallow	0	0	21-40	50	151-200	50
			40+	0	200+	0

[1]Source. University of Minnesota AG-BU-0519 Soil Test Recommendations 1986.

E. Variety selection:

In Minnesota and Wisconsin, varieties of field pea with cream-colored seed are most commonly grown. Buyers have not encouraged production of green varieties because of bleaching at harvest time. Century, Lenca. Miranda, Paloma and Trapper produce seed of satisfactory cooking quality. Procon seed has not been tested for culinary quality but it may be used as a protein concentrate feed for livestock. Century, Lenca, Trapper, and Procon are also useful as forage crops and may be grown alone or in mixture with small grain for silage or feed grain.

Recommended Fieldpea Varieties:

Century—Medium in yield and maturity with long vines. Seeds are large and cream-colored. Released by Agriculture Canada, Ottawa in 1960.

Lenca—High in yield and medium in maturity and vine length. Seeds are medium in size and cream-colored. It is susceptible to powdery mildew. Released by Agriculture Canada, Morden, in 1979. Production of certified seed limited to Canada.

Miranda—Very high in yield, early, and very short. Seeds are very large and cream-colored. It is susceptible to powdery mildew. Released by Cebeco-Handelsraade of the Netherlands. Seed is distributed by Wilbur-Ellis Co., Spokane, WA 99206. Sale of seed is regulated by U.S. Variety Protection Act.

Paloma—Very high in yield, early and very short. Seeds are large and cream-colored. Released by Cebeco-Handelsraade of the Netherlands.

Procon—Very high seed yield with 25% protein. This variety is very early, blooming in 59 days and maturing in 99 days. It is short vined but not dwarf with white flowers. Seeds are large and cream-colored and are used for protein concentrate in livestock rations. Released by Minnesota Agricultural Experiment Station in 1986.

Trapper—Low yielding, late maturity, long vined variety. Seeds are small and cream-colored. Suitable for birdfeed markets that require small, "yellow" seed. Released by Agriculture Canada, Morden in 1970.

Belinda—Very high seed yield, early, and very short. Seeds are large and cream-colored. Developed by Cebeco-Handelsraade of the Netherlands. Seed distributed by International Seeds Inc., Halsey, OR 97348.

Tipu—High seed yield, medium maturity, with long vines. It has white flowers and yellow or cream-colored seed. It has a semi-leafless plant type with normal stipules and leaflets reduced to tendrils with good standability. Released by Agriculture Canada, Morden in 1985. Production of certified seed is limited to Canada. Distribution by SeCan 512 - 885, Meadowlands drive, Ottawa, Ont. K2C 3N2.

Victoria—High seed yield, early, with medium length vines. Seeds are small and cream-colored. Developed by Svalof A. B. Plant Breeding Station, Sweden. Seed is distributed by Bonis and Company, Ltd., Lindsay, Ontario. Plant variety protection is pending.

Bellevue—Medium in maturity and vine length. Seeds are medium size and cream-colored with a smooth seed coat. It has a higher yield than Century or Trapper and is susceptible to Ascochyta and Septoria leaf blotch. Seed was developed by Agriculture Canada, and is distributed by SeCan 512 - 885, Meadowlands Drive, Ottawa, Ont. K2C 3N2.

Helka—Early in maturity and medium vine length. It has a semi-leafless, bush-type growth habit and is greenseeded. It is resistant to Ascochyta, Fusarium and BYMV. It was developed by Hankkija, Finland and distributed by NorFarm Seeds, Box 37, Roseau, MN 5675 1.

Impala—Medium to early in maturity, leafless with cream-colored seed. It is resistant to Ascochyta race C and was developed by Cebeco-Handelsraade (Netherlands). Seed is distributed by International Seeds, Box 168, Halsey, OR 97348.

Kimo÷Early to medium in maturity with short vines. It has green, medium-large seed and is semi-leafless. It was developed by Hankkija, Finland and was distributed by NorFarm Seeds, Box 37, Roseau, MN 5675 1.

Renata—Medium in maturity, with large cream-colored seed and semi-leafless plant type. It is highly resistant to Fusarium wilt and is resistant to Ascochyta race C and Downy Mildew. The variety was released by Cebeco-Handelsraade (Netherlands) and is distributed by International Seeds, Box 168, Halsey, OR 97348.

Solara—Medium in maturity, short with very large bluish seed. It is semi-leafless and is resistant to Fusarium wilt and Ascochyta race C. Developed by Cebeco-Handelsraade (Netherlands) and distributed by International Seeds, Box 168, Halsey, OR 97348.

Other varieties:

Maple—Medium to low in yield, late, with long vines. The variety has large olive-colored seed with brown mottle and indistinct hilum. This is an excellent variety for pigeon feed use generally grown under contract when buyers offer a higher price than for recommended varieties.

Tara—High in yield and medium maturity with long-vines. Seeds are medium in size and cream-colored. It has satisfactory cooking quality but the irregular seed shape is undesirable. It is resistant to powdery mildew. Released by Agriculture Canada, Morden in 1978. Production of certified seed limited to Canada.

Progeta—A leading white pea variety in the United Kingdom is resistant to pea bacterial blight, Race 2. Distributed by Sharpes and Company; U.K.

F. Weed Control:

Weed competition may severely reduce yield of field pea. Heavy weed infestations should be controlled by cultural or chemical measures prior to rotating into field pea, and prior to planting.

1. **Mechanical control:**
   Harrowing immediately after seeding, will destroy newly emerged shallow seeded annual grasses and broadleaves. Cultivation should be avoided during pea emergence and for several days after emergence to permit rooting and stand establishment. If post-emergence harrowing is necessary, it should be done when field pea are in the 4 to 6-leaf stage and should be viewed as a method of last resort for weed control.
2. **Chemical control:**
   a. Pre-plant incorporated (PPI):
      Treflan 4E (trifluralin) can be applied at a rate of 0.5 qt/acre, before planting, for the control of annual grasses and many broadleaf weeds. Treflan may be weak on wild mustard, smartweed, common ragweed,

velvetleaf, and black nightshade. Treflan should be incorporated two or three in. within 24 hours of after application.
Command 4E (clomazone) can be applied at a rate of 1 pt/acre prior to planting. Command should be incorporated immediately after planting to minimize off-site movement and users should maintain a proper distance from susceptible species as detailed on the label. This herbicide controls annual grasses and many broadleaf weeds but is weak on pigweed and only partially controls cocklebur and black nightshade.

b. Preemergence herbicides:
Lasso 4E (alachlor) can be applied at a rate of 2 qt/acre. It should be sprayed after planting before field pea and weeds emerge. Alachlor controls most annual grasses and many broadleaf weeds including black nightshade but it is weak on velvetleaf, mustard, smartweed, and common lambsquarter. Preplant treatment also provides reasonable yellow nutsedge control.
Ramrod 4F (propachlor) can be applied at a rate of 4 qt/acre and is used to control many annual grasses.

c. Post-emergent herbicides:
Basagran 4E (bentazon) can be applied posternergence at a rate of 0.75 to 1.0 qt/acre. Apply when annual broadleaves are small and actively growing, but only after three pairs of pea leaves (usually four nodes) are present. Do not include crop oil in spray mixture. Provides excellent control of velvetleaf, wild mustard and common ragweed. Basagran will give some control of yellow nutsedge and erratic control of Canada thistle.
Can-trol or Thistrol 2E (MCPB) can be applied at rates of 1 to 2 qt/acre. This herbicide should be applied before the flowering stage when the crop has 6 to 12 nodes and before thistles are 9 in. tall. MCPB controls many annual broadleaf weeds and inhibits Canada thistle bud formation. Canada thistle buds may reduce market quality of field pea. MCPB is weak on smartweeds, mustards, and black nightshade.
Paraquat 1.511 (Grarnoxone) can be applied at a rate of 3 to 5 pt/acre before or after seeding but before pea emergence. Paraquat is a non-selective herbicide and will injure newly emerging field pea if they come in control with this herbicide.
Roundup 3E (glyphosate) can be applied at a rate of 2 qt/acre before or after seeding but before crop emergence. Roundup, like paraquat, is a non-selective herbicide so it is important to not contact the crop. Roundup provides excellent control of quackgrass and good suppression of Canada thistle and other perennials.

Note: Additional information on weed control in field pea may be obtained from: Commercial Vegetable Weed, Insect and Disease Control Guide: Beans and Field pea, 1989 Minnesota Extension Service, AG-FO-1881, and Commercial Vegetable Production in Wisconsin, 1990, University of Wisconsin-Extension, A3422 or similar publications from other states extension service. Be sure to check labels of all herbicides for up-to-date clearance on field peas.

G. Diseases and Their Control:

Seed rots are soil-borne fungal diseases caused by *Pythium, Fusarium solani* or *Rhiziotonia solani.* Seed is infested shortly after planting and seedlings fail to emerge. Treatment of seed with a fungicide can be a cost effective control.

Fusarium root rot is favored by warm dry soil conditions, excessive compaction and low soil fertility. Initial infections usually occur where the cotyledons are attached to the stem. Symptoms include a brownish-red discoloration of the vascular tissue. The vascular tissue of the root may also be discolored (reddish streaks). Control is best achieved by planting field pea in a four year rotation with other crops.

Ascochyta blight is seed-borne and is characterized by purplish to black, streaky, and irregularly shaped lesions on the stem. Septoria blight, a fungus, causes the leaves to appear yellowish and shrunken. Bacterial blight produces water-soaked lesions on all parts of the plant, which may appear creamy and slimy under highly humid conditions. Powdery and downy mildew cause leaves to turn yellow under cool, moist conditions. Warm dry weather reduces mildew growth.

Pea mosaic, a viral disease, induces severe stunting and mottling of leaves with streaks of yellowing on the stems. Early infection causes the plant to die. Crop rotation is recommended for control.

H. Insects and Their Control:

Insect pests have generally not caused serious problems in field pea production areas. However, the following insects may, on occasion, be found in field pea fields:

Pea aphids occasionally become numerous and cause injury by sucking plant sap which cause foliage and blossoms to wilt and shrivel. Aphids may also be vectors for viral diseases. The pea aphid is light green in color, and if necessary, may be controlled with an insecticide.

Loopers, army worms and alfalfa caterpillars are foliage feeders and may occasionally become a problem in field pea fields. If necessary, these insects may be controlled with an insecticide.

Seedcorn maggot feeds on sprouting seed or on seedlings. To control this insect, coat the seed with an insecticidal seed treatment.

Note: Information on insects obtained from Commercial Vegetable Weed, Insect, and Disease Control Guide, 1989, Minnesota Extension Service, AG-FO-1881. Information on specific insecticides may be obtained from this or similar state extension publications.

I. Harvesting:

Field pea plants are prostrate vines at maturity and may be difficult to harvest. The crop is usually harvested the same time as wheat, or as soon as the seed is hard. Seeds may shatter if harvesting is delayed, however, losses from shattering may be reduced by harvesting field pea before all pods are dry. Harvesting at night or early morning, when pods are wet with dew, will also reduce shattering. Field pea do not ripen as uniformly as other crops, therefore it may be necessary to harvest while there are green leaves and pods remaining. The coloring may bleach out of the seeds if pods lay on the moist ground for long periods. Bleaching of seed is undesirable and will reduce seed quality.

Field pea may be swathed or straight combined. If swathing just prior to full maturity, a light roller can be placed behind the swather to help prevent wind damage. Field pea may be swathed when fully mature and should be combined immediately to prevent wind damage. Straight combining will eliminate the possibility of windrow damage caused by high winds and reduce losses at the cutter bar. A desiccant may be used to enhance crop drying prior to combining. It is essential to maintain a low cutter bar height to reduce losses. Floating cutter bars and raking-type pickup reels are available to increase harvest efficiency. To reduce seed shattering, the combine reel should be adjusted to a low speed.

J. Drying and Storage:

Federal grain standards have been established for whole and split field pea. Splitting involves a mechanical process and results in separation of the two seed cotyledons. After dockage has been removed, the seeds are graded. Reductions in grade may be the result of weevil damage, heat damage, bleached or shriveled seeds and seeds with cracked seed coats. A certain percent of splits are allowed in whole field pea and a certain percentage of whole field pea is allowed in split field pea. For safe storage, dry field pea should be maintained at 14% moisture.

VI.. Yield Potential and Performance Results:

Field peas ranged from 1700 to 3000 lb/acre in Minnesota tests, Tables 3 and 4.

Table 3. Yield and agronomic characteristics for field pea in Minnesota, 1981-85[1].

Variety	Yield[2] (lb/acre)	Seed Protein (%)	Days from planting to:		Height (in.)
			Bloom	Maturity	
Century	1960	26	64	104	57
Lenca	2334	25	63	102	50
Miranda	3008	23	57	97	21
Paloma	2780	25	59	99	21
Procon	2950	25	58	97	27
Trapper	1741	27	64	106	55

Belinda	2813	25	58	99	20
Tipu	2544	24	63	105	54
Victoria	2368	25	59	100	46
LSD 5%	91				

[1]Average of trials located at Becker, Grand Rapids, Crookston and Roseau, Minnesota, 60 lb/bu.
[2]10% moisture basis.

Table 4. Yield and agronomic characteristics of field pea varieties at Roseau, MN, 1989.

Variety	Yield (lb/acre)	Seed Protein (%)	Days from planting to:		Height (in.)
			Bloom	Maturity	
Bellevue	1771[1]	26	56	-	64
Helka	2223	24	64	86	64
Impala	1744	24	54	88	53
Kimo	2409	23	53	87	59
Miranda	1060	25	52	87	59
Procon	1585	24	53	85	51
Renata	1204	25	52	84	54
Solara	1472	24	53	86	49
Tipu	1529	24	55	88	73
Titan	1037	24	55	93	56
Trapper	1106	28	55	93	68
LSD 5%	430				

[1]10% moisture basis.

VII. Economics of Production and Markets:

World-wide demand for field pea is strong, however the European Community may regulate field pea imports more severely in the near future and this is expected to weaken demand. In 1986, in the United States the f.o.b. warehouse price for dry field pea was over $10.00/cwt. Growers have reported gross incomes of $300/acre growing field pea for seed. Field pea sold wholesale for $8 to 9/cwt. could gross $200 or more/acre. Growers who anticipate selling field pea to a wholesale buyer should contact that buyer prior to planting to determine which varieties are best suited for the area and which are in the highest demand.

U.S. plantings of dry field pea (yellow) in 1989 are estimated at over 30,000 acres. Canadian plantings (1989) totaled over 450,000 acres.

Table 5. Summary of Estimated Production Costs and Returns for Field Pea. Roseau County, Minnesota, September 1990.

Item	Unit	Price ($)	Quantity	Amount ($)
Income	Bu.	5.00	42.00	210.00
Direct Expenses				
Fertilizer	Acre	30.25	1.00	30.25
Herbicides	Acre	16.05	1.00	16.05
Seed	Acre	33.00	1.00	33.00
Fuel	Gal.	0.80	9.36	7.49
Repair & Maintenance	Acre	10.10	1.00	10.16
Interest	Acre	0.12	96.94	3.08
Total Direct Expenses				100.02
Returns Over Direct Expenses				109.98
Allocated Overhead	Acre	77.48	1.00	77.48
Allocated Full-time Labor	Hour	8.00	2.10	16.34
Crop Loss/Insurance	Acre	0.03	210.00	6.30
Total Expenses and Costs				200.13
Returns Above Total Expenses and Costs				9.87

Computed average total cost to grow a bu. of field pea = $ 4.77

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Flax

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I. History:

Common flax (*Linum usitatissimum* L.) was one of the first crops domesticated by man. Flax is thought to have originated in the Mediterranean region of Europe; the Swiss Lake Dweller People of the Stone Age apparently produced flax utilizing the fiber as well as the seed. Linen cloth made from flax was used to wrap the mummies in the early Egyptian tombs. In the United States, the early colonists grew small fields of flax for home use, and commercial production of fiber flax began in 1753. However, with the invention of the cotton gin in 1793, flax production began to decline. During the 1940's fiber flax production in the U.S. dropped to nearly zero. Today a few individuals still grow fiber flax for their own use to make linen. Presently the major fiber flax producing countries are the Soviet Union, Poland, and France. Wisconsin had 2,000 acres for seed in the state in 1966 with an average yield of 18 bushels per acre, however there has been no acreage reported in recent years. Minnesota had 378,000 acres in 1920 and over 1,600,000 acres in 1943. Since 1943 acreage has steadily declined with only 15,000 acres grown in 1988. The state average yield was 9.5 bushels per acre in 1920, while in 1987 it was 16 bushels. The yield dropped to 10 bushels per acre in 1988 due to dry conditions. States having the largest seed flax acreages are North Dakota, South Dakota, and Minnesota.

Flax is an alternative cash crop, especially in areas of Wisconsin and Minnesota where allocated acreages for other cash crops are limited or where other crops are not adapted. At one time the flax acreage was concentrated on the clay soils in eastern Wisconsin. However, flax is adapted and has been successfully grown in other areas of the state. In Minnesota, flax acreage is concentrated in the northwestern part, however flax has been grown successfully in nearly all counties.

II. Uses:

A. Industrial Uses:

Flax is still produced in the United States for its oil rich seed. Linseed oil has been used as a drying agent for paints, varnishes, lacquer, and printing ink. Unfortunately these markets have eroded somewhat over the years with the production of synthetic resins and latex. One bright spot in the market has been the use of linseed oil as an antispalling treatment for concrete where freezing and thawing effects have created problems on streets and sidewalks. Occasionally the straw is harvested and used to produce some paper products.

B. Livestock Feed:

Linseed oil meal is an excellent protein source for livestock containing about 35% crude protein. Flax straw on the other hand, makes a very poor quality forage because of its high cellulose and lignin content. Green flax straw should not be grazed or fed as it is high in prussic acid. The danger of prussic acid poisoning is greater immediately following a freeze.

C. Human Food:

Recently there has been some interest in seed flax as a health food because of its high amount of polyunsaturated fatty acids in the oil (Table 1).

Table 1: Oil and Mineral compostion of flaxseed.[1]

Character measured	Mean[2]	Mineral element	Mean[2]
	% of seed		%
Oil in seed	40.3	K	0.89
Fatty acid	% of total fatty acids	P	0.60
Linolenic	49.3	Mg	0.33
Linoleic	14.7	Ca	0.21
Oleic	24.1	Na	0.04
Stearic	4.3		ppm
Palmitic	6.1	Zn	56.9
	Number	Fe	46.2
Iodine value of oil	179.3	Mn	32.0
		B	11.5
		Cu	9.5
		Sr	1.4
		Mo	0.7

[1]Adapted from "Growing Seed Flax in the North Central States"
[2]Shown on oven–dry basis

III. Growth Habits:

Seed flax is an annual plant that grows to a height of 12 to 36 inches. It has a distinct main stem with numerous branches at the top which produce flowers. Branches from the base of the plant may also occur depending on variety, stand, and environment. The plant has a branched taproot system which may extend to a depth of 3 to 4 feet in coarse textured soil. Spring-sown varieties of the North Central region are less cold tolerant, exhibit less basal branching, and grow more upright in the seedling stage than fall-sown varieties of Texas and southern California.

The flax flower has five petals and a five-celled boll or capsule, which may contain up to 10 seeds when filled. Under most conditions an average of six to eight seeds per boll is normal. Some varieties produce bolls that tend to split open from the apex in varying degrees, whereas other varieties have bolls that remain tightly closed. Varieties with tight bolls suffer less weather damage to ripe seeds and resist shattering better than varieties with split bolls. Most current commercial seed flax varieties have semitight bolls.

Flax is normally self-pollinated, but insects cause some natural crossing. Frequency of cross pollination seems to be associated with varietal differences and environmental conditions. Individual flowers open in the first few hours after sunrise on clear, warm days, and the petals usually fall before noon. Most commercial varieties have blue petals. Petals may also be white or different shades of purple, blue or pink. The seeds may be various shades of yellow, brown, greenish-yellow, greenish-brown, or nearly black. Seed color of most commercial varieties is light brown.

Flax is an excellent companion crop to help establish small seeded grasses and legumes. Plant characteristics that favor its use as a companion crop are (1) limited leaf area and short stature which allow much light to reach the forage seedlings, (2) early maturity, and (3) less extensive root system than many crops which reduces competition for soil moisture.

Flax in Wisconsin and Minnesota is a spring annual with a 90 to 110 day growing season. The typical life cycle consists of a 45 to 60 day vegetative period, followed by a 15 to 25 day tlowering period, and 30 to 40 day maturation period. Proper harvest time is important in flax production. Early harvest reduces yield while late harvest can change the chemical make-up of the oil and thus its quality and value.

IV. Environment Requirements:

A. Climate:

The concentration of flax acreage in the North Central states is in part due to the large acreage of fertile land suitable for flax and a lack of other competing crops with more favorable economic returns. The North Central area also has moderate summer temperatures and rainfall which is sufficient but not excessive for good flaxseed yields.

Flax yields tend to decrease as precipitation diminishes. Annual rainfall ranges from 30 inches in parts of Wisconsin and Minnesota to 15 inches in eastern Montana. More important than total rainfall is the amount of precipitation that falls during the growing period. Adequate moisture and relatively cool temperatures, particularly during the period from flowering to maturity, seem to favor both high oil content and high oil quality.

B. Soil:

Flax is best adapted to fertile, fine textured, clay soils. It should not be grown on very coarse textured, sandy soils. Flax on peat or muck soils will be disappointing unless problems related to drainage, fertility, and weed control are solved.

C. Seed Preparation and Germination:

More uniform stands of flax are frequently obtained when the seed is treated with a suitable fungicide. In areas where wireworms are a problem, an insecticide needs to be used along with a fungicide as a seed treatment. The seed coat of flax is easily damaged during harvest and handling. Sometimes this damage is so slight it is not visible but even such slightly damaged seed is susceptible to seed decay. Thus, all seed should be treated with a fungicide. Sound, uninjured flax seed should always be selected for planting if available.

V. Cultural Practices:

A. Seedbed Preparation:

The best seedbed for flax is similar to the ideal seedbed for small seeded grasses and legumes. It should be wellworked. The soil should be firm to avoid large air pockets. Fall plowing is preferred if erosion is not serious. The seedbed may be worked fairly shallowly, except where deeper plowing is required when flax follows corn. Cultivation following early fall plowing will aid in weed control. In the spring, shallow discing and harrowing are the usual practices of seedbed preparation. In most cases, a more uniform planting depth (and seedling emergence) will result if the field is rolled before planting.

B. Seeding Date:

Research in several states indicates that early seeding gives the highest yields in most years. Plant about the same time as for oats. Seedling flax plants have tolerance to light frost. Planting is sometimes delayed to allow cultivation for weed control in fields where weeds may be a very serious problem. Late planting of flax may not cause as great a yield reduction as it does with small grains.

C. Method and Rate of Seeding:

A seeding rate of 42–50 pounds of good seed per acre is recommended. Lower seeding rates often result in more severe weed problems. A one–half to one inch planting depth is suggested in clay soils. Flax seed is comparatively small and may fail to emerge from greater depths, especially if crusting occurs. Inexperienced growers often plant too deep, especially if the soil is loose. Flax is usually sown with a grain drill. Presswheel-type grain drills are ideal. A roller type seeder often used to plant forage legumes may also be used.

D. Fertility and Lime Requirements:

Flax requires about the same soil fertilization program as small grains. Apply lime to maintain soil pH in the 6.0 to 6.5 range. Follow soil test recommendations for phosphorous and potassium fertilizer applications where soil tests for P and K are low (L) or very low (VL). These elements are especially important if a legume is being seeded with flax. Annual nitrogen, phosphate, and potash recommendations for Wisconsin are shown in Table 2 and for Minnesota in Tables 3 and 4. If large amounts of fertilizer are required, it is commonly applied to the previous crop in the rotation. Stands of flax will likely be reduced if combined total rates of N, P_2O_5 and K_2O applied with the seed exceed 20 lbs./acre.

Table 2: Annual nitrogen, phosphate, and potash recommendations for flax in Wisconsin.

	Nitrogen recommendation					
	organic matter %				Phosphate and Potash recommendation[1]	
Yield level	< 2	2–5.0	5.1–10	> 10	P_2O_5	K_2O
bu/a	lb/a					
20 to 40	50	30	20	10	20	20

[1]Amounts shown are for medium (M) soil test levels. Apply 50% of rate if soil test is very high (VH) and omit if soil test is excessively high (EH).

Table 3: Annual nitrogen recommendations for flax in Minnesota.

	Based on previous crop and organic matter level			
	Previous crop			
	Corn, sugar beets, potatos, small grain	Soybeans, sunflowers	Alfalfa, clover, black fallow	Organic soil
Based on nitrate test[1]	Organic matter level[3]			

Expected yield	Soil–N (0–2 ft.)+ fertilizer N	Low to medium	High	Low to medium	High	Low to medium	High	
(bu./acre)	(lb./acre)[2]	N to apply (lb./acre)						
35 or more	120	100	80	60	40	30	20	20
30–34	100	80	60	60	40	30	20	20
25–29	80	60	40	50	30	20	0	20
20–24	70	50	30	40	20	0	0	0
less than 20	60	40	20	30	20	0	0	0

[1]for use in western Minnesota only
[2]Subtract nitrate – N (lb./acre, 0–2 h) from this value to obtain N to apply (lb./acre)
[3]Irrigated soils are included in the low to medium category.

Table 4: Annual phophorus and potassium recommendations for flax in Minnesota.

Phophorus (P) Soil Test (lb./acre)	P_2O_5 to apply (lb./acre)	Potassium (K) Soil Test (lb./acre)	K_2O to apply (lb./acre)[1]
0–10	40	0–100	80
11–20	30	101–200	40
21–30	20	201 –300	20
30+	0	300+	0

[1]Recommended rates are for total amount to apply—broadcast plus drill.
Caution:
Flax: Do not apply more than 10 lb./acre nitrogen or 20 lb./acre $N+P_2O_5+K_2O$ in the drill row.

E. Variety Selection:

The most important factors to consider in variety selection are maturity, disease resistance, standability, and oil content and quality. Each of these factors will influence yield or quality. Pasmo is the most serious disease affecting flax in Wisconsin and Minnesota.

Recommended Varieties for Oil Seed Production:

Dufferin—High yield when sown early, not recommended for late sowing. Very late, brown seed, blue flowers, variable plant height. High oil percent. Resistant to rust and wilt. Licensed in 1975 by Agriculture Canada, Ottawa.

Rahab—High yield. Medium maturity, good lodging resistance. Brown seed, blue flowers. High oil percent. Resistant to rust, moderately susceptible to wilt and pasmo. Released in 1985 by South Dakota Agricultural Experiment Station.

Verne—High yield, particularly when sown late. Early maturity, good lodging resistance. Blue flowers, brown seed. Excellent resistance to rust and wilt, moderately resistant to pasmo. Released in 1987 by Minnesota Agricultural Experiment Station.

Other Varieties:

Clark—Medium yield. Early. Brown seed, blue flowers. Medium oil percent. Resistant to rust, moderately resistant to wilt and pasmo. Released in 1983 by South Dakota Agricultural Experiment Station.

Culbert and Culbert 79—Medium yield. Early maturity, good lodging resistance. Brown seed, blue flowers. High oil percent. Resistant to rust, moderately resistant to wilt, moderately susceptible to pasmo. Culbert released in 1975 by Minnesota Agricultural Experiment Station. Culbert 79 selected from Culbert and released in 1979 by South Dakota Agricultural Experiment Station. The two varieties do not differ significantly.

Flor—Medium yield. Medium maturity. Brown seed, blue flowers. High oil percent. Resistant to rust, susceptible to wilt, moderately susceptible to pasmo. Released in 1981 by North Dakota Agricultural Experiment Station.

Linott—Medium yield. Early maturity. Brown seed, blue flowers. High oil percent. Resistant to rust (has a trace of susceptible plants), moderately susceptible to wilt and pasmo. Licensed in 1967 by Agriculture Canada, Ottawa.

Linton—Medium yield. Medium maturity, medium lodging resistance. Brown seed, blue flowers. Mcdium oil percent. Resistant to rust and wilt, moderately susceptible to pasmo. Released by North Dakota Agricultural Experiment Station in 1985.

McGregor—High yield when sown early. Very late, very resistant to lodging. Brown seed, blue flowers. Medium oil percent. Resistant to rust, moderately resistant to wilt, and susceptible to pasmo. Licensed in 1981 by Agriculture Canada, Ottawa. Production of certified seed limited to Canada.

NorLin—High yield. Medium maturity. Brown seed, blue flowers. Medium oil percent. Resistant to rust, moderately susceptible to wilt and pasmo. Licensed in 1982 by Agriculture Canada, Ottawa. Production of ccrtified seed limited to Canada.

NorMan—High yield. Late maturity. Brown seed. blue flowers. High oil percent. Resistant to rust, moderately susceptible to wilt and pasmo. Licensed in 1984 by Agriculture Canada, Morden. Production of certified seed limited to Canada.

Note: Variety descriptions from Report 24, "Varietal Trials of Farm Crops" University of Minnesota Agricultural Experiment Station, St. Paul, Minnesota, 1989.

F. Weed Control:

1. Cultural and Mechanical: Weeds are generally more of a problem in flax than in small grain. Growers should sow flax on relatively weed free land and where quackgrass is not a serious problem. Use post-harvest tillage and/or herbicides the previous season to suppress perennial weeds such as Canada thistle and quackgrass and to stimulate germination of annual weed seeds. Good weed control with a minimum of weed seed production in the preceding year's crop will facilitate a cleaner flax field. Delayed sowing of flax to permit additional spring tillage for weed control may be successful in some fields but the planting delay may be detrimental to the flax.

2. Chemical: There are no soil applied herbicides recommended for weed control in flax in Wisconsin. Walk your fields every 5 to 7 days after planting and use the appropriate postemergence herbicide if necessary. In Minnesota, Eptam and Treflan can be applied and incorporated in the fall while Ramrod can be applied preemergence in the spring.

Poast can be applied at .5 to 2.5 pints/acre to control annual grasses like foxtail, fall panicum, barnyardgrass, and wild oats. Treat when weeds are up to 4 inches tall. Volunteer cereals can be controlled with 1 1/2 pints/acre. Always use a crop oil concentrate or Dash with Poast. This product does not prevent further weed seed germination. If a second flush of annual grasses appears, make a second application. Quackgrass control is not mentioned in the flax section of the Poast label, but the 1 1/2 pint/acre rate would normally suppress this weed. Do not apply Poast within 75 days of harvest and do not graze or feed treated flax forage to livestock.

Poast can be tank mixed with either Buctril or MCPA. This is appropriate when a mixture of grasses and broadleaves is present. Use only a crop oil concentrate (not Dash) as the additive. Some leaf burn, slowed crop growth, and delayed crop maturity may result from these tank mixes. Grass control may also be somewhat reduccd.

Wild oats can also be controlled with Carbyne and Hoelon. Carbyne at 1 to 1.5 pints per acre applied postemergence when wild oats is in the 2–leaf stage will control wild oats. Hoelon should be applied at 2 to 2.67 pints pcr acre when wild oats is in the 1– to 4–leaf stage. Dowpon applied at 1 pound per acre when flax is 1 to 6 inches tall will control small (less than 2 in.) foxtail. Dowpon can be mixed with MCPA Amine.

To control annual broadleaf weeds postemergence, apply 1/3 to 1/2 pt/A of MCPA Amine (forms containing 4 lb acid equiv/gal), when flax is 2 to 6 inches tall but before the bud stage. Flax can be seriously injured if this treatment is applied between bud stage and when 90% of the bolls have formed. Seed germination may be reduccd by treatment after full bloom. MCPA may cause injury to flax at any stage of growth but is generally less injurious than 2,4–D.

Buctril (bromoxynil) can be applied postemergence to control broadleaf weeds, especially wild buckwheat and smartweed. This treatment is weaker on pigweed and wild mustard than MCPA. Apply 1 pt/A in 10 to 20 gal of water before weeds exceed the four-leaf stage and the flax is 2 to 8 inches tall. Do not treat flax during or after the bud stage. High temperatures on day of treatment and for the next 3 days must not exceed 85 730176;F to avoid flax injury.

G. Diseases and their Control:

Rust is a fungus disease which first appears as yellow orange pustules on the leaves and stems. The spore masses are darker color in later stages. Good fall plowing that buries straw and stubble aids in controlling the disease, but the most efficient control for rust is the use of resistant varieties.

Pasmo is a fungus disease characterized by yellowgreen to brownish spots on the leaves, stems, and bolls. Infected leaves die and drop off. Infected stems appear as alternate green and brown areas giving a blotchy appearance. Gencrally the disease becomes more severe as the crop approaches maturity. The fungus is carried overwinter on flax plant debris. This disease has been observed on flax in Wisconsin and Minnesota.

Wilt is a soil-borne fungus disease. It is most serious where flax is not rotated with other crops. Recommended varieties are highly resistant to this disease.

Seedling Blight diseases attack the germinating seed. Losses are most severe in extremely cold, wet growing conditions. The fungi may enter the seed through cracks in the seed coat. Seed treatment will help to prevent losses.

Aster Yellows and Crinkle are both virus diseases which are transmitted by certain insect vectors. These diseases may be present to a limited extent each season; however, losses are usually light.

H. Insects and Other Predators and their Control:

Flax may be infested from time of emergence to maturity by various insect pests. To keep damage low, examinc fields regularly for pests and use control measures promptly.

Cutworms damage the seedlings by cutting off the plants at or near the soil surface. Severe damage may be done in 1 or 2 days when the plants are young.

Wireworms, although often serious pests of cereal grains in the seedling stage, seldom damage flax.

Aphids sometimes become so abundant on flax in midsummer that all the plants in a field may be covered with them. These infestations normally cause little damage.

The aster leafhopper and the tarnished plant bug, like aphids, feed by sucking juices from the flax plants. The leafhopper can carry the mycoplasm that causes aster yellows and infect the plants with this disease while feeding. Tarnished plant bugs damage flax by feeding on the growing tips, which become distorted and die back. The damage from these insects is most serious on late-seeded crops.

Grasshoppers may be a hazard to flax, especially before harvest. If flying adults invade a field, they can quickly cause large numbers of bolls to drop to the ground by chewing through the succulent portions of the small stems below the bolls. In the spring young hoppers may also damage seedling flax.

The beet webworm, a slim, lively, dark green caterpillar, may eat leaves, flowers, and patches of bark from flax stems and branches. When abundant, usually in July and August, the larvae migrate in large armies.

I. Harvesting:

Flax is more difficult to harvest than small grains; however, flax does not shatter or lodge as easily. Because of green weeds and uneven ripening, flax is usually windrowed and allowed to dry before combining. It may be combined standing if it is relatively weed free and appears to be uniform in maturity. Flax is ready to harvest when 90 percent of the bolls have turned brown. The seed should be under 12% moisture before combining.

Flax is usually ripe when the stems turn yellow, the bolls turn brown, and the seed can be easily threshed. In wet summers the stems may remain green and the plants continue to flower long after the early bolls are ripe. Under such conditions flax should be harvested when all but the very late bolls are ripe. It is important to harvest soon after it is mature because weeds usually become a greater problem. If left standing for a long period of time, the seed quality for oil purposes may be seriously reduced.

Adjust the combine cylinder speed (800–1300 RPM) and cylinder concave clearance (1/16–1/4") to avoid cracking and yet remove all the seed from the bolls. A sharp cutter bar is necessary when combining direct. Adjustment in the cleaning is important to minimize losses. A sieve with an opening of 1/16 to 3/16" is suggested. Careful loss evaluation will aid in refining these adjustments.

Flax seed over 11% moisture usually cannot be stored safely for extended periods. Top market prices are usually based on 9% moisture. Flax should be left in the windrow to dry until the seed reaches this moisture level. Seed containing large amounts of green weed seed and inert matter should be cleaned before storing.

If the straw is to be marketed, it should be baled and stacked when thoroughly dry. The straw should be fairly weed free if the highest prices are to be obtained.

J. Drying and Storage:

Flax seed shipped to market often contains from 10 to 40 percent dockage and cracked flax seed, other grains, weed seeds, and chaff. These admixtures are mostly undesirable when extracting linseed oil, but they are of value for feed.

Excessive dockage may be screened from the flax before marketing to save freight charges if the screenings are of aufficient local value to offset cleaning costs and losses from shrinkage during cleaning. However, only a few farms and not all local elevators are equipped for such cleaning. Cleaning on the farm or at the local elevator saves screenings for feeding in the community, but they often are more valuable in the terminal markets where they can be incorporated into commercial mixed feed.

To clean flax seed, use a 4 x 16 mesh wire sieve (or 4 x 14 for large-seeded varieties) to separate the grain and larger weed seeds from flax. A metal sieve with round holes onefourteenth of an inch in diameter will remove most of the small weed seeds and fragments of flax seed. The air blast can be regulated to blow out all immature and shrunken flax seed and trash.

For safe storage, flax seed should contain 11% moisture or less. Store only in dry tight bins or containers. Flax seed will flow through very small openings.

VI. Yield Potential and Performance Results:

A. Wisconsin:

Flax yield tests have not been conducted in Wisconsin since 1972. Yields at Madison in 1971 and 1972 ranged from 18–20 bu/a, (Table 5).

B. Minnesota:

The most recent flax yield tests conducted in Minnesota show that several varieties average 18–20 bu/a. Yield and other plant characteristics are shown in Table 6.

VII. Economics of Production and Markets:

Market outlets for seed or straw should be located before planting. Most local buyers may be able to handle flax if they can make arrangements in advance. The flax straw processing plants are in Minnesota. The straw is usually shipped to these plants as needed.

The University of Minnesota publishes information yearly on the cost of production and expected net return from growing various crops including flax. These crop budgets must be adjusted according to individual situations to be useful. A budget plan for 1989 comparing four different crops is summarized in Table 7. A land charge of $55.20 is included in the overhead cost of all crops. Transportation costs to market would usually be higher in Wisconsin than Minnesota because the nearest flax terminals are Minneapolis and Duluth–Superior.

Table 5: Yield and Agronomic Data for Several Flax Varieties at Madison, Wisconsin, 1971–72.[1]

Variety	Yield (bu/A)	Bloom Date	Mature Date	Height (in.)
Bison	18.3	6/25	8/5	22
Bolley	19.5	6/26	8/8	23
Windom	18.9	6/25	8/4	21
Summit	19.4	6/25	8/5	21
Nored	20.0	6/30	8/7	22
Arny	19.0	7/1	8/7	25

[1]Planted May 5,1971 and May 12, 1972. Data from J.H. Torrie, Department of Agronomy.

Table 6: Yield and Agronomic Characteristics of Flax Varieties in Minnesota.

					Planting to bloom				Disease reaction		
Variety	Yield[1]	Oil	Test weight	Seeds/ pound	first	full	Lodging	Height	Wilt	Pasmo	Rust
	bu/a	%[2]	lbs/bu	no.	days		score[3]	inches	score[4]		rating[5]
Dufferin	20.7	42	53	82,470	56	61	2.7	24	2.0	5.2	R
Rahab	20.7	41	53	78,210	54	58	2.9	33	3.7	3.0	R
Verne	20.8	41	53	82,470	51	56	3.3	22	1.6	3.1	R
Clark	18.9	40	54	79,580	51	56	3.6	22	3.3	3.4	R
Culbert	19.1	41	54	76,880	50	56	2.6	21	2.6	3.1	R
Culbert 79	18.1	41	54	76,880	51	57	2.5	21	2.5	3.1	R
Flor	19.5	41	53	82,470	54	58	3.7	22	4.7	3.3	R
Linton	19.3	40	54	81,000	54	59	3.3	22	1.4	3.6	R
McGregor	20.2	40	54	87,230	56	62	1.8	24	3.2	4.2	R
NorLin	20.9	40	54	78,210	53	59	3.2	22	3.7	3.4	R
NorMan	21.0	41	53	79,580	55	60	4.0	22	3.8	4.0	R

[1]Average of 25 tests.
[2]Oven–dry.
[3]1 = erect, 9 = flat.
[4]1 = best, 9 = poorest.
[5]R = resistant.

Table 7: Estimated Budget for growing flax compared to corn, soybean and wheat.

	Corn[1]	Soybean	Wheat[1]	Flax
Yield/bu/A	115	42	45	20
Price/bu[2]	$2.58	$7.15	$4.07	$7.60
Total Returns/A	296.70	300.30	183.15	152.00
Cash Expense/A	129.94	79.41	51.57	49.57
Overhead Cost/A	129.62	117.79	108.23	109.76
Total Cost/A	259.56	191.20	159.80	159.32
Return Over Total Cost	37.14	109.10	23.35	(–7.32)
Return Over Cash Cost	166.76	220.89	131.58	102.43

[1]Participation in goverment crop program could add additional income per acre for corn and wheat.
[2]Average US price on May 15, 1989.

VIII. Information Sources:

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Rutabaga

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I. History:

The rutabaga (*Brassica napobrassica*), or swede, is believed to have originated from a hybrid between the turnip (*Brassica rapa*) and wild cabbage (*Brassica oleracea*), probably in Bohemia and as recently as the 17th century. Rutabagas are grown for human and animal consumption. Researchers in the United States determined in the early 1900s that the fleshy roots of rutabagas are valuable energy sources for young livestock. However, livestock farmers at that time were turning away from the brassica crops (which also include rape, kale, and turnips) because much hand labor was required for their production and utilization. One study showed that the labor requirement for these crops was three times that needed for corn silage production.

In the late 1970s, however, researchers began to recognize the potential of the root brassicas as forage crops, thereby eliminating the need for manual labor in harvesting and storage. In general, the forage brassicas are high-quality, high yielding forage crops that are well suited to seeding into existing pastures with little or no tillage.

Rutabaga is a cool-weather crop and is grown primarily in the northern parts of the United States and Europe, in Great Britain and in Canada.

II. Uses:

Brassicas are high-quality forage if harvested before heading. Livestock readily graze on the stems, leaves and roots of rutabaga plants. Above-ground parts normally have 20 to 25% crude protein and 65 to 80% total digestible nutrients (TDN). The roots have 10 to 14% crude protein and 80 to 85% digestibility.

Rutabaga and other brassicas can provide grazing during the late summer and fall after other forage crops have played out. Rutabaga maintains its nutritional quality and palatability, if not heading, well into freezing temperatures and may be grazed in the Upper Midwest into November.

III. Growth Habits:

Rutabaga is a biennial, which can overwinter as a storage root. The 'root' consists of the hypocotyl - the plant part that lies between the true root and the first seedling leaves (cotyledons) - and the base of the leafy stem. A rutabaga root can be distinguished from a turnip by the presence of a swollen "neck" bearing a number of ridges, the leaf-base scars. The storage root may be purple, white or yellow, with yellowish flesh. Rutabaga leaves are bluish, thick like cabbage, and smooth. They emerge from the crown in a broad, low-spreading growth habit that inhibits growth of weeds. Rutabaga flowers are small and have light-yellow petals. They differ from turnip flowers in that they are not raised above the unopened buds on the raceme.

IV. Environment Requirements:

A. Climate:

Rutabaga plants are both cold hardy and drought tolerant. They can be grazed 150 to 180 days after planting and can provide forage late in the Fall. Their most vigorous root growth takes place during periods of low temperature. The leaves maintain their feeding quality even after repeated exposure to frost.

B. Soil:

Like other brassicas, rutabaga grows best in a moderately deep, fertile and slightly acid soil. Rutabaga will not do well in soils that are heavy, wet or poorly drained.

V. Cultural Practices:

A. Seedbed Preparation:

Rutabaga, like other brassicas, can be seeded into a sod with minimum tillage. The sod should be suppressed or killed, as the young rutabaga seedlings cannot compete with grasses. Once established, the rutabaga plants will smother out most other weeds. To kill sod, apply 2 qt/acre of Roundup at least three days prior to seeding. A reduced rate of herbicide can be used in 3 to 10 gal/acre of water to suppress sod or to prepare a field of wheat stubble for seeding with rutabaga.

Rutabaga can also be planted with a forage crop seeder on a conventional seedbed. Plow the seedbed at least six weeks before sowing. The seedbed should be fine, firm and free of weeds and clods.

The advantages of direct drilling brassicas into sod include fewer crop losses due to insect pests and less soil erosion on sloping sites where pastures are often located. A field of brassicas established in sod gives animals a firm footing in all kinds of weather. It also allows the original sod species to grow again the following spring if it has only been suppressed.

B. Seeding Date:

Rutabaga seeds do not germinate well in cold soil. Plant rutabaga when the soil temperature is at least 50¡F. This means at com planting time or later. Later plantings may not have sufficient time to produce good forage growth.

C. Method and Rate of Seeding:

Rutabaga seed can be planted in 6 to 8 in. rows at a rate of 1.5 lb/acre with a minimum-till drill. Alternatively, the crop can be seeded with a forage crop seeder on a conventional seedbed or broadcast followed by cultipacking. The seed should not be covered with more than 14 in. of soil.

D. Fertility and Lime Requirements:

Test the soil and lime to a pH of 6.0. Fertilizers should be applied at the time of seeding to give the crop a competitive edge on weeds. Apply 100 lb/acre nitrogen to soils containing 2 to 5% organic matter. 120 lb/acre if less than 2% organic matter and 60 to 80 lb/acre if soils contain more than 5% organic matter. Requirements for phosphorus and potassium are similar to those of a small grain. In Wisconsin and Minnesota, when soil tests are in the medium range, about 20 to 30 lb/acre of P_2O_5 and 120 lb/acre of K_2O should be applied. Fertilizer applications should be banded at least 2 in. to the side or below the seed or broadcast. Boron and sulfur may also be needed. If the soil tests "low" in boron, apply 1 lb boron/acre on sandy soils and twice this on other soils. Apply 10 to 15 lb sulfur/acre if a soil sulfur test indicates a need for this element.

E. Variety Selection:

Some promising rutabaga varieties for use in the Upper Midwest are Calder and Sensation.

F. Weed Control:

Weeds are generally not a problem once the rutabaga crop is established. However, sod and annual weeds should be controlled chemically before planting. Sod can be suppressed or killed with Roundup, as described under Seedbed Preparation. If annual weeds are present at planting time, eliminate them with a burn-down herbicide such as Gramoxone.

G. Diseases and Their Control:

Rutabaga crops may suffer from clubroot, root knot, leaf spot, white rust, scab, anthracnose, mosaic and rhizoctonia rot. In some cases, diseases can lead to crop failure. To prevent problems with diseases, brassicas should not be grown on the same site more than two years in a row.

H. Insects and Other Predators and Their Control:

Insects we generally not a problem on rutabaga crops seeded in sod. However, an insecticide should be applied at the time of planting under conventional tillage.

I. Harvesting:

Rutabaga plants are ready for grazing or green-chop when the forage is about 12 in. tall (150 to 180 days after planting). It is best not to wait too long, because fungal diseases may begin to cut yields after the plants reach maturity. The pasture should be grazed for a short period of time and the livestock removed to allow the plants to regrow. If grazed to a 5 in. stubble, one to four grazing periods may occur, depending on planting date and growing conditions.

The forage quality of rutabaga is so high that it should be considered similar to concentrate feeds, and precautions should be taken to prevent animal health problems. Livestock should not be hungry when put on pasture the first time so that they do not gorge themselves. If the livestock are moving from a feed of low nutritional quality, feed a high-quality diet for two to three weeks prior to grazing rutabaga, or feed rutabaga for 30 min/day for one week prior to heavier grazing. This will allow for the development of a rumen microbial population that is adequate to digest the high levels of protein in forage rutabagas. A lower quality hay should be made available (2 to 3 lb of dry roughage/head/day for sheep and 10 to 15 lb for cattle) to provide fiber in the animals' diet. Livestock should not feed on rutabaga during the breeding season or after the plants have begun to flower.

VI. Yield Potential and Performance Results:

Rutabaga produces 6 tons or more of dry matter/acre.

VII. Economics of Production and Markets:

Rutabaga is a highly nutritious forage crop that can provide grazing in the late fall after other forage crops are finished for the year.

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Turnip

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I. History:

Turnip (*Brassica rapa* L.) is a root Brassica crop and has been used as a vegetable for human consumption in Europe since prehistoric times. Turnip root has been a popular livestock fodder for at least 600 years wherever the crop can be grown. For most of that time turnip roots have been managed as forage. Researchers in the United States determined in the early 1900s that turnip roots are valuable energy sources for young ruminant animals. However, livestock farmers at that time were turning away from the Brassica root crops (which also include rutabagas or swedes) for fodder because much hand labor was required for the production and utilization of the large roots. One study showed that the labor requirement on a nutrient basis for these crops was three times that needed for corn silage production.

In the late 1970s, however, researchers began to demonstrate the potential of turnip as pasture. The development of varieties with partially exposed roots rendered the roots more available to grazing animals. Livestock graze turnip tops and roots readily, and the forage is of high quality. Pasturing eliminates the need for manual labor in harvesting and storing. In general, the root Brassicas are fast-growing, high yielding and well adapted to seeding into existing pastures with little or no tillage or to seeding into a conventionally prepared seedbed.

Turnip is a cool-weather crop and well adapted for the northern parts of the United States and Europe and for Great Britain and Canada. However, truck-growing areas of the South also produce turnip roots and greens in all seasons for human consumption.

II. Uses:

Turnip produces high-quality forage if harvested before heading. Livestock eat the stems, leaves and roots of turnip plants. Above-ground parts normally contain 20 to 25% crude protein, 65 to 80% in vitro digestible dry matter (IVDDM), about 20% neutral detergent fiber (NDF) and about 23% acid detergent fiber (ADF). The roots contain 10 to 14% crude protein and 80 to 85% IVDDM.

The high levels of glucosinolates (which can cause thyroid enlargement in young growing sheep and cattle) can be a problem if turnip forage is fed for long enough. Glucosinolates are higher in older (90-day) than 60-day forage. Oral or subcutaneous iodine administration can alleviate thyroid problems. Turnip roots usually are higher in glucosinolates than the tops and leaves. Two other anti-quality factors, S-methyl cysteine sulphoxide (SMCO) and free nitrates can also be present. SMCO is the main problem and can cause anemia. To minimize the potential for animal health problems from these factors, forage from turnips should be fed in combination with other forages.

Turnip and other Brassicas can provide grazing at any time during the summer and fall depending on the seeding date. A promising use may be for late fall grazing. These crops maintain their forage quality, if not headed, well into the fall even after freezing temperatures and may be grazed in the Upper Midwest into November. Many turnips can be grazed twice to permit utilization of top growth and roots.

III. Growth Habits:

Turnip is a member of the mustard family and is therefore related to cabbage and cauliflower. Turnip is a biennial which generally forms seed the second year or even late in the fall in the first year if planted early in the spring. During the first or seeding year 8 to 12 erect leaves, 12 to 14 in. tall with leaf blades 3 to 5 in. wide are produced per plant. Turnip leaves are usually light green, thin and sparsely pubescent (hairy). In addition, a white-fleshed, large global or tapered root develops at the base of the leaf petioles. The storage root varies in size but usually is 3 to 4 in. wide and 6 to 8 in. long. The storage root consists mainly of the hypocotyl, the plant part that lies between the true root and the first seedling leaves (cotyledons). The storage mot generally has little or no neck and a distinct taproot. The storage root can overwinter in areas of mild winter or with adequate snow cover for insulation and produce 8 to 10 leaves from the crown in a broad, low-spreading growth habit the following spring. Branched flowering stems 12 to 36 in. tall are also produced. The flowers are clustered at the top of the raceme and are usually raised above the terminal buds. Turnip flowers are small and have four light-yellow petals.

IV. Environment Requirements:

A. Climate:

Brassicas are both cold-hardy and drought-tolerant. They can be planted late-even as a second crop-and provide high-quality grazing late in the fall. Turnip planted in July will provide grazing from September to November. The most vigorous root growth takes place during periods of low temperature (40 to 60¡F) in the fall. The leaves maintain their nutritional quality even after repeated exposure to frost.

B. Soil:

Like other Brassicas, turnip grows best in a moderately deep loam, fertile and slightly acid soil. Turnip does not do well in soils that are of high clay texture, wet or poorly drained. For good root growth turnip needs a loose, well aerated soil.

V. Cultural Practices:

A. Seedbed Preparation:

Turnip seed is small and it is essential that it be seeded into a fine, firm seedbed with adequate moisture for germination. Plow and disk or harrow to produce a seedbed that is fine, firm and free of weeds and clods.

Turnip, like other Brassicas, can also be seeded into a sod or into stubble of another crop with minimum tillage. When seeding into sod, it should be suppressed or killed, as the young Brassica seedlings cannot compete with established grasses. To kill sod, apply 2 qt/acre of Roundup at least three days prior to seeding. A 0.5 qt/acre rate of Roundup can be used in 3 to 10 gal water/acre to suppress sod or to prepare a field of wheat stubble for seeding with turnip. Once established, turnip will compete with most weeds.

The advantages of direct drilling turnip into sod include fewer crop losses due to insect pests, such as the flea beetle, and less soil erosion on sloping sites where pastures are often located. A field of turnip established in sod gives animals a firm footing in all kinds of weather. It also allows the original sod to grow again the following spring if it has only been suppressed.

B. Seeding Dates:

Turnip seed does not germinate well in cold soil. Turnip should not be planted until the soil temperature is at least 50¡F or at corn planting time. The crop can be planted any time during the summer until about 70 days before a killing frost (August I in the southern half of Wisconsin. earlier elsewhere in Wisconsin and in Minnesota). Plantings after these dates may not have sufficient time to produce good forage growth.

C. Method and Rate of Seeding:

Turnip seed can be planted in 6 to 8 in. rows at a rate of 1.5 to 2.5 lb/acre with a minimum-till drill when sod seeding. In conventionally prepared seedbeds, the crop can be seeded with a forage crop seeder or broadcast followed by cultipacking. The seed should not be covered with more than 1/2 in. of soil. A plant population of 5 to 6 per sq. ft. is desirable.

D. Fertility and Lime Requirements:

Good soil fertility is very important for good yields. Soil tests should be taken to assure proper fertilization. Lime acid soils to pH 6.0. Fertilizers should be applied at the time of seeding or within 3 days of seeding to give the crop a competitive edge on weeds. Apply 100 lb/acre nitrogen to soils containing 2 to 5% organic matter, 120 lb/acre if less than 2% organic matter and 60 to 80 lb/acre if more than 5% organic matter. Requirements for phosphorus and potassium are similar to those of a small grain. In Wisconsin and Minnesota, when soil tests are in the medium range, about 20 to 30 lb/acre of P_2O_5 and 120 lb/acre of K_2O should be applied. Fertilizer applications should be banded at least 2 in. to the side and below the seed or broadcast. Boron and sulfur may also be needed. If the soil tests "low" in boron, apply 1 lb boron/acre on sandy soils, and twice this amount on other soils. Apply 10 to 15 lb of S/acre if a soil sulfur test indicates a need for this element.

E. Variety Selection:

Three forage turnip varieties are recommended for use in the Upper Midwest: Green Globe, and York Globe from New Zealand and Sirius turnip from Sweden. In Pennsylvania, Green Globe and York Globe yielded more than Sirius at 60 days after planting, but Green Globe reached its peak yield later than the other two. Sirius yields were more variable from year to year than Green Globe or York Globe. The tops and leaves of Sirius have less glucosinolate than the other two varieties.

F. Weed Control:

Weeds are generally not a problem once the turnip crop is established. However, sod and annual weeds should be controlled chemically and/or culturally before planting. Sod can be suppressed or killed with Roundup, as described under Seedbed Preparation. If annual weeds are present at planting time, eliminate them with a burndown herbicide such as Gramoxone. Tillage before planting can be used for weed control on a conventional seedbed.

G. Diseases and Their Control:

Turnip crops may suffer from clubroot, root knot, leaf spot, white rust, scab, anthracnose, turnip mosaic virus and rhizoctonia rot. in some cases, diseases can lead to crop failure if rotation or other control measures are not used. Resistant varieties are available for some diseases. To prevent problems with diseases, Brassicas should not be grown on the same site more than two years in a row. If clubroot is a problem, rotation should be six years.

H. Insects and Other Predators and Their Control:

Turnip crops are attacked by two different flea beetles, which eat holes in the cotyledons and first leaves, chew stems and cause extensive plant loss. The cabbage flea beetle and the striped flea beetle feed exclusively on Brassicas, including related weeds such as yellow rocket. Problems with these flea beetles are much greater when Brassicas are grown under conventional tillage. Both flea beetles can be controlled with insecticides applied to the soil at planting.

Turnip crops can also be damaged by infestations of the common turnip louse or aphid. This insect feeds on the undersides of the leaves and may be so close to the ground that it is difficult to reach with a dust or a spray. In cases of severe infestation, the outer leaves curl and turn yellow. Aphid-tolerant varieties such as 'Forage Star' can give some protection against this insect.

I. Harvesting:

Turnip plants are ready for grazing or green-chop when the forage is about 12 in. tall (70 to 90 days after planting). It is best not to wait too long because fungal diseases may begin to cut yields approximately 110 days after planting. The pasture should be grazed for a short time and the livestock removed to allow the plants to regrow. If grazed to a 5 in. stubble, 1 to 4 grazing periods may occur, depending on planting date and growing conditions. Strip or block-grazing is desirable to insure complete grazing.

The forage quality of turnip is sufficiently high, especially in protein, that it should be considered similar to concentrate feeds, and precautions should be taken to prevent animal health problems. Livestock should not be hungry when put on pasture the first time so they do not gorge themselves. If the livestock are moving from a feed low in nutritional value, feed a high-quality diet for two to three weeks prior to grazing turnip, or feed turnip for 30 min/day for one week prior to heavier grazing. This will allow for the development of a rumen microbial population that is adequate to digest the high levels of protein in forage turnips. A lower quality hay should be made available (2 to 3 lb of dry roughage/head/day for sheep and 10 to 15 lb for cattle) to provide some fiber in the animals' diet.

Livestock should not feed on turnip during the breeding season or after the plants have begun to flower. Nitrate nitrogen toxicity can be a problem, especially if ruminants are allowed to graze on immature crops or if soil nitrogen levels are high. The risk may remain for a longer period of time in autumn than in summer. Dairy cows should not be fed more than 50 lb turnip/head/day and should not be milked immediately after feeding on turnip to avoid milk tainting.

VI. Yield Potential and Performance Results:

Yields of forage turnip range between 3 and 4 tons of dry matter/acre when harvested or grazed about 90 days after planting. Up to 1,000 grazing days/acre for 900 lb steers and 2,300 grazing days/acre for 90 lb lambs have been obtained for Forage Star turnip.

VII. Economics of Production and Markets:

Turnip is a highly nutritious forage crop that has a short growing season and can provide late fall grazing after other forage crops are finished for the year. Seed prices range from $1.50/lb for garden-variety turnips to about $8/lb for some new hybrid varieties.

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Jerusalem Artichoke

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I. History:

Jerusalem artichoke (*Helianthus tuberosus* L.) is familiar to many as a weed, but has some potential as a crop plant. Native to the central regions of North America, the plant can be grown successfully throughout the U.S. under a variety of temperature and rainfall regimes. Several North American Indian tribes used Jerusalem artichoke as food prior to the arrival of European settlers. The explorer Champlain took Jerusalem artichokes from North America to France in 1605. By the mid 1600s it was widely used as a human food and livestock feed there.

In France, the artichoke is called "topinambour," although the word "Jerusalem" has several explanations. The artichoke became a staple food for North American pilgrims and was thought of as a new feed in a "new Jerusalem." A second theory is that the word Jerusalem is a twisting of the Italian word for sunflower-girasol. One additional explanation involves a 17th century gardener named Petrus Hondins of Ter-Heusen, Holland who was known to distribute his artichoke apples throughout Europe. Ter-Heusen was modified to Jerusalem in the United States. In recent years the fresh tubers have been widely marketed in the U.S., but in quite limited quantities.

II. Uses:

The plant can be grown for human consumption, alcohol production, fructose production and livestock feed.

A. Human Food:

Similar to water chestnuts in taste, the traditional use of the tuber is as a gourmet vegetable. Jerusalem artichoke tubers resemble potatoes except the carbohydrates composing 75 to 80% of the tubers are in the form of inulin rather than starch. Once the tubers are stored in the ground or refrigerated, the inulin is converted to fructose and the tubers develop a much sweeter taste. Dehydrated and ground tubers can be stored for long periods without protein and sugar deterioration. Tubers can be prepared in ways similar to potatoes. In addition, they can be eaten raw, or made into flour, or pickled.

They are available commercially under several names, including sunchokes and lambchokes.

B. Alcohol Production:

In France the artichoke has been used for wine and beer production for many years. Ethanol and butanol, two fuel grade alcohols, can be produced from Jerusalem artichokes. The cost of producing ethanol currently is not competitive with gasoline prices, and therefore the success of ethanol plants has been limited.

C. Fructose Production:

About 50% of the 12 million tons of sugar consumed annually by Americans is grown and produced in the United States. Fructose is more soluble in water than sucrose, so fructose provides a more desirable syrup. In addition, it is 1.5 times sweeter than sucrose and can be consumed safely by diabetics.

The majority of domestically produced fructose is obtained from corn. Although the Jerusalem artichoke is a viable fructose source, the U.S. sugar industry has been hesitant in utilizing it because farmers have been concerried with its potential as a weed problem, and because it requires extra planting and harvesting equipment along with storage difficulties.

D. Forage Production:

The quality of artichoke tops make them a suitable livestock feed, but the forage quality has no advantage over other forage crops and should be classified as a maintenance feed. Both crude protein and digestible protein concentrations are low when compared with alfalfa (Table 1). Artichoke tops are superior in TDN to the perennial forages listed, but it has less TDN than corn silage.

Optimal forage quality can be obtained by harvesting tops during mid September when protein levels will be at their maximum. However, tuber yields will be reduced at this time (Table 2). The smaller size may make the tubers unharvestable. For greater tuber production it is more advantageous to harvest the tops after a hard frost. Protein levels in the forage will be reduced, but will still provide an acceptable feed. Roots, tubers and tops can be fed as a combined ration. Tops can be fed fresh or ensiled, although the forage does not ensile well because of its high concentration of soluble sugars and high moisture content. The potential advantage of the crop for forage may arise from the fact that it adapts well to a wide variety of soils and habitats.

Table 1. Feeding value and forage quality characteristics of Jerusalem artichoke tops and tubers and other selected forages.

Forage	DM[1]	TDN	DP	CP	CF

	%				
Jerusalem artichoke tops	27	67	3	5	18
Jerusalem artichoke tubers	21	78	6	10	4
Alfalfa, full bloom	91	53	10	14	35
Smooth brome, post bloom	94	46	2	6	33
Corn silage	29	70	5	8	22
Beet pulp	91	75	5	10	21

Morrison. Feeds & Feeding p. 1018 22 ed.
IDM - Dry matter, TDN - Total digestible nutrients, DP - Digestible protein, CP - Crude protein, CF - Crude fiber.

Table 2. The effect of top harvest on top and tuber yield of Jerusalem artichokes in 8-row, 30-foot plots on peat soil at North Branch, MN - 1981.

Cutting Scheme*	Top Fresh Wt (lb/acre)	Tuber Fresh Wt (lb/acre)	Fresh Wt/Tuber (%)	Total Dry Wt (lb/acre)
1	25637	1429	30.5	3298
2	23961	1457	-	3533
3	40584	1407	14.0	5689
4	5772	10654	57.5	7591
LSD	2990	874	31	474

*1 - Top harvest in early August
2 - Top harvests in early August and early September
3 - Top harvest in early September
4 - No top harvest prior to maturity
Source: Waters, et. al., University of Minnesota

III. Growth Habits:

The Jerusalem artichoke is a perennial with tuber bearing rhizomes. Stems are stout, pubescent and grow 3 to 12 ft in height. The leaves range from 114 to 3 in. wide and 4 to 8 in. in length. The plant bears many yellow flower heads in late August and September that are approximately 11/2 to 3 in. in diameter. The thick, rough textured leaves have coarse hairs on the upper surface and fine pubescence underneath. They are opposite on the lower part of the plant and alternate on the upper portion.

The tubers vary from knobby to round clusters, range from red to white in color, and are rougher in conformation than potato tubers. Cultivated varieties yield white tubers that are clustered near the main stem in contrast to wild types which produce reddish elongated tubers at the end of long rhizomes.

IV. Environment Requirements:

A. Climatic:

Most cultivars require a growing season of at least 125 frost-free days. Optimum yields are obtained where temperatures range from 65 to 80°F. Rainfall of 50 in. or less is required. In dry areas irrigation may be necessary to begin germination.

B. Soil:

Although the plant adapts well to a wide range of soil types and pH levels, artichoke production is favored by slightly alkaline soils. Yields are poor on heavy clays, particularly if there is waterlogging. Tuber and top yields are limited if soil moisture is less than 30% of field capacity during the tuber formation period (early September to November).

C. Seed Preparation and Germination:

Tubers sprout approximately 10 to 17 days after planting, but soil temperatures must be at least 44°F before germination begins. Jerusalem artichokes are propagated vegetatively by the use of sound, disease-free small tubers or pieces of tubers weighing approximately 2 oz and having at least 2 to 3 buds each.

V. Cultural Practices:

A. Method and Rate of Seeding:

Recommended planting rates of 1,000 lb/acre of seedstock tubers yield between 10,000 to 14,000 plants/acre. The tubers and tuber pieces are cut to approximately I to 2 oz in size and planted 12 to 24 in. apart with 30 to 36 in. between rows.

Table 3 shows yields of two varieties at two plant populations in 3 row, 20 ft plots in Minnesota. Fresh weight yields were higher with 18 in. × 12 in. spacings (29,040 tubers/acre) than 36 in. × 24 in. spacings (7,260 tubers/acre). These studies were conducted using 2 oz tuber pieces. Further Minnesota studies have indicated no difference in yield between 1 and 2 oz tubers; however, 1 oz tubers may be more susceptible to dessication in dry soils.

Table 3. Tuber yield of two Jerusalem artichoke varieties in two plant populations on sand soil at the Staples Irrigation Center, Staples, MN - 1981.

Variety	Spacing (in)	Tuber Fresh Wt (lb/acre)	Dry Wt/Tuber (g)
Mammoth French White	36 × 24	9791	9.1
Mammoth French White	18 × 12	16011	5.6
Columbia	36 × 24	24442	10.5
Columbia	18 × 12	34503	6.0
LSD		6331	1.8

Source: Waters, et. al., University of Minnesota

Planting depths are similar to potatoes. Tubers should be covered by 2 to 4 in. of soil. Hilling is recommended to increase moisture retention and to concentrate the tubers for easier harvesting. Because it is difficult to remove all of the tubers during harvest, additional planting may not be necessary in the second year.

B. Fertilization:

University of Minnesota trials on irrigated, leached sand soil have found increases in tuber yield in response to nitrogen rates of 60 and 120 lb/acre (Table 4). Yield increases in response to potassium were observed at rates of 150 lb/acre, but only at high nitrogen rates. Fertility programs similar to that of potatoes are suggested as a starting point for artichokes.

Table 4. Response of Jerusalem artichokes to nitrogen (N) and potassium (K) fertilizer on leached, sand soil at the Staples Irrigation Center, Staples, MN - 1981.

Fertilizer Applied (lb/acre)		Tuber Wt (lb/acre)	Dry Wt/Tuber (g)
N	K		
0	0	9082	7.8
0	150	8467	8.7
60	0	11243	9.6
60	150	11831	11.4
120	150	13129	11.4
LSD		1520	3.2

Source: Waters, et. al., University of Minnesota

C. Varieties:

Many varieties of Jerusalem artichoke exist worldwide. Popular varieties in the U.S. and yields in Minnesota in, small plot trials are listed in Table 5.

D. Weed Control:

1. **Mechanical:** Jerusalem artichoke plants are extremely vigorous and will compete strongly with weeds. An early season cultivation is recommended to reduce emerging weeds, with a subsequent tillage operation to improve hilling of rows.
2. **Chemical:** There are no herbicides currently registered for use in Jerusalem artichoke.
3. **Control of Jerusalem Artichokes in Subsequent Crops:** Tubers over-winter very well in the soil. As a result, volunteer Jerusalem artichokes can be a serious weed problem in the following crop. It spreads into other crops, and will grow even taller than corn. One possible herbicide treatment to eliminate Jerusalem artichoke is Roundup (glyphosate). [Glyphosate should be applied in the fall to plants which were undisturbed all season]. Some Jerusalem artichokes will probably still escape and require treatment in subsequent years. 2,4-D and Banvel are effective herbicides for control of Jerusalem artichoke.

E. Disease and Their Control:

Few diseases are reported to affect Jerusalem artichoke. The primary disease is Sclerotinia (white mold), which can cause early wilt, stalk rot and degradation of the tubers. This pathogen also can cause severe yield reductions in dry edible bean, sunflower, and soybean.

If possible, susceptible crops should be rotated with small grains or corn. Avoid close rotations with dry edible beans, sunflowers, safflower, mustard and soybeans. Diseases such as downy mildew, rust and southern stem blight have been reported but have not been of economic concern. No fungicides are currently labeled for Jerusalem artichokes.

F. Insects and Their Control:

Insects have not been serious problems, but the potential is greater if large acreages develop. Stalk boring insects have been observed, but have caused limited damage. No insecticides are currently registered for use on the crop.

G. Harvesting:

Harvesting the tuber crop is similar to potatoes, with a few exceptions. The potato vine is weak and usually has senesced before harvest, which is in contrast to the continued growth of the strong artichoke stems. Potato tubers separate easily from the stems, while the large mass of artichoke tubers are strongly attached and intertwined with the roots. By adding small chains and increasing agitation, you can convert a potato digger to a Jerusalem artichoke digger. Artichoke tubers are smaller than potatoes, so these modifications are necessary to decrease the potential 50% loss that may occur with a conventional potato digger. Tops, roots, and tubers can be sorted as they are harvested, or they can be dried and then sorted. Artichoke tubers will wilt and soften much faster than potato tubers and thus cannot be left at low humidities too long before storage.

H. Storage:

Tubers can be harvested in the fall or left in the ground for winter storage and spring harvest. Tubers should be stored at 33 to 340 F and at very high humidity. Spoilage is more prevalent with diseased, bruised, or skinned tubers. Tubers that are kept for seed should not be frozen in storage.

VI. Yield Potential and Performance Results:

Typical tuber yields are approximately 15 ton/acre, with a range of 5 to 25 ton/acre. The variety and time of harvest determine the yields for both the tops and tubers. Total per plant yield ranges between 4 to 8 lb for tops, 3 to 6 lb for tubers, and 1 to 2 lb for roots.

Table 5. Tuber yield of four Jerusalem artichoke varieties in 3-row, 20-foot plots at Staples, MN - 1981.

Variety	Tuber Fresh Wt (lbs/acre)	Tuber Dry Wt (lbs/acre)	Dry Wt/Tuber (g)
Columbia	22398	5769	15.7
Mammoth (MN)	8628	2166	9.3
Oregon	12477	3096	11.4
Mammoth	11159	2784	9.7
LSD	2612	552	5.2

Source: Waters, et. al., University of Minnesota

VII. Economics of Production and Markets:

A. Economic Factors:

Economic considerations for artichoke production will depend on numerous factors, including equipment and labor costs. Differences in variable and fixed costs make it difficult to estimate production expenses, but costs may range from $ 1,000/acre for seed, $60 to 150/acre for custom cutting and planting, $25 to 50/acre for custom cultivation, and $250 to 400/acre for custom harvesting. Additional expenses can include storage, transportation, and supplemental seedstock.

B. Market Potential:

The seedstock market for Jerusalem artichoke tubers is speculative and should not be relied on as an outlet. Between 1980 and 1982, the largest market was for seed tubers, which required a constant expanding production. Currently, the only stable market is a limited one for the tubers as a gourmet vegetable.

Market viability depends on the development of processing technology and the economic feasibility of such facilities. Consumer demand and a stable price for tubers are additional factors that contribute to its acceptability. Try to locate a guaranteed market and price before growing the crop.

VIII. Information Sources:

- The Tropical Tuber Crops. 1978. L C. Onvueme, Wiley, NY.
- Tropical and Subtropical Agriculture. Vols. I and 11. 1961. J. L Ochse, et al., MacMillan Co.
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Lentil

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I. History:

Lentil (*Lens culinaris* Medik.) may have been one of the first agricultural crops grown more than 8,500 years ago. Production of this cool season annual crop spread from the Near East to the Mediterranean area, Asia, Europe and finally the Western Hemisphere. It may have been introduced to the United States in the early 1900s. The crop has received little research attention to improve its yield and quality. It grows well in limited rainfall areas of the world.

Lentil is a pulse (grain legume) crop. In North America much of the acreage is in eastern Washington, northern Idaho, and western Canada where drier growing season conditions prevail. It has been grown in that area since the 1930s as a rotation crop with wheat. Most of the lentil production in the United States and Canada is exported, but domestic consumption is increasing.

II. Uses:

Lentil is a protein/calorie crop. Protein content ranges from 22 to 35%, but the nutritional value is low because lentil is deficient in the amino acids methionine and cystine. Lentil is an excellent supplement to cereal grain diets because of its good protein/carbohydrate content. It is used in soups, stews, casseroles and salad dishes. Sometimes they are difficult to cook because of the hard seed coat that results from excessively dry production conditions.

Lentils which fail to meet food grade standards (graded #3 or below) can be used as livestock feed because of their high protein content and lack of digestive inhibitors.

Lentil can be used as a green manure crop and one particular Canadian variety, Indianhead, provides a large amount of fixed nitrogen (estimated to be 20 lb/acre).

III. Growth Habits:

Lentil plants are slender, semi-erect annuals with compound leaves (4 to 7 pairs of leaflets) with a tendril at the tips. Plants normally range from 12 to 20 in. tall, the taller plants resulting from cool growing season temperatures, good moisture and good fertility.

Plants can have single stems or many branches depending upon the population in the field.

Flowering begins on the lowest branches, gradually moving up the plant and continuing until harvest. Each flower produces a short pod containing one or two lens-shaped seeds. Flowers can be white, lilac or pale blue in color and are self-pollinated. At maturity plants tend to lodge because of their weak stems.

Lentil produced in North America has larger seeds than that from India and the Near East. The seeds (2 to 7 mm in diameter) come in colors of tan, brown, or black, and some varieties produce purple or black mottled seeds. Lentil seed number varies from 15,600 to 100,000 seeds/lb.

IV. Environment Requirements:

A. Climate:

Lentil is adapted to cool growing conditions, and the young plants are tolerant of spring frosts. This allows for early spring planting dates.

Lentils have been grown extensively in the semi-arid parts of the world, where they have slightly lower yields, but good seed quality. High humidity and excessive rainfall during the season encourages vegetative growth, which prevents good yield and can reduce seed quality. Ten to twelve in. of annual rainfall will produce high yields of good quality seed. Excessive drought and/or high temperatures during the flowering and pod-fill period also reduce yields.

B. Soil:

Lentil is adapted to all soil types, from sand to clay loam, if there is good internal drainage. Lentil does not tolerate flooded or waterlogged soils, and does best on deep, sandy loam soils high in phosphorus and potassium. Good drainage is required, because even short periods of exposure to waterlogged or flooded field conditions kill plants. A soil pH near 7.0 is best for lentil production.

C. Seed Preparation and Germination:

Unless nodulated field pea or lentil has been grown recently on a field, the seed should be inoculated with *Rhizobium leguminosarum* just prior to planting (within 24 hours). Follow the instructions for inoculation, and protect treated seed from high temperatures and drying winds until planted. Various forms of inoculant are available, some of which can be placed in the furrow with the seed.

Good quality lentil seed does not need to be treated with insecticides or fungicides, because it germinates rapidly and seedlings emerge quickly. Seed treatment compounds can interfere with the nodulation process.

V. Cultural Practices:

A. Seedbed Preparation:

A firm, smooth seedbed with most of the previous crop residue incorporated is best for lentil. Uneven surfaces, large clods, rocks or protruding crop residue can interfere with seed placement and complicate later swathing and combining.

B. Seeding Date:

Lentil should be seeded in late April to early Mail when small grain is being planted. Later seeding dates produce shorter plants and late maturing pods which increase harvest losses.

C. Method and Rate of Seeding:

Lentil should be planted 1 1/2 in. deep, but this can be increased to 2 1/2 in. when the upper layers of soil are excessively dry at planting time. Because of the small seed size of some varieties, lentil cannot emerge if planted too deep or if the soil has crusted extensively. Lentil has hypogeal emergence, which means that the growing point emerges but the cotyledons remain in the soil.

Seeding rates vary depending upon seed size, but a target population of 400,000 plants/acre should be reasonable. This could require between 30 and 80 lb/acre of seed, depending upon variety and seed size. This would provide about 20 plants/square ft.

Because of the fragile growth habit of lentil and the fact that the crop does not compete well with weeds, the best yields are from fields planted with a grain drill which can ensure proper depth and distribution as well as good seed-soil contact. Because of seed size variation, care must be taken to calibrate the drill properly.

D. Fertility and Lime Requirements:

Inoculation with the proper *Rhizobium* will provide the nitrogen requirements of lentil. However, if available nitrogen is low (organic matter less than 2%), an early nitrogen supplement of about 30 to 40 lb/acre is required to sustain the young plants until root nodulation develops. If applied as starter, this material should be applied adjacent to but not in contact with the seed. Smaller amounts of N (10 to 30 lb/acre) may provide some benefit on higher organic matter soils, especially where drainage is somewhat restricted. Care should be taken not to provide too much nitrogen, which could inhibit nodulation and produce excessive vegetative growth at the expense of seed yield.

As for most legumes, sulfur needs are medium to high, and responses may be seen on light colored sandy soils where manure has not been applied.

Phosphorus and potassium are recommended for maximum yields on soils testing medium or low. Optimum soil tests range 15 to 30 ppm (30 to 60 lb/acre) for P and 90 to 120 ppm (180 to 240 lb/acre) for K for most soils. Band applications of P may be of some benefit on very low P or high pH (above 7.6) soils.

Lime needs for lentil have not been well established. However, it is likely similar to that of other leguminous vegetables - 6.0 on mineral soils and 5.6 on organic soils.

E. Variety Selection:

Growers should consider maturity, growth habit, seed size and color as well as yield potential when selecting a variety of lentil. Currently buyers prefer lentils with larger seeds that are light in color and without mottling on the seed coat.

Several varieties have been tested in research conducted by University of Minnesota scientists. (See Table 1 for performance data of these varieties.)

The USDA Plant Introduction Station at Pullman, Washington, has tested large numbers of lines from all over the world and scientists there continue to evaluate and develop new varieties. Some of the Canadian research centers also are releasing new varieties. For the latest information on new and old variety performance, contact your local extension office or crop consultant.

Table 1: Characteristics and seed yield of Lentil varieties.

Variety	Grand Rapids 1982-85 (lb/acre)	Crookston 1981, 85 (lb/acre)	Becker[1] 1982-84 (lb/acre)	Seeds (no./lb)	Seed Protein (%[2])	Height (in)	Lodging (score[3])	Days from planting to	
								bloom	maturity
Brewer[4]	943	2031	1357	8,890	27.4	18	4.9	60	111
Chilean 78[5]	750	---	1226	9,650	26.5	19	4.8	61	110
Eston	1029	1733	1650	15,120	25.1	17	3.4	63	113
Jasper[6]	1043	1525	---	15,120	26.5	17	3.8	63	116
Laird[7]	343	1344	820	7,440	24.2	21	3.5	67	115
Primera[6]	554	1895	---	5,670	28.3	18	4.9	64	119

Red Chief[4]	757	1673	1574	9,070	26.7	18	5.6	60	111

[1]irrigated; [2]oven-dry; [3]1=erect, 9-flat; [4]1982-85; [5]1982-84; [6]1985; [7]1981-84.

F. Weed Control:

Lentil is not very competitive (especially as seedlings) with many of the grasses and/or broadleaf weed species that infest farm fields, so weed control before planting and early in the growing season is critical.

Mechanical: Harrowing or rotary hoeing fields after emergence is recommended only if there is a serious weed problem. Because of the slender early stem growth, the plants are easily damaged at this time. If harrowing or hoeing is planned, be sure to use the recommended seeding rates discussed earlier because the plant stand will be reduced slightly along with the weeds. Rotary hoeing is normally done 7 to 10 days after seeding.

Chemical: Roundup (glyphosate) can be used as a preplow treatment in the fall or spring to control quack grass. Apply 1 qt/acre in 5 to 10 gal/acre of water when the quackgrass is 6 to 8 in. tall and actively growing. Fall treatment is encouraged, as planting will be delayed with spring applications. To control annual grasses, Poast (sethoxydim) can be used in postemergence treatment when the grasses are 4 to 6 in. tall. A rate of 1 pt/acre controls many annual grasses; check the label and select the rate appropriate for your weed species. Always use 1 qt/acre of Dash or a crop oil concentrate when Poast is applied.

G. Diseases and Their Control:

Because most of the lentil production in the United States is in the dryer, less humid environments of the west, the crop is relatively free from major diseases.

Ascochyta blight, *Sclerotinia* (white mold), *Fusarium* root rot and *Rhizoctonia* root rot are possible disease problems for lentil. Since no effective treatment is available for these diseases, crop rotation is the most effective method of preventing a disease problem.

Avoid fababean, fieldbean, field pea, mustard, canola, rapeseed, soybean, sunflower, sugar beet and potato in too close a rotation, because these crops are susceptible to the same diseases. Corn and small grains are good rotation crops in conjunction with lentil. Some scientists feel a three to four-year rotation away from lentil is best for reducing disease problems. Always use good quality disease-free seed to prevent introduction of disease into clean fields.

H. Insects and Other Predators:

Lentil can be attacked by aphids, thrips, Lygus bugs, seedcorn maggots and wireworms, but major problems from these insects are seldom noted. If a serious problem is developing in a field, you should consult your local Extension office for information about obtaining threshold values and recommendations for control.

I. Harvesting:

Lentil should be swathed when plants begin to turn yellow and the lower pods become brown to yellow-brown in color. This will occur within several days and should be carefully watched, as pods can readily shatter. Lentil should be swathed when there is sufficient moisture to toughen the pods. Swathing should not be done during hot, dry periods of the day.

Lentil has a weak stalk and tend to lodge badly. This means that low cut is required in order to minimize losses. Windrowing can be a very slow and difficult operation. A dry field surface which is level, firm and free of stones is necessary to reduce harvesting difficulties. A pick-up reel and lifter guards are very helpful when windrowing. A floating cutterbar mounted on a windrower can further minimize windrowing losses and difficulties.

Depending on the weather, windrowed lentil may take a week or more to dry down. Since the lentil windrow has no strong stubble to hold it off the ground, air circulation through the windrow is poor. This may result in seed discoloration and mold development during periods of extended wet weather.

Lentils are considered dry at 14% moisture content. Combining at this moisture level can result in high losses and damaged seeds. It may be advisable to combine at a higher moisture content of 18 to 20%, and dry artificially.

If the field is uniformly mature, it is possible to combine lentil directly. This should only be attempted at moisture levels of 18 to 20%, to prevent excessive preharvest shattering. A combine equipped with a floating cutterbar should be used to minimize header losses.

Once in the combine, lentils thresh easily. Compared to wheat settings a slower cylinder speed is necessary to prevent cracking, and the concaves should be set wider. Initial wind and sieve settings for wheat may be used.

J. Drying and Storage:

If lentil seed is harvested at moisture contents greater than 14%, it will have to be dried to prevent heating and molding in storage. It is best to let the seed dry down in the field, if the drier plant material can be handled by the combines without major losses due to shattering of the pods.

Lentils can be dried in heated air dryers, but a maximum temperature of 110°F is recommended to reduce cracking of seed coats. Natural air drying has advantages over heated air, but proper design of the system is necessary. The design must ensure good airflow through the seed, which usually means that thinner layers of the seed must be used in this process.

VI. Yield Potential and Performance Results:

Yields vary with variety, management and environmental conditions. Under good research management and excellent growing conditions, lentil has yielded in excess of 2,000 lb/acre. In production fields growers should be able to expect 1,000 to 1,500 lb/acre yields. Yields in research trials in Minnesota (see Table 1) have ranged from 343 to 2,031 lb/acre, depending upon variety and location.

VII. Economics of Production and Markets:

The price of lentil has varied widely in recent years, ranging from $.15 to $.35/lb. This is a direct reflection of the volatile nature of world prices for this commodity. With favorable prices, lentil has provided a very attractive alternative crop for good producers. Seed damage, presence of foreign material and high moisture content will reduce the grade of lentil and result in a lower price. As with other specialty crops, growers should always locate markets and delivery points and determine a suitable price before planting a new crop.

VIII. Information Sources:

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- Growing Lentils in Washington. 1968. Extension Bulletin 590, Cooperative Extension Service, Washington State University, Pullman, WA.
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Lupine

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I. History:

Lupine cultivation is at least 2,000 years old and most likely began in Egypt or in the general Mediterranean region. The lupine plant, like other grain legumes (beans, peas, lentils, etc.) fixes atmospheric nitrogen, and produces seed high in protein. There are over 300 species of the genus *Lupinus* (L.), but many have high levels of alkaloids (bitter tasting compounds) that make the seed unpalatable and sometimes toxic. Historically, lupine alkaloids have been removed from the seed by soaking. But plant breeders in the 1920's in Germany produced the first selections of alkaloidfree or "sweet" lupine, which can be directly consumed by humans or livestock. White lupine (*L. albus* L.), yellow lupine (*L. luteus*), and blue or narrow-leafed lupine (*L. angustifolius*) are cultivated as crops. Lupines are currently grown as a forage and grain legume in USSR, Poland, Germany, the Mediterranean, and as a cash crop in Australia, where it is exported to the European seed markets. Both winter-hardy and non-hardy types are available.

II. Uses:

A. Nutritional Value:

Sweet white lupine is high in protein (32–38%), low in oil (10%), TDN (75–80%), and does not contain trypsin inhibitors. The seed can be fed directly without heat treatment and has been successfully fed to turkeys, calves, lambs, swine and lactating dairy cattle. Methionine is a limiting amino acid and may be required in rations for poultry and swine.

When animals graze lupine stubble, a disease called lupinosis can develop. It is caused by a mycotoxin. Symptoms are loss of appetite and jaundice. Lupinosis has been a problem in sheep grazing in Australia and in Europe.

B. Dairy:

In Minnesota trials, a complete replacement of soybean meal with lupine meal for dairy cows resulted in a reduced feed intake and a slight reduction in milk production. The current recommendation is that lupine can replace up to 65% of the soybean meal (10% of the total mix) in a diet. Calves fed ground lupine as the only supplemental protein source in starter diets showed no decrease in production compared to a soybean meal diet.

C. Lambs:

Lambs fed whole lupine seed grew at the same rate as lambs consuming soybean meal at the same level of protein, indicating that lupine can replace up to 100% of the soybean meal in lamb diets.

D. Swine:

Current Minnesota recommendations are that white lupines are unacceptable for growing pigs (under 225 lbs). A 1988 Minnesota study reported a 2% reduction in feed intake for each 1% lupine in the diet. This translated directly into a reduction in gain. Pigs are quite sensitive to alkaloids and palatability can be a problem when alkaloid levels exceed 0.04% of diet dry matter (most sweet lupines are less than 0.03%). Even at this level, feed intake of lupine diets can be severely reduced due to a problem with palatability. Better feeding has resulted from using the yellow and blues lupine species.

E. Poultry:

Turkey rations containing up to 15% lupine in the diet have not decreased production compared with soybean meal diets. Larger quantities result in reduced feed intake and gain, probably because of fiber content. Methionine should be added as a supplement.

F. Food for Humans:

The United States has a developing specialty human food market for lupine in the form of lupine flour, lupine pasta, and hulls for dietary fiber. Sweet lupines have been shown to increase the protein and fiber crops in conjunction with durum wheat in specialty pastures, and to be an excellent source of white-colored fiber, as an additive to breads and cereals.

III. Growth Habit:

The growth habit of lupine is different from other grain legumes. Emergence is epigeal (cotyledons emerge above ground before development of true leaves), and early seedling growth is considerably slower than later vegetative stages. Maximum vegetative growth rate occurs during flowering. The main stem and each branch usually terminate in an inflorescence, which is a simple raceme with varying numbers of flowers. Even aher the main stem flowering has ceased, the plant can develop lateral secondary as well as tertiary flower sets from a sequence of lateral branches. Species and cultivars differ in ability to set pods on these secondary and tertiary branches. The process is highly influenced by environmental conditions.

IV. Environment Requirements:

A. Climate:

Lupine is a cool-season crop, and is relatively tolerant of spring frosts. The flowering process is affected by high temperatures which cause blasting of flowers and a subsequent yield reduction. In areas which normally experience high temperatures in early summer, such as many parts of southern Minnesota and Wisconsin, the risk to the crop is great.

B. Soil:

Lupine is adapted to well-drained, coarsely textured, neutral to acidic soils. Iron chlorosis and disease problems often result from plantings on poorly drained, higher pH soils. Reports from Minnesota, New York and parts of New England indicate that many lupine production problems are due to planting on soils too heavy, too wet, or too high in pH. An area of adaptation in central Minnesota on the more acidic, better drained soils has been identified, as have other localized areas in the state. Many alkaline soils with high clay content are considered inappropriate for lupine production.

V. Cultural Practices:

B. Seeding Date:

Results from trials conducted in Minnesota and Wisconsin (Table 1) show that planting in early to mid-April results in maximum grain yields. Large yield reductions from plantings after early May have been reported at several locations. The primary requirement is to plant early enough to complete flowering before the excessive heat of early summer. Planting too early, when cold affects the seed, can sometimes result in vernalization which causes a determinant growth habit, reduced plant growth, and lower yield. Since the importance of this process is poorly understood, it is recommended that growers plant in mid-April in most of Minnesota & Wisconsin, but when freezing temperatures begin moderating.

Table 1: Date of seeding effect on lupine yield. Minnesota and Wisconsin.

		Seeding Date			
Location	Year	April 10–15	April 28–May 2	May 16–20	June 5–20
		bu/A[1]			
Staples, MN	1985	--	54	33	0
Staples, MN	1986	17	67	37	0
Staples, MN	1987	52	28	17	0
Arlington, WI	1988	30	15	0	--

Marshfield, WI	1988	15	11	0	--

[1]60 pounds/bushel

C. Method and Rate of Seeding:

Yield increases between 37–110% have been achieved in Minnesota and Wisconsin trials by narrowing row spacing from 30" to 6". Lupine planted in narrow rows has also been reported to mature earlier. But since lupine can be susceptible to weed infestations, some growers may need to use wider row spacings to allow for cultivation.

Seeding rates of 6 plants/ft^2 (255,000 seeds/A or 170 lbs/A) for narrow rows and 70–80 lbs/A in wider (30") rows are recommended to maximize yield and compete effectively with weeds. Slightly higher yields or improved plant population result from higher seeding rates, but high seed costs encourage lower seeding rates. White lupine has very large seed so planting equipment must handle the seed without damaging it.

Control of seeding depth and rate is crucial to successful stand. The large-seeded lupine requires aufficient moisture for germination, but planting too deep can cause failure due to seedling diseases. A depth of 3/4 – 1-3/4" is recommended depending on soil type and condition.

D. Fertility, Inoculation and Rotations:

Soil fertility recommendations for lupine have not been fully developed, but the requirements are probably similar to field bean or soybean. No yield differences have been observed due to application of P, K, S or micronutrients to lupine in five years of study at Staples, Minnesota.

Yield increases of nearly 60% have occurred in Minnesota due to inoculation of the seed with the specific nitrogen fixing bacteria for lupine (*Rhizobium lupini*) on fields not previously planted with lupine. Since inoculant is inexpensive, lupine seed should bc treated to insure good N availability. Lupine is relatively efficient in fixing nitrogen from the atmosphere, but the crop response to fertilizer N has not been determined.

The lupine crop, like other grain legumes, often increases the nitrogen content in the soil the following year, when compared to fallow or non-legume crops. The extent and utilization of this contribution remains open to question. In one Minnesota study, nitrate-N was increased significantly in only one of four locations. Current evidence suggests that under most soil conditions (especially on sandy soils), lupine harvested for grain does not leave significant amounts of N in the soil for the following crop. These results are similar to those obtained from field bean and soybean studies. A "rotation effect" of increased cereal yields after grain legumes (compared with cereal-cereal rotations) can still occur due to other factors. Wheat yields following lupine were greater in two of four Minnesota locations.

E. Variety Selection:

Several varieties of white, blue, and yellow lupine have been developed worldwide. Experimental selections are currently being evaluated in Minnesota, Wisconsin and North Dakota. In 1988 the most commonly grown variety in Wisconsin and Minnesota was Ultra, however seed of Primorsky, Kiev, and other varieties were available.[1]

F. Weed Control:

Lupine is a poor competitor with weeds, and is slow to develop a full canopy. For this reason effective weed control is essential for success with this crop. Poor lupine performance in Minnesota and Wisconsin has often been associated with poor weed control. A particular problem at many locations is late-germinating annual broadleafs, such as lambsquarters, pigweed and ragweed; fields with excessive populations of these weeds should be avoided.

Select fields free of perennial weeds like quackgrass, milkweed, bindweed, Canada thistle, etc. Avoid fields with atrazine residues and high levels of annual weed seed buildup in the soil. Early planting will give the crop a headstart on many weeds.

1. Mechanical: Lupine is often planted in narrow rows (7 to 10 inches apart) where row cultivation is not feasible. However, a rotary hoe is safe to the crop and effective on many annual weeds it done at the right time. Inspect fields every 4 to 5 days after planting and rotary hoe when a flush of weeds has germinated and is just beginning to emerge. Rotary hoeing lupines is similar to using this implement in soybeans: a few crop plants will be killed but the benefits greatly exceed the loss. Follow the planter wheeltracks to avoid compacting additional area between the rows. Rotary hoe when soils are relatively dry, and drive at least 5 MPH. If the crop is grown in rows—cultivate.

2. Chemical: Two herbicides currently registered for use in lupines are Prowl and Dual. A tank mix applied before planting and incorporated uniformly to a 2-inch depth is suggested. Product rates and incorporation methods are the same as for soybean. If lupines become a commonly grown crop, additional herbicides will most likely obtain EPA registration.

G. Diseases:

Lupine disease organisms are present in most fields. All varieties currently grown are susceptible to root rots caused by Rhizoctonia and Fusarium fungi. These diseases are credited with some reductions in yield throughout the region, especially on heavier, poorly drained soils. Phytophthora and Pythium have been a problem under certain conditions. Ascochyta and Botrytis stem canker have also been reported. The only protection against these diseases is resistant varieties. Unfortunately, genetic resistance is not yet available so avoid sites with excessive soil moisture and higher pH.

H. Insects:

Corn seed maggot has been reported to reduce lupine stands by more than 50% in New York state, and has been a severe problem some years in Minnesota. This problem could be aggravated by high organic matter and fresh manure application, which attract adult insects. Chemical insecticide treatments on the planted seed may deter some maggots. Potato leaf hopper and tarnished plant bug (Lygus bug) have been observed in Minnesota and Wisconsin lupine fields and have resulted in zero pod set and yields in lupines planted in mid-May in Wisconsin.

I. Harvesting:

Lupine planted in April generally will be ready for harvest during August in southern Minnesota and Wisconsin and September in northern areas of these states. Lupine is resistant to lodging and shattering under most conditions and there is usually ample distance between the soil surface and the lowest pod. Moisture content of the seed at harvest should be 1518% to reduce damage. Under certain environmental conditions, a large percentage of the plants in a field can remain vegetative late in the season. Late broadleaf weeds have also been an impediment to a clean harvest. Such fields should be winrowed and dried prior to combining.

J. Drying and Storage:

Lupine seed should be air-dried for storage.

VI. Yield Potential and Performance Results:

Lupine has responded to favorable growing conditions by producing yields up to 70 bushels/acre in north-central Minnesota under irrigation. Average yields in many Minnesota and Wisconsin Experiment Station trials have been much lower and vary widely by location and year (Table 2).

In Wisconsin trials conducted under the drought conditions in 1988 yields ranged from 9 to 42 bu/A (Table 3).

Such variation demonstrates the importance of proper management practices and suggests that the risk for this crop may be higher than for other crops. As with all new crops, you should start with a small acreage and expand only with experience.

Table 2: Average lupine yields at Minnesota Experiment Stations, 1972–75 and 1981–86.

Location	No. Test Years	Treatment	Average Yield	
			lbs/A	bu/A
Becker	1	Dryland	828	13.8
	7	Irrigated	1891	31.5

Rosemount	7	Dryland	1580	26.3
Elk River	3	Dryland	1237	20.6
	3	Irrigated	1891	31.5
Grand Rapids	5	Dryland	898	15.0
Crookston	3	Dryland	51	0.8
Morris	1	Dryland	307	5.1
Staples	4	Irrigated	3604	60.1

Table 3. Average lupine yields at Wisconsin locations, 1988.

	Variety		
Location	Primorsky	Ultra	Average[1]
	bu/A		
Ashland	8.1	10.9	8.8
Spooner (Irrigated)	39.3	40.7	41.9
Antigo	14.4	20.1	24.6
Sturgeon Bay	11.2	12.5	12.5
Marshfield	15.3	10.6	13.0
Hancock	20.4	24.7	21.4
Arlington	18.8	30.9	27.9

[1]Average of 8 experimental and released varieties.

VII. Economics of Production and Markets:

Australia exports substantial quantities of lupine for the European livestock feed market, and a Minnesota company has started to explore this market. The first export shipment of U.S. grown lupine (primarily from Minnesota and Wisconsin) to the Netherlands occurred in Fall, 1987.

Because of this diversity of use, lupine demand is unpredictable. This is the case with most minor crops. The price of lupine has been determined by the price of soybean meal or whole soybean. For example, one company sets the price of lupine equal to soybean or at 80% of the current soybean meal price.

The ability of a farmer to make a new crop enterprise work depends on both market and biological risk factors. For lupine, the production risk at this time seems to be more important than the market risk, since the market is relatively diverse. However, no grower should consider producing lupine as a cash crop until markets are fully investigated.

The cost of chemical weed control for lupine is about the same or slightly less than soybean (from $8–22/A). However, cultivation can eliminate this cost for lupine. Seed cost for lupine currently is $36–40/A compared to $8–12 for soybean, so the total costs of production are slightly higher for lupine.

Calculated break-even yield for these cash expenses is given in Table 5, using a $5 market price for soybean and lupine. The actual price of lupine has been about 80–90% that of soybean. The percentage of experiment station trial yields which have exceeded this amount is also shown. These data demonstrate the risk of lupine compared to soybean. It is important to remember that some of these locations (Tables 2 & 3) were not appropriate for lupines, and that the probability for success with lupine will be increased by planting in specific areas of adaptation.

Table 4: Estimated production cash costs* for soybean and lupine (Central Minnesota & Wisconsin).

Expense	Soybean	Lupine
	dollars/acre	
Seed	9.00	37.00
Fertilizer	11.60	11.60
Chemical (herbicide)	17.40	17.40
Fuel	9.60	9.60
Repairs & maintenance	16.64	16.64
Irrigation expenses	25.00	25.00
Interest on cash Exp.	4.00	4.00
Total (non-irrigated)	68.24	96.24
Total (irrigated)	93.24	121.24

* These costs do not include the "fixed" costs of production (land, machinery, taxes, etc.)

Table 5: Break-even yield level for cash expenses and percentage of Minnesota Experiment Station yield trials which have exceeded this amount.

Crop and Treatment	Calculated Break-Even Yield[1]	Trials Exceeding Break-Even Yield	Number of Tests
	lbs/A	%	location/years
Lupine (non-irrigated)	1138	36	14
Lupine (irrigated)	1438	71	22
Soybean (non-irrigated)	884	100	10

Soybean (irrigated)	1064	100	14

[1]Cash expenses only, does not include overhead costs. Price used was $5/bu for both soybean and lupine.

VIII. Information Sources:

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Footnotes:
[1]In the Minnesota–Wisconsin region, the white springsown lupine varieties have performed best. New varieties are becoming available; see "Varietal Trials of Farm Crops", Item AD-MA-24, Univ. of Minnesota Agric. Exp. Station.

Meadowfoam

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I. History:

Meadowfoam (*Limnanthes alba* Benth.) is a low growing herbaceous winter annual that is adapted to poorly drained soils. *Limnanthes* means marshflower and the common name "Meadowfoam" arose due to the appearance, at full bloom, of its solid canopy of creamy white flowers. Meadowfoam is native to northern California, southern Oregon, and Vancouver Island, British Columbia. The oil from meadowfoam seed has unique chemical properties that make it one of the most stable vegetable oils known.

Research and development of meadowfoam began in the late 1950s as the result of a USDA search for plants that might provide a renewable source of raw materials for industry. Commercial development began in 1980 on an experimental 35 acre farm scale operation in Oregon. However, the lack of consistent funding has slowed the development of both the agronomic and the oil utilization aspects of this unique renewable oil resource.

II. Uses:

Meadowfoam seeds (nutlets) contain 20 to 30% oil. Meadowfoam oil contains three previously unknown long chain fatty acids. The oil is over 90% C_{20} to C_{22} fatty acids and is most similar to high euric acid rapeseed oil. Rapeseed oil is slightly more saturated than meadowfoam oil. Meadowfoam oil can be chemically transformed into a liquid wax ester that is a substitute for sperm whale oil and jojoba oil. Meadowfoam oil can also be converted to a light colored premium grade solid wax, a sulfur polymer factice potentially valuable to the rubber industry, or used as a lubricant, detergent or plasticizer. Potential industrial applications for meadowfoam oil are currently being researched by USDA-ARS at the New Crops Research Center in Peoria, Illinois.

After the oil is removed by crushing the seed and utilizing a solvent extraction process, the remaining meal may be used as a feed source. Meadowfoam meal fed to beef cattle at levels up to 25% of total intake had no negative impact on weight gain. Use of the meal for other livestock may require steam cooking or using a lower percentage of meal in the total feed supply. Further research in this area is necessary.

III. Growth Habit:

Meadowfoam is an erect annual herb with one or more branches arising from the base and grows to a height of 10 to 18 in. It has a shallow fibrous root system that allows for easy transplanting at any stage of growth. Leaves are pinnately dissected, flowers are regular, perfect, and usually conspicuous on axillary peduncles.

Meadowfoam requires insect pollination to set seed. Cool, wet, or windy weather during flowering limits the activity of pollinators and therefore reduces the number of fertilized flowers. Meadowfoam is not self pollinating because the male reproductive organs mature before the female organs are mature (pollen is released from the anthers before the stigma of the flower is receptive). This plant adaptation is common for enhancing cross pollination. Two or three colonies of bees per acre of meadowfoam are needed for adequate pollination (note: other flowering plants in the vicinity may be preferred by pollinators). The development of self pollinating varieties should increase yield potential.

IV. Environment Requirements:

A. Climate:

Meadowfoam has a very low tolerance to water stress and therefore is well adapted to the cool wet Mediterranean climate of the Pacific Northwest. Many areas in the U.S. may be able to produce meadowfoam if, in the future, market demands make oil production profitable. Under conditions of below average precipitation in the Willamette Valley, irrigation during flowering and seed development was found to significantly increase yields.

B. Soil:

Meadowfoam grows well on most soil types, however sandy soils with low water holding capacity are less favorable under dry conditions.

C. Seed Preparation and Germination:

Secondary dormancy of the seed occurs at temperatures over 60¡F when the seed is imbibing water. It also appears that light may be a factor in initiating dormancy. Seed sown on the soil surface shows a higher level of secondary dormancy than seed that is covered with soil.

V. Cultural Practices:

A. Seedbed Preparation:

The seedbed should be moderately fine to allow for uniform seed placement.

B. Seeding Date:

Meadowfoam is normally grown as a winter annual in the Pacific Northwest. Planting in October after soil temperatures in the seed zone are below 60°F aids in germination. Warmer soil temperatures promote seed dormancy which can lead to poor germination and poor stand establishment. Meadowfoam has been grown as a spring planted annual in areas where winter temperatures are too cold to allow fall planting.

C. Method and Rate of Seeding:

Plant densities of 3 to 4 plants/square ft have resulted in the highest yields. Different conditions at planting time and soil type will affect the seeding rate necessary to achieve this plant density. Seeding rates of 15 to 40 lb/acre have been successful. Good seed-soil contact is required for uniform germination. Drilling seed 1/4 to 3/4 in. deep in 3 to 7 in. rows, is recommended over broadcast seeding followed by incorporation, although both methods have produced successful yields.

D. Fertility and Lime Requirements:

Although no fertility research has been conducted on Meadowfoam in Minnesota or Wisconsin, some work from the Pacific NW has shown that nitrogen fertilization increases yield, however it may result in delayed flowering and a decrease in the percent oil content of the seed. Soil pH should range between 5.5 and 6.0, with fertilizer requirements of 40 to 60 lb N/acre, 20 lb P_2O_5/acre at soil tests of 10 to 20 ppm P, and 20 to 30 lb K_2O/acre at soil tests of 80 to 100 ppm K. Excess fertilization which promotes lush vegetative growth may create conditions favorable for diseases.

E. Variety Selection:

Variety selection began with selected individuals within the species *L. alba.* The first, 'Foamore' selected for its upright habit, was named by Oregon State University in 1975. It is 10 to 12 in. tall and yields 800 to 1300 lb/acre. 'Mermaid' released in 1985 by Oregon State University is 12 to 14 in. tall, upright, and has good seed retention. Seed stock is controlled by the Oregon Meadowfoam Growers Association (OMGA). Varieties from the cross of *L. floccosa* × *L. alba* shows increased seed size, increased oil content, and reduced lodging. Continued development of new higher yielding varieties is expected.

F. Weed Control:

Competition from weeds can severely reduce the yield of meadowfoam. Two herbicides; propachlor at 4 lb/acre (broad spectrum) and diclofop at 1 lb/acre (post-emergent, grass control) have been shown to be effective for weed control in meadowfoam fields but, are NOT registered for use at this time.

1. **Mechanical:** Begin with a weed free seedbed and avoid fields known to have a wild mustard problem.

2. **Chemical:** No herbicides have been approved for use at this time.

G. Diseases and their Control:

Botrytis cinerea affects stems, leaves, and flowers and results in shriveled seed and reduced yields. *Botrytis* destroyed commercial meadowfoam fields in 1983 and in 1984 in the Pacific Northwest. Fungicide applied at 40 to 50% bloom has been shown to be effective, however no fungicides are currently approved for commercial use.

H. Insects and Other Predators and their Control:

Insect pests have not been a problem in meadowfoam fields. However insects collected in association with meadowfoam plants include the spotted cucumber beetle, nitidulid beetle, seed bug, and seed-feeding Carabidae beetle.

I. Harvesting:

Meadowfoam can be harvested with the same equipment used in grass seed production. The crop is cut when 90% of the seeds are mature and the stems are greenish-yellow. Windrowing early in the morning with a dew present helps to prevent shattering. Meadowfoam is allowed to dry in the swath for 7 to 10 days or to a seed moisture content of 12 to 16%. Threshing is more efficient when the moisture content of the seed and other plant material is low. Combine efficiency is increased by slow ground speed, high cylinder speed, close cylinder clearance, open sieves, and high wind speed. Post harvest, meadowfoam fields have little plant residue remaining.

J. Drying and Storage:

Meadowfoam oil is very stable in storage. Production of meadowfoam oil has been stockpiled for sale to foreign and domestic buyers mostly in the cosmetic and personal care products industries.

VI. Yield Potential and Performance Results:

Research plots have produced over 2000 lb/acre of seed. Unfortunately commercial fields have generally yielded less than 750 lb/acre largely due to disease and pollination problems. Future development of new varieties should lead to consistently higher yields.

VII. Economics of Production and Markets:

Meadowfoam oil is in direct competition with rapeseed oil for the high volume industrial oilseed market. Penetration into this market requires that the price of meadowfoam oil be competitive and the supply dependable. The price of meadowfoam oil was as high as $4.00/lb in 1986 but has been declining and is expected to reach $2.00/lb due to increased efficiency of large scale production and the value of using higher yielding varieties.

Product development that takes advantage of the unique long chain fatty acids found in meadowfoam oil would tend to lead to a high value, low volume market that would certainly accelerate the development of full scale production.

VIII. Information Sources:

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Millets

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I. History:

Millets are some of the oldest of cultivated crops. The term millet is applied to various grass crops whose seeds are harvested for food or feed. The five millet species of commercial importance are proso, foxtail, barnyard, browntop and pearl. In China, records of culture for foxtail and proso millet extend back to 2000 to 1000 BC Foxtail millet (*Setaria italica* L.) probably originated in southern Asia and is the oldest of the cultivated millets. It is also known as Italian or German Millet. Its culture slowly spread westward towards Europe. Foxtail millet was rarely grown in the U.S. during colonial times, but its acreage increased dramatically in the Great Plains after 1850. However, with the introduction of Sudan grass, acreage planted to foxtail millet decreased.

Proso millet (*Panicum miliaceum* L.) was introduced into the U.S. from Europe during the 18th century. It was first grown along the eastern seaboard and was later introduced into the Dakotas where it later was grown on considerable acreage. In North Dakota acreage has ranged from 50,000 to 100,000 acres while in Minnesota only a few thousand acres have been grown.

Today, foxtail millet is grown primarily in eastern Asia. Proso millet is grown in the Soviet Union, mainland China, India and western Europe. In the United States, both millets are grown principally in the Dakotas, Colorado and Nebraska.

Barnyard or Japanese millet (*Echinochloa frumentaceae* L.), is a domesticated relative of the seed, barnyard grass. It is grown for grain in Australia, Japan and other Asian countries. In the United States, it is grown primarily as a forage.

Browntop millet (*Panicum ramosum*) is a native of India and was introduced into the United States in 1915. It is grown in southeastern United States for hay or pasture and bird and quail feed plantings on game preserves. It is sometimes sold to Minnesota sportsmen for this purpose. Seed and forage yields of browntop millet have been low in Minnesota tests and it did not compete well with weeds.

Pearl or cattail millet *(Pennisetum glaucum)* originated in the African savannah and grown since prehistoric time. It is grown extensively in Africa, Asia, India and Near East as a food grain. It was introduced into the United States at an early date but was seldom grown until 1875. It is primarily grown in southern United States as a temporary pasture. It is preferred over sudangrass as a forage crop in the south. Varieties planted at Rosemount, Minnesota produced very little seed, and their forage yield was low compared to foxtail varieties.

II. Uses:

The most commonly grown millets in the midwestern states are proso and foxtail with a limited acreage of barnyard.

The major uses of proso millet are as a component of grain mixes for parakeets, canaries, finches, lovebirds, cockatiels and wild birds and as feed for cattle, sheep, hogs and poultry. Millet for birdfeed purposes is often grown under contract. Large bright or red seed is preferred, and premiums are sometimes paid for superior quality. Two types of bird feed mixes are marketed. One type is for wild birds and the other for caged birds. The cage bird mixes require the better quality proso for which premiums are paid.

Proso millet as livestock feed is similar to oats and barley in feeding value. It is commonly fed in ground form to cattle, sheep, and hogs. Whole seed can be fed to poultry. The protein values compare favorably with sorghum and wheat and are higher than corn. Proso also has considerably higher fiber levels, due to attached hulls. The average composition of proso grain is shown in Table 1. Proso performs best in livestock rations when fed in mixtures with other grains. If the amino acid levels are balanced, the feeding value to hogs is nearly equal to corn. Proso can be cut for hay, but it is not as suitable as foxtail for this purpose.

Foxtail millet is usually grown for hay or silage often as a short-season emergency hay crop. Some seed is used for finch and wild bird feeds. It does not necessarily yield more forage than proso but is free of foliage hairs and is finer stemmed. For forage, foxtail millet is harvested at the late boot to late bloom stage. The composition of foxtail millet relative to other forages is shown in Table 2. Foxtail millet should not be fed to horses as the only source of roughage since it acts as a laxative. If foxtail millet has been severely stressed it may accumulate nitrate at levels toxic for livestock. Several landraces of foxtail millet have been developed over time and include what is called Common, Siberian, Hungarian, and German Foxtail.

Table 1: Average composition of proso millet.[1]

Nutrient	Content	Nutrient
Crude protein	12.0%	B-complex vitamins
Crude fiber	8.0%	Thiamine
Ether extract (fat)	4.0%	Niacin (nicotinic acid)

Total Digestible Nutrients	75%	Riboflavin
Digestible Energy	1500 kcal/lb	Pantothenic acid
Calcium	0.05%[3]	Choline
Phosphorus	0.30%[2]	Critical Amino acids:
Carotene	none[3]	Lysine
Vitamin D	none[3]	Mythionine
Vitamin B_{12}	none[3]	Threonine
		Thryptophan

[1]Adapted from "Proso Millet in North Dakota."
[2]Inadequate for swine rations.
[3]Grossly inadequate for swine rations.

Table 2: The average composition of foxtail millet hay and its comparison to other hay crops.

Feed	Protein (%)	Ether Extract (%)	Crude Fiber (%)	Nitrogen Free Extract (%)	Ash (%)
Millet					
Foxtail	8.3	2.6	25.8	43.8	7.2
Pearl	8.0	1.8	31.6	37.6	8.9
Oat (full bloom)	7.9	2.6	28.1	39.9	5.8
Sudan-grass (full bloom)	9.1	2.0	25.7	41.4	8.5

Crampton, E. W. and L.W. Harris. 1969. Applied Animal Nutrition. W. A. Freeman and Co., San Francisco.

III. Growth Habits:

Millets are annual grasses. Proso millet grows to a height of approximately 40 in. and has a hollow stem. Both stems and leaves are curved with short hairs. Proso millet has a large, open panicle inflorescence. When the grain is threshed, most of the seed remains enclosed in the inner hull. Hulls are extremely variable in color and, depending on the variety, may be white, red, yellow, brown or striped.

Foxtail millet has slender, erect leafy stems and may grow up to 50 in. tall. The inflorescence is a dense, bristly panicle resembling the panicles of weedy foxtails. As in proso millet, the seeds are enclosed in the hull and also range in color from creamy white, red, yellow or dark purple. Both proso and foxtail millet are highly self-pollinated but have been known to occasionally outcross.

Proso and foxtail millet are short season crops. In Minnesota and Wisconsin, proso millet will mature in 70 to 90 days from planting, depending on the variety. Foxtail millet requires approximately 60 days to reach the heading stage.

IV. Environment Requirements:

A. Climate:

Millets require warm temperatures for germination and development and are sensitive to frost. For these reasons, they are normally planted from mid-June to mid-July in Minnesota and Wisconsin. Optimum soil temperatures for seed germination are between 68 and 86°F. Proso and foxtail millet are efficient users of water and grow well in areas of low moisture, partly because they are early and thereby avoid periods of drought. Millets are often grown as catch crops where other crops have failed or planting is delayed due to unfavorable weather.

B. Soil:

Millets grow well on well-drained loamy soils. They will not tolerate water-logged soils or extreme drought. Proso millet does not perform well on coarse, sandy soils.

C. Seed Preparation and Germination:

A fungicide will provide protection against head smut (*Sphacelothaca destruens*) and may increase seedling survival.

V. Cultural Practices:

A. Seedbed Preparation:

Seedbed preparation for millet is similar to that for spring-seeded small grains. Weeds should be controlled prior to planting and the seedbed should be firm and well-worked. Since millets are planted late in the season, spring plowing and cultivation for weed control are practical.

B. Seeding Date:

Suggested seeding dates in Minnesota and Wisconsin range from June 15 to July 15. Seeding later in the season may be risky due to early frosts, and yields may be lower than with earlier plantings. Millet is best established when soil temperatures reach 65°F at a depth of one in.

C. Method and Date of Seeding:

A seeding rate of 20 lb/acre (25 seeds/ft 2) is recommended for proso millet. Foxtail 2 millet should be sown at a rate of 15 lb/acre (75 seeds/ft). Millets are normally seeded with a grain drill at a depth of one in. Even though the seed is small, it can develop extreme elongation of the first internode and emerge from I in. and even deeper unless a hard crust forms. Press wheels on the drill will increase seedbed firmness and aid in stand establishment. Millets compete poorly with weeds; therefore, high seeding rates are necessary to establish a dense stand.

D. Fertility and Lime Requirements:

Nitrogen is generally the most limiting nutrient in millet production. Rates of nitrogen should be based on yield goals and cropping history (Table 3). Excess nitrogen, whether applied or residual, may result in lodging. Allow for nitrogen applied as manure or other waste. Phosphorus and potassium should be applied as needed based on soil recommendations (Table 4). Drill row applications of fertilizer (except straight phosphorus fertilizers) may cause seedling injury and are not recommended. A pH of 5.6 or higher is recommended for millet.

Table 3: Annual nitrogen recommendations for millet.

Based on nitrate test[1]		Based on previous crop and organic matter level						
		Corn, sugar potatoes, beets small grain		Soybeans, sunflowers		Alfalfa, clover, Black fallow		
Expected yield	Soil-N (0-2 ft.)[2] + fertilizer N	Organic matter level[3]						Organic soil
		Low to medium high		Low to medium high		Low to medium high		
(cwt/acre)	(lb/acre)	N to apply (lb/acre)						
30	120	100	80	80	60	40	20	20
25-29	100	80	60	60	40	30	20	20
20-24	80	60	40	50	30	20	0	20
15-19	70	50	30	40	20	0	0	0
less than 14	60	40	20	30	20	0	0	0

[1]For use in western Minnesota only.
[2]Subtract nitrate - N (lb/acre, 0-2 ft.) from this value to obtain N to apply (lb/acre).
[3]Irrigated sandy soils are included in the low to medium category.

Table 4: Annual phosphorus and potassium recommendations for millet[1].

Phosphorus (P) Soil Test (lb/acre)	P_2O_5 to apply (lb/acre)	Potassium (K) Soil Test (lb/acre)	K_2O to apply (lb/acre)
0-10	40	0-100	80
11-20	30	101-200	80
21-30	20	201-300	20
30+	0	300+	0

[1]Recommended rates are for total amount to apply-broadcast. (For soil tests reported in ppm, multiply by 2 to get lb/a).

E. Variety Selection:

The most important factors to consider in selecting a variety are maturity and lodging potential. Seed color may also be important if grain is to be used for bird feed. Three types of millet are adapted in Minnesota and Wisconsin and other areas of the Upper Midwest: proso, foxtail and barnyard (Japanese). Characteristics of individual millet varieties follow:

Recommended Forage Variety:

Empire—Foxtail. Very late and tall. Poor lodging resistance. Very small, plump yellow seed of low test weight. Released by Agriculture Canada.

Recommended Grain Varieties

Cerise—Red proso. Very early. Medium height. Fair lodging resistance. Small, orange seed of high test weight. Released by Nebraska Agricultural Experiment Station in 1974.

Dawn—White proso. Very early. Short. Fair lodging resistance. Medium size, white seed of medium test weight. Released by Nebraska Agricultural Experiment station in 1976.

Minco—White proso. Late. Medium height. Fair lodging resistance. Medium size, white seed of high test weight. Released by Minnesota Agricultural Station in 1976.

Minsum—White proso. Early. Medium height. Poor lodging resistance. Large, white seed of medium test weight. Open heads with long, spreading branches contrast with more compact heads of other white proso varieties. Released by Minnesota Agricultural Experiment Station in 1980.

Rise—White proso. Medium maturity. Short. Fair lodging resistance. Medium size, white seed of medium test weight. Released by Nebraska Agricultural Experiment Station in 1983.

Other Varieties

Barnyard or Japanese—Forage. Late. Very tall. Very good lodging resistance. Medium size, gray seed of low test weight. High yielding forage millet but coarse.

Cope—White proso. Very tall. Fair lodging resistance. Large, white seed of medium test weight. Released by Colorado Agricultural Experiment Station in 1978.

German, German R. and German No. 8—Foxtail. Very late. Very tall. Good lodging resistance. Very small, yellow seed of low test weight. High forage yield but too late for good seed production.

Panhandle—White proso. Early. Medium height. Poor lodging resistance. Large, white seed of medium test weight. Lower yield than Minsum. Released by Nebraska Agricultural Experiment Station in 1967.

Red Leonard—Red proso. Very late. Tall. Fair lodging resistance. Medium size, orange seed of high test weight. Lower grain yield than Cerise in 1982 trials. Released by Colorado Agricultural Experiment Station in 1983.

Sno-Fox—Foxtail. Late. Medium height. Poor lodging resistance. Small, white seed of medium test weight. Released by Nebraska Agricultural Experiment Station in 1980.

F. Weed Control:

1. **Mechanical:** Millets do not compete well against weeds. For this reason, it is important to control serious weed problems prior to planting. Since millets are not seeded until the middle of June, germinating annuals and emerging perennials can be controlled by frequent cultivation during early growth.
2. **Chemical:** To control broadleaf weeds in proso millet, 2,4-D amine can be applied when the crop is 4 to 6 in. tall. Spraying should be avoided when heading or flowering. Atrazine which was used for control of annual broadleaves and some grasses in proso millet will not be labeled for such use after September of 1990.

G. Diseases and Their Control:

Head Smut (*Sphacelotheca destruens*) can be a problem in proso millet but can be controlled by seed treatment.

Kernel Smut (*Ustilago crameri*) can be present in both proso and foxtail millet. This disease requires seed treatment and crop rotation for effective control, as the inoculum will remain in the soil for several years.

Bacterial Stripe Disease (*Pseudomonas syringae* pv. *panici*) has been found in Wisconsin and South Dakota. Affected plants have brown water-soaked streaks on the leaf, blades, sheaths and stems. The long narrow lesions show numerous thin, white scales of the exudate. The disease is thought to be seed-borne.

H. Insects and Mites and Their Control:

Wheat Curl Mite—Foxtail millet is known to harbor this insect which may transmit wheat streak mosaic to winter wheat. Cutting foxtail for hay by early August and then undercutting the stubble should kill the crop and prevent it from acting as a host.

Grasshoppers—This insect has been the most serious on millets. Insecticides are cleared for use on millets for control of grasshoppers.

Armyworms—This insect can be prevalent but can be controlled by insecticides.

I. Harvesting:

Proso millet is ready for harvest when seeds in the upper half of the panicle are mature. Seeds in the lower half of the panicle may still be in the dough stage but should have lost their green color. At this point, the leaves and stems may still be green. Millet is usually harvested by swathing to allow drying of straw before combining. Swathing too early reduces yield, test weight and color quality. Harvesting too late increases loss as a result of shattering and lodging. Rodents and birds can cause damage to proso during ripening. Control programs are often needed.

Foxtail millet should be harvested for hay or silage from the late boot to bloom stage. At this stage, hay quality is at its peak, and protein levels of 12 to 14% may be common. As the plant matures, protein declines. Also mature bristles from delayed harvest may cause lump jaw and sore eyes in cattle feeding from bunks. When harvesting foxtail millet for seed production, it should not be cut until completely ripe, then swathed and threshed. Sometimes it is direct combined after a killing frost, but some seed loss will occur.

J. Drying and Storage:

Millet seed should be stored at 13% moisture or less. Federal grain standards have not been established for millet. However, good quality millet seed should have a minimum of broken kernels and be relatively free from weed seeds.

VI. Yield Potential and Performance Results:

A. Minnesota:

The most recent millet yield tests conducted in Minnesota show that proso millet yields 2500 to 2800 lb/acre while foxtail millets yield 3.0 to 4.4 T/acre of forage. In these studies foxtail millet had 240,000 seeds/lb with a test weight of 47 lb/bu while the proso varieties ranged from 66,000 to 81,000 seeds/lb and test weights of 51 to 56 lb/bu.

Table 5: Yield and agronomic data for several millet varieties tested at Rosemount and Becker, Minnesota, 1983-1985.

Type and Variety	Grain yield		Forage yield[2]		Days from planting to		Mature height (in)
	Rosemount[3] (lb/acre)	Becker[4] (lb/acre)	Rosemount (T/acre)	Becker (T/acre)	Heading	Maturity	
Foxtail							
Empire	1950	570	4.4	3.0	59	99	47
Proso							
Dawn	3432	1588	3.5	1.8	39	74	31
Minco	3978	1537	5.0	2.0	42	83	40
Minsum	3602	1679	4.1	2.1	39	78	38
Rise	3936	1491	4.3	1.8	42	81	35
Cerise	3657	2005	4.4	2.4	38	73	40
LSD 5%	372	303	0.3	0.2	--	--	--

[1]10% moisture basis; [2]Dry matter basis and includes grain; [3]Clay-loam soil; [4]Sandy soil.

VII. Economics of Production and Markets:

Production costs for proso millet are similar to small grains; however, with the market price of proso millet ranging from 6 to 8 cents/lb, income/acre is less than for a good crop of hard red spring wheat. There are numerous outlets for markets or contracts in Minnesota both in Minneapolis and northern Minnesota. Some markets in the Minneapolis area are Knight Seed Co. in Burnsville and Barzan of Minneapolis. One market in northern Minnesota is Minn-Dak Growers Assoc., Grand Forks, ND.

VIII. Information Sources:

- Varietal Trials of Farm Crops. 1990. L.H. Hardman, Ed., Minnesota Report 24. Agricultural Experiment Station, University of Minnesota. 46 p.

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Mungbean

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I. History:

The mungbean, *Vigna radiata* (L.) Wilczek has been grown in India since ancient times. It is still widely grown in southeast Asia, Africa, South America and Australia. It was apparently grown in the United States as early as 1835 as the Chickasaw pea. It is also referred to as green gram, golden gram and chop suey bean. Mungbeans are grown widely for use as a human food (as dry beans or fresh sprouts), but can be used as a green manure crop and as forage for livestock. Virtually all the domestic production of mungbean is in Oklahoma. Fifteen to twenty million pounds of mungbean are consumed annually in the United States and nearly 75 percent of this is imported.

II. Uses:

Mungbean seeds are sprouted for fresh use or canned for shipment to restaurants. Sprouts are high in protein (21%–28%), calcium, phosphorus and certain vitamins. Because they are easily digested they replace scarce animal protein in human diets in tropical areas of the world. Because of their major use as sprouts, a high quality seed with excellent germination is required. The food industry likes to obtain about 9 or 10 grams of fresh sprouts for each gram of seed. Larger seed with a glassy, green color seems to be preferred.

If the mungbean seed does not meet sprouting standards it can be used as a livestock food with about 1.5 ton of mungbean being equivalent to 1.0 tons of soybean meal for protein content. Feeding trials have been conducted at Oklahoma State University for swine and young calves with good results.

III. Growth Habits:

Mungbeans are in the Legume family of plants and are closely related to adzuki and cowpea (in the same genus but different species). They are warm season annuals, highly branched and having trifoliate leaves like the other legumes. Both upright and vine types of growth habit occur in mungbean, with plants varying from one to five feet in length. The pale yellow flowers are borne in clusters of 12–15 near the top of the plant. Mature pods are variable in color (yellowish-brown to black), about five inches long, and contain 10 to 15 seeds. Self pollination occurs so insect and wind are not required. Mature seed colors can be yellow, brown, mottled black or green, depending upon variety. These round to oblong seeds vary in size from 6,000 to over 12,000 per pound, depending upon variety. Germination is epigeal with the cotyledons and stem emerging from the seedbed.

IV. Environment Requirements:

A. Climate:

Mungbeans are a warm season crop requiring 90–120 days of frost free conditions from planting to maturity (depends on variety). Adequate rainfall is required from flowering to late pod fill in order to ensure good yield. Late plantings which result in flowering during the high temperature-low moisture period in July and August will reduce yield. High humidity and excess rainfall late in the season can result in disease problems and harvesting losses due to delayed maturity.

Mungbeans (if proper varieties are used) are adapted to the same climatic areas as soybean, drybean and cowpea. Mungbeans are responsive to length of daylight so short days hasten flowering and long days delay it. Varieties differ in their photoperiod response.

B. Soil:

Mungbeans do best on fertile sandy, loam soils with good internal drainage. They do poorly on heavy clay soils with poor drainage. Performance is best on soils with a pH between 6.2 and 7.2 and plants can show severe iron chlorosis symptoms and certain micronutrient deficiencies on more alkaline soils. Mungbean has phosphorus, potassium, calcium, magnesium and sulfur requirements similar to other legumes which must be met by fertilizer additions if the soil is deficient in these elements.

C. Seed Preparation and Germination:

Because the major use of mungbean is for sprouts; excellent germination must be maintained by careful harvesting and storage systems. Seed is not generally treated with fungicides, insecticides or bactericides because of the possibility of ingestion of treated seed.

Because the seed is small, careful handling and attention to planting machinery adjustments is necessary to ensure planting with little damage to the seed.

If mungbean is being planted in a field for the first time the proper nitrogen fixing bacteria must be provided. This inoculant can be applied to the seed just before planting or applied in the furrow in peat or granular form. Care must be taken to distribute this inoculant uniformly in the field. Be sure to use the bacteria that is specific for mungbean or closely related species.

Only certified seed should be used so that quality and variety purity are guaranteed. Currently Oklahoma Slate University Crop Improvement Association is a source of foundation and certified seed of certain varieties, some of which may be adapted to this area.

V. Cultural Practices:

A. Seedbed Preparation:

The soil should be tilled to remove weeds and to prepare a seedbed which will provide good seed-soil contact. The final seedbed needs to firm with a surface free of clods and debris to allow a good distribution of seeds. If moisture is short, keep preplant tillage to a minimum to prevent drying out the top two or three inches.

B. Seeding Date:

Mungbean should be planted between May 15 and June 6 like the other legumes (field bean, adzuki, cowpea) which are being grown as the major crop on the field. Too late a planting date results in bloom and pod fill during the hottest, driest period of the summer. In some areas mungbean is planted as a second crop after the small grain is harvested. If this is done planting should occur immediately after the grain harvest with a minimal disturbance of the seedbed. It is doubtful that the growing season in Wisconsin and Minnesota would be long enough to plant after small grain harvest.

C. Method and Rate of Seeding:

Seeds should be planted 1 1/2" deep in a well prepared seedbed with a good moisture content. If the surface layers are dry this depth can be increased to 3" if the soil type is one which does not crust easily. The seedlings of mungbean can have a hard time breaking through a thick crust and stands will be reduced.

Planting equipment for soybean, fieldbean, adzuki and cowpea can be used to plant mungbean but careful adjustments must be made to properly deliver and distribute the very small seed (6,000–12,000 seeds/lb). In 30" rows the recommended planting rate is 9 seeds/ft; in 20" rows 6 seeds/ft.; and in 6"–10" rows 2–3 seeds/ft. Populations of 150,000–200,000 plants per acre will be achieved with these rates.

Because of possible weed outbreaks with early season planting and the need for cultivation to control them, row spacings of 20"–30" are recommended. In later plantings or planting as a second crop the narrow rows will produce higher yields.

D. Fertility and Lime Requirements:

Mungbeans require phosphorus, potassium and certain micronutrients at levels similar to other field beans. The amount to add as fertilizer should be based on soil test levels.

organic matter content and projected yield level. Phosphorus and potassium recommendations for Minnesota and Wisconsin are given in Table 1.

If the field has been previously inoculated with the proper Rhizobium for nitrogen fixation, additional nitrogen is not required. However some growers provide 30–50 lbs of N to assist in early plant establishment, especially on sandier soils. Like the other legumes most of the nutrient uptake occurs later in the season so starter fertilizers have not been very helpful.

Mungbean require slightly acid soil for best growth. If they are grown in rotation, lime for the pH of the most acid sensitive crop. If soil pH is below 6.3, lime should be added to raise pH to the desired level. For best results, lime should be applied one year prior to growing mungbeans and thoroughly incorporated.

Table 1. Phosphorus (P) and Potassium (K) recommendations for mungbeans.

	P Soil Test (lb./acre)[1]				K Soil Test (lb./acre)[1]			
Expected Yield	0–10	11–20	21–30	30+	0–100	101–200	201–300	300+
(lb./acre)	P_2O_5 to apply[2] (lb./acre)				K_2O to apply[2] (lb./acre)			
3000 or more	80	60	40	0	120	90	50	0
2500–2900	70	50	40	0	100	70	40	0
2000–2400	60	40	30	0	80	50	30	0
1500–1900	50	30	30	0	70	40	0	0
1400 or less	40	30	0	0	60	30	0	0

[1]For soil P and K reports in ppm. (ppm x 2 = lb./acre).
[2]Recommended rates are for total amount to apply—broadcast + row. Low rates may be row-applied.

E. Variety Selection:

Hundreds of experimental lines of mungbean have been tested in the United States (primarily at Texas A & M University, Oklahoma State University and the University of Missouri) over the years. Much of this testing and research has been coordinated with the Asian Vegetable Research and Development Center in Taiwan which is the international center responsible for mungbean research worldwide. A few years ago some work on mungbean was also being done at the Morden, Manitoba research station for Agriculture Canada, especially looking for earlier maturing, upright growth habit varieties.

Maturity, upright versus prostrate growth habits, small versus large seed types and color of seed are important attributes to be considered when selecting a variety. The sprouting industry desires a superior germination rate of the seed to produce a thick, crisp, white colored hypocotyl with a minimum of roots present. There are varietal differences for several of these characteristics.

Currently the only breeding programs are at Oklahoma State and Texas A & M Universities, but some private seed companies have seed of certain varieties of their own.

All of the varieties provided by these programs may not be adaptable in the Upper Midwest, so a grower should be careful about using them without a certain amount of testing.

F. Weed Control:

1. Mechanical: Rotary hoeing and/or field cultivation should be used as required to remove weed competition until flowering begins. Later emerging weeds are not as damaging to yield as the early ones. Avoid cultivation in the field when the plants are still damp because this can spread bacterial and fungal disease. Growers planting mungbean for the first time should plan on using wider row spacings so that cultivation can be done if weeds become a problem.

2. Chemical: Dual (metolachlor) is approved for preemerge or preplant incorporate use and Treflan (trifluralin) is available for preplant incorporate use. Both herbicides give excellent grass control and fair to good suppression of annual broadleaves. Follow label directions to select the appropriate rate for your soil type and organic matter content. Currently no postemerge chemicals are available for control of later emerging weeds. Broadleaf weed control is difficult because many of the chemicals damage the mungbean. It is hard to get label clearance for a minor crop like mungbean, but it may fit under the dry pod crop grouping of certain labels already cleared. Check with your local Extension agent, consultant or chemical company representative before using any chemical on mungbean.

Because mungbean are eaten directly by humans the label restrictions are quite strict as to use and timing of all chemicals applied to the crop.

G. Diseases and Their Control:

Mungbeans are susceptible to the usual array of pathogens which attack other legumes such as white mold, Phytophthora, mildew, bacterial rots, Rhizoctonia, etc.

Proper rotation, tillage practices, and water management (if under irrigation) can be effective in reducing the impact of these diseases. Contact your Extension agent or crop consultant for assistance.

H. Insects and Other Predators and Their Control:

Mungbeans do not generally require insecticide sprays to control problems in the field. Seed corn maggot and wireworms could attack seeds in the early germination period and reduce stand under certain conditions. Occasional grasshopper or caterpillar infestation could occur and result in defoliation. Mungbeans are no more affected by insect problems than the other legumes. Weevils can attack the seed in storage.

I. Harvesting:

Pod maturity in mungbean is not uniform because the plants flower over an extended period. This makes it difficult to decide when to harvest. Generally harvest should begin when one half to two-thirds of the pods are mature. Seeds might be between 13%–15% moisture at this time. Some growers swath the plants to allow further maturity of the pods and then combine using a pick up header on a small grain combine. This is an especially useful harvest system for the vine type varieties or when there is delayed maturity or problem weeds present. Swathing should be done earlier in the day to prevent severe shatter losses.

Direct combining can be done in weed free, uniformly mature fields of the upright growth habit type of mungbean. It is also important to adjust the cylinder speed and concave clearance for complete threshing with a minimum of seed breakage. After combining the seed should be quickly cleaned to remove green pods, leaf material, debris, etc. which could create drying and storage problems. In developing countries, the mungbeans are handpicked as the pods mature. As many as five pickings are done on some high yielding lines.

J. Drying and Storage:

Prior to storing, remove all leaf material, stems, immature pods, dirt, insect parts and other debris. Mungbeans at about 12% moisture can then be stored in regular grain bins previously fumigated to control bean weevils. If beans are higher in moisture then 12% they can be dried slightly by moving unheated air though thin layers until they are near the 12% value. Because they will be sprouted and eaten direct, care should be taken to keep all possible contaminants away from the storage area.

VI. Yield Potential and Performance Results:

The yields of mungbeans depend largely on weather conditions, soil, cultural practices, and variety. Yields can range from 300 to over 2,000 pounds per acre. Yields from second crop plantings are not as large as main crop yields.

VII. Economics of Production and Markets:

Production costs for mungbeans in the Upper Midwest have not been determined, but the cash costs should be about the same as navy, pinto, adzuki, cowpea or soybean. Because of the lack of locally available seed sources, seed cost will likely be slightly higher.

As with all specialty crops with limited market uses, a grower should always identify markets before producing mungbeans on a large scale. Contact price varies widely but is likely to be in the same general area as adzuki, navy and pinto contracts. Local health food stores, restaurants and brokers may be able to purchase your production.

VIII. Information Sources:

- Mungbean in Grain Legumes as Alternative Crops. 1987. Cupka, T.—A Symposium sponsored by Center for Alternative Crops & Crop Products. Bloomington, MN. July 23–24, 1987. pp. 89–96.
- Mungbean Culture and Varieties. 1975. USDA Bulletin CA-NE-11.
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References to pesticide products in this publication are for your convenience and are not an endorsement of one product over other similar products. You are responsible for using pesticides according to the manufacturer's current label directions. Follow directions exactly to protect the environment and people from pesticide exposure. Failure to do so violates the law.

Mustard

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I. History:

Mustard (*Brassica* spp.), a native to temperate regions of Europe, was one of the first domesticated crops. This crop's economic value resulted in its wide dispersal and it has been grown as a herb in Asia, North Africa, and Europe for thousands of years. Ancient Greeks and Romans enjoyed mustard (sinapis) seed as a paste and powder. In about 1300, the name "mustard" was given to the condiment made by mixing mustum, which is the Latin word for unfermented grape juice, with ground mustard seeds.

Mustard has been a major specialty crop in North America since supplies from western Europe were interrupted by World War II. California and Montana were the major production areas until the early 1950s. Production of mustard in the Upper Midwest began in the early 1960s. Mustard is currently grown on approximately 250,000 acres annually in the United States. North Dakota has the largest share of domestic production. Canadian mustard production increased for twenty years until it peaked in the mid-1980s. Alberta, Manitoba, and Saskatchewan currently grow a large share of the world's mustard crop. The French people are the largest consumers of mustard (1.5 lbs/person/year), and buy approximately 70% of the annual Canadian production.

Three types of mustard, yellow, brown, and oriental, are grown in North America. Yellow mustard (*Brassica hirta*) comprises about 90% of the crop in the Upper Midwest. In Europe, yellow mustard is also known as white mustard (*Sinapis alba* - an older botanical name).

Brown and oriental mustards (*Brassica juncea*) are grown on limited acres. This crop is commonly produced in a rotation with small grains.

II. Uses:

More than 700 million lbs of mustard are consumed worldwide each year. Yellow mustard is usually used for prepared or table mustard, a condiment, and as dry mustard. Dry mustard is frequently used as a seasoning in mayonnaise, salad dressings, and sauces. Flour made from yellow mustard is an excellent emulsifying agent and stabilizer, and consequently, it is used in sausage preparation. Brown and oriental mustards are also used as oilseed crops. However, the strong flavor of this high-protein oilseed has made it unpopular in the livestock feed and vegetable oil markets of North America. As a result, mustard produced in North America is used primarily as a spice or condiment.

III. Growth Habit:

Mustard is an annual herb with seedlings that emerge rapidly, but then usually grow slowly. Plants cover the ground in 4 to 5 weeks with favorable moisture and temperature conditions. The tap roots will grow 5 ft into the soil under dry conditions, which allows for efficient use of stored soil moisture. Plant height at maturity varies from 30 to 45 in. depending on type, variety, and environmental conditions.

Flower buds are visible about five weeks after emergence. Yellow flowers begin to appear 7 to 10 days later and continue blooming for a longer period with an adequate water supply. A longer flowering period increases the yield potential. About half of the flowers produce dark, reddish-brown seeds that are retained in pods of 0.5 to 0.75 in. in length. Flowers pollinated during the first 15 days of the flowering period produce most of the seed.

IV. Environment Requirements:

A. Climate:

Mustard is a cool season crop that can be grown in a short growing season. Varieties of yellow mustard usually mature in 80 to 85 days whereas brown and oriental types require 90 to 95 days. Seedlings are usually somewhat tolerant to mild frosts after emergence, but severe frosts can destroy the crop. Mustard, especially the brown and oriental types, has a partial drought tolerance between that of wheat and rapeseed. Moisture stress caused by hot, dry conditions during the flowering period frequently causes lower yields.

B. Soil:

Mustard can be raised on variable soil types with good drainage, but is best adapted to fertile, well-drained, loamy soils. Soils prone to crusting prior to seedling emergence can cause problems. This crop will not tolerate waterlogged soils since growth will be stunted. Dry sand and dry, sandy loam soils should also be avoided.

C. Seed Germination:

Seed will germinate at a soil temperature as low as 40°F.

V. Cultural Practices:

A small grain crop following mustard in the rotation will usually yield more than when following continuous small grain. Mustard has several of the same diseases and insect pests as flax, oilseed rape (canola), sweet clover, soybeans, field peas, lentils, and sunflowers. Therefore, crops from this group should be avoided in the same rotation as mustard. Cereal grains are not very susceptible to the pest and disease problems of mustard.

A. Seedbed Preparation:

The seedbed should be firm, fairly level, and free of weeds and previous crop residue. Soil is firm enough for seeding when only a shallow depression of a heel is made when someone stands on the soil. Shallow tillage, just deep enough to kill weeds, should keep soil moisture

close to the surface and leave a firm seedbed. If necessary, the seedbed should be packed before planting to obtain a firm seedbed. Firm seedbeds with adequate moisture allow shallow planting and encourage rapid, uniform seed germination and emergence of seedlings. A number of growers in North Dakota have also successfully planted mustard in standing small-grain stubble and minimum-tilled stubble.

B. Seeding Date:

Planting should occur as early in the season as the environmental conditions allow. The soil temperature should be at least 40 to 45°F at a depth of 1 in. If seedlings are damaged by frost after emergence, 4 or 5 days may pass before the full extent of the damage is known. Plants should recover if the growing points are not destroyed. An earlier seeding date allows plants to benefit from the spring moisture in establishing a good canopy before weeds emerge, and to avoid heat stress during summer that causes flower or pod abortion. Early seeding also reduces the risk of damage from fall frosts that can reduce crop yields and quality. The recommended seeding date in northern Minnesota and Wisconsin is May 1 to 25. Seeding later than May 15 frequently results in lower yields.

C. Method and Rate of Seeding:

Yellow mustard, which has approximately 100,000 seeds/lb, is solid seeded with a grain drill at a rate of 8 to 14 lbs/acre. The higher rate should be used on heavy, fertile soils or on those where emergence is difficult. Brown and oriental mustards have 200,000 seeds/lb and should be solid seeded at a rate of 5 to 7 lbs/acre. Seed is small and must be planted shallow at a 1/2 to 1 in. depth. If very dry soil conditions exist seeding depth should be increased to 1 1/2 in. If mustard stands are poor, quick decisions for reworking and reseeding should be made.

D. Fertility Requirements:

Mustard generally responds to nutrient additions in a similar way as does rape or canola. Soil tests should be used to determine nutrient need. Optimal (medium) soil test levels are about 15 to 20 ppm Bray P, and 80 to 100 ppm K. At these levels fertilizer should be applied at a rate of about 45 lbs/acre P_2O_5 and 80 lb/acre K_2O. When fertilizer is banded, the bands should be placed below and to the side of the seed furrow. Mustard responds well to nitrogen additions with optimum yields occurring at about 100 to 120 lb/acre N. Where mustard follows legumes or manure additions, appropriate credits should be taken.

Work in the western U.S. shows that mustard responds well to sulfur(s) on low S-supplying soils. Sulfur fertil-sandy soils in northwestern Wisconsin and northern Minnesota which have not been manured in the past two years.

On soils deficient in boron (testing at less than 0.5 ppm B), apply 0.5 to 1 lb/acre in a uniform broadcast application. Never band B near the seed.

Soils with a pH near neutral (7.0) are desired for this crop. Nevertheless, an alkaline pH and slightly saline soils are tolerated. Mustard has a tolerance to soil salinity that is similar to barley.

E. Variety Selection:

Varieties of yellow mustard are usually earlier maturing, lower yielding, and shorter in height than brown or oriental varieties. Yield differences among the types of mustard are reflected usually in the prices offered by contracting firms. Contracting firms usually supply growers with the appropriate varieties. Some mustard varieties include:

Gisilba—Yellow mustard. Similar to Ochre in field performance. Originated in Germany. Distributed by Northern Sales Co. Ltd., Winnipeg. Licensed in 1974.

Kirby—Yellow mustard. Released by Colman Foods, Norwich, England in 1970. Distributed by Minn-Dak Growers Association, Grand Forks, ND.

Ochre—Yellow mustard. Released by Agriculture Canada, Saskatoon. Licensed in 1981.

Tilney—Yellow mustard. Similar to Kirby in field performance but has a high mucilage content desired by processors. Released by Colman Foods Norwich, England in 1978. Distributed by Minn-Dak Growers Association, Grand Forks, ND.

Carrow 85—Oriental mustard. Undesirable small seed. Released by Colman Foods, Norwich, England in 1980.

Domo—Oriental mustard. Released by Agriculture Canada, Saskatoon. Licensed in 1977.

Lethbridge 22A—Oriental mustard. Released by Agriculture Canada in 1967, Lethbridge. Licensed in 1974.

Blaze—Brown mustard. Released by Agriculture Canada, Saskatoon. Licensed in 1976.

Varietal trials for mustard in your area should be consulted for yield and other agronomic characters as in Minnesota (Table 1).

F. Weed Control:

Weeds can greatly reduce mustard yields. Weed seeds, which are difficult to remove, can cause high losses during seed cleaning and lower market grades. Good weed control is based on preparation of a clean field and shallow seeding to encourage quick, uniform emergence. Young mustard seedlings do not compete well with weeds and the early establishment of a uniform, vigorous crop helps control annual weeds. The crop cannot be cultivated after emergence.

Mustard, especially the oriental and brown types, should be grown on land with as little wild mustard as possible to avoid costs of removal and loss of tame mustard seeds. Wild mustard seed can be mechanically separated from the larger-seeded yellow type, but separation is not possible with the smaller-seeded brown and oriental types. Wild mustard seed often reduces the crop quality to the sample grade. Production of rapeseed and mustard on the same fields is also not recommended since seed mixtures can occur easily and degrade both crops.

Control of perennial weeds such as Canada thistle, field bindweed, and quackgrass, should be started in the fall or prior to planting in the spring. Control Canada thistle by applying Roundup (glyphosate) before the last killing frost in the fall when it is still actively growing. Spring treatment of Canada thistle prior to planting is not usually adequate for complete control. Apply Roundup to quackgrass when it is at least 8 in. tall and growing actively. Allow 3 days between application and tillage. Control field bindweed with Roundup when it is actively growing on moist sod and is at or past full bloom, preferably in late summer or fall the year before planting mustard. Spring treatment to control perennial weeds before planting is usually not practical.

Trifluralin (Treflan EC) is labeled for use on mustard in Minnesota and North Dakota for control of a wide variety of grasses and broadleaf weeds; however, it will not control wild mustard. The rate of herbicide applied will vary with the soil type, organic matter content, and species of weeds that need to be controlled. Check the label for the correct rate to use on your fields. Trifluralin must be applied before seeding and incorporated thoroughly in the soil for maximum effectiveness. Mustard is sensitive to the broadleaf herbicides used on cereal crops, such as 2,4-D and MCPA, and spray drift from adjacent fields must be avoided. Crops that can be sprayed with 2 4-D or MCPA should follow mustard in the rotation so volunteer plants can be controlled.

G. Diseases and Control:

This crop is vulnerable to several diseases, among which the most serious are Sclerotinia stalk rot (white mold), downy mildew, white rust, leaf spots, and mosaic virus. Good cultural practices are the most effective control measures for diseases. These practices should include keeping records of disease occurrence, compliance with the proper crop rotation, control of host plants for diseases in fallow fields and non-crop areas, and use of seed treatments.

Sunflower, rapeseed, canola, safflower, soybeans, crambe, and drybeans should not be grown in rotation with mustard since they have similar disease problems. If these crops are produced in rotation with mustard, damage from these diseases can increase to economic levels. Numerous broadleaf weeds can also serve as hosts or sources of infection for these diseases. Wild mustard, pigweed, field pennycress, and shepherd's purse are examples of predominant hosts. One of the best methods to avoid serious disease problems in mustard (and leaf diseases of small grains) is to produce this crop in a small grain rotation. Mustard should be spaced four or more years apart in the crop rotation to avoid problems with soil-borne diseases. After potato or flax crops, one year should pass before mustard is raised on the same field due to the presence of root rot or damping-off pathogens.

H. Insects and Other Pests:

Growers should monitor fields closely to detect insect problems that can result in significant yield losses. Flea beetles and caterpillars of the diamondback moth have been the most serious pests. Young seedlings can be seriously damaged by flea beetles soon after emergence. Feeding activity of adult beetles causes a shot-holed appearance to cotyledons and the first true leaves. Damaged plants may die or suffer a reduction in vigor. Hot, sunny weather encourages feeding while cool, damp conditions slows insect feeding and promotes crop growth. Injured plants may wilt and die during hot, dry weather, which results in mild to severe yield losses. Serious crop damage does not usually occur once the crop develops beyond the seedling stage since vigorous plants can outgrow beetle defoliation.

Losses caused by flea beetles can be minimized by practicing the proper cultural methods. A well-tilled, firm seedbed with adequate fertility should permit young seedlings to outgrow beetle damage during the vulnerable stages early in the season. The presence of a few flea beetles or scattered shot-holing is not cause for serious concern. However, if beetles are numerous and feeding damage is present on most cotyledons, prompt control may be necessary. Malathion EC at 1 1/4 lbs/acre, Carbaryl (Sevin) at 1 lb/acre, Ethyl parathion 8E at 1/2 lb/acre, and Thiodan EC at 3/4 lb/acre can be used for control of flea beetles. Read labels for waiting period and correct timing.

Larvae of diamondback moths eat leaves, flowers, and green seed pods. Malathion used at 2 1/2 lbs/acre will control these caterpillars. Damage from sugar beet nematodes can be avoided when sugar beets are not grown on the same field two years before or after mustard, since mustard is a host plant for this nematode. Consult local Extension bulletins for further information on the control of insects and other pests.

I. Harvesting:

The normal maturation of the crop, wind, and rain do not cause shattering before cutting. However, the actual harvesting operations can cause great shattering losses when the plants are overripe. Yellow mustard does not shatter readily and can be straight combined if the crop has matured uniformly (10% moisture) and is free of green weeds. If the crop is weedy or uneven in maturity it should be swathed. Swathing, if deemed necessary or preferred, should be done when 60 to 70% of the seed has turned yellow-green. Plants should be cut just beneath the height of the lowest seed pods. The swath will then settle into the stubble and reduce the chance of being blown by high winds. Yellow mustard does not cure quickly. Straight combining is therefore recommended at 12 to 13% moisture, followed by artificial drying, to obtain uniform quality and highest yield.

Brown and oriental varieties will shatter more readily when ripe and should be swathed. The swathing should begin after the general leaf drop and when the overall field color has changed from green to yellow or brown. Pods sampled from the middle of racemes from several plants, in arm representing the average maturity, should be examined for physiological maturity. About 75% of the seeds may have reached the mature color of yellow or brown. The remaining green seeds will mature in the swath before combining.

Swathing should be done under conditions of high humidity or when morning dew is on ripe pods to decrease shattering losses. Windrows tend to be bulky and subject to scattering by the wind. A roller or steel drum should be used to press the swath into the stubble. The combine should be adjusted so seeds are threshed completely by using the lowest cylinder speed, which is set at approximately 600 RPM, and the appropriate cylinder opening. The reel may cause shattering when straight combining, but it can be removed or lifted above the plants it the stand is good. If the reel is needed, remove half of the bats and reduce its speed. Cylinder speed may need to be adjusted during the day as crop moisture content may vary.

J. Drying and Storage:

When the mustard seed reaches a moisture content of 10% or less it can be stored safely. The harvested seed should be handled carefully since it will crack easily when moved in and out of storage. The damaged seed becomes dockage and is a loss to the grower. Air temperatures for seed drying should not exceed 150°F and seed temperature should stay below 120°F. Use of drying equipment designed for corn or wheat may require some modification when drying mustard. A fine screen will be needed to prevent loss of the smaller seed. Storage bins must be free of cracks or holes.

VI. Yield Potential and Performance Results:

Mustard yields in the Upper Midwest have been variable due to differences among varieties, cultural practices, and environmental conditions. Yields for research trials in Minnesota have ranged from 868 to 1,861 lbs/acre (Table 1.). The MINN-DAK Growers Association reported that yields in the past few years were low due to weather conditions. Growers were producing 800 to 900 lbs/acre of yellow mustard, while brown and oriental mustards were yielding 1,000 to 1,100 lbs/acre. A fair estimate for the yield potential of production fields in the Upper Midwest would be 800 to 1,000 lbs/acre. However, yields of 1,400 lbs or more per acre are possible in areas with favorable growing conditions.

Table 1. Average yield and other agronomic characteristics of yellow, brown, and oriental varieties of mustard in Minnesota field trials*.

Variety	Yield at 3 Locations			Oil[4] (%)	Test weight (lbs/bu)	Seeds Number (1,000 lb)	Days from planting to		Lodging Score[5]	Height (in)
	Roseau 1981-82 94-95 (lbs/acre)	Crookston 980-81 1985 (lbs/acre)	Rosemont 1979-83 (lbs/acre)				Bloom	Maturity		
Yellow (*Brassica hirta*)										
Kirby	1524	868	1144	27	55	89	43	94	3	41
Ochre	1494	927	1222[3]	27	5S	91	41	92	4	39
Tilney	1861[1]	1473	1041[1]	31[2]	54	94	42	94	2	45
Oriental (*Brassica juncea*)										
Domo	1437	1204[2]	1626[3]	38[3]	52	169	45	94	4	45
Brown (*Brassica juncea*)										
Blaze	1595	973	1466[3]	35	53	199	47	94	4	45

*Data from Varietal Trials of Farm Crops, 1990 edition, Minnesota Agricultural Experimental Station, Univ. of Minnesota, Report 24 (AD-MR-1953).
[1]One year of data; [2]Two years of data; [3]Three years of data; [4]Oven-dry basis, average of four years/location; [5]1=erect, 9=horizontal.

VII. Economics of Production and Markets:

The cash production costs are less due to lower seed and pesticide costs than for hard red spring wheat. In 1991 the cash costs were estimated at $67.00 for hard red spring wheat and $56.00 for mustard for northwestern Minnesota.

Mustard is produced as a specialty grain and should be grown under contract to guarantee a selling price and market for the producer. A contract is made by the grower with the shipper to supply seed of a specified quality for delivery at a future date. Contract prices for mustard seed in the Upper Midwest for 1991 were 10.5 cents/lb (up to a certain poundage/acre, such as 600 lbs) for yellow mustard and 9 cents/lb for brown and oriental mustards (up to 800 lbs/acre). Contract prices for Canadian mustard in 1991 were approximately 11 cents/lb for yellow mustard for the first 500 to 1,000 lbs/acre, 9 cents/lb for brown mustard for the first 700 to 1,200 lbs/acre, and 8 cents/lb for the first 500 to 1,200 lbs/acre of oriental mustard.

Consumption of mustard has been steady and growth of the mustard market is directly related to population growth. This stability of demand is due to the lack of any real substitutes for mustard. Consumers will not substitute for mustard as this would not save much money. There is a limited number of alternative markets when a surplus is produced.

VIII. Information Sources:

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Peanut

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I. History:

The cultivated peanut or groundnut (*Arachis hypogaea* L.), originated in South America (Bolivia and adjoining countries) and is now grown throughout the tropical an warm temperate regions of the, world. This crop was grown widely by native peoples of the New World at the time of European expansion in the sixteenth century and was subsequently taken to Europe, Africa, Asia, and the Pacific Islands. Peanut was introduced to the present southeastern United States during colonial times. Peanut was grown primarily as a garden crop in the United States until 1870. As a field crop, peanut was used commonly for hog pasture until about 1930.

Peanut, an important oil and food crop, is currently grown on approximately 42 million acres worldwide. It is the third major oilseed of the world next to soybean and cotton (FAO Food Outlook, 1990). India, China, and the United States have been the leading producers for over 25 years and grow about 70% of the world crop. Peanut was ranked ninth in acreage among major row crops in the United States during 1982 and second in dollar value per acre. Production of peanut in the U.S.A. during 1989-1990 was estimated at 1.8 million tons. or about 8% of the world production of 23.2 million tons (FAO Food Outlook, 1990). In 1983, Georgia, Texas, Alabama, and North Carolina grew 80% of the 1,375,000 acres of peanut in the United States. Virginia, Oklahoma, Florida, South Carolina, and New Mexico were the other states with more than 10,000 acres of peanut.

The peanut crop in the U.S.A. is composed of four market types from two subspecies. *A. hypogaea hypogaea* includes the Virginia and Runner market types. The second subspecies, *A. hypogaea fastigiata*, includes two botanical varieties of economic importance: *vulgaris*, the Spanish market type, and *fastigiata*, the Valencia market type. Virginia peanuts have the largest pods and elongated seeds, while Runner peanuts are medium-size varieties of the Virginia type. Spanish types have smaller round seeds and Valencia is intermediate in size and shape. Valencia is grown primarily in New Mexico, Spanish in Oklahoma and Texas, and other types in the Southeast and Texas. The Runner type includes 70% of the edible trade in the U.S.A. with Virginia and Spanish accounting for 20 and 10%, respectively. Valencia peanuts generally constitute less than 1% of the U.S. market (Knauft and Gorbet, 1989).

Peanut has only occasionally been grown in northern states due to its warm temperature requirement. Use of poorly adapted varieties and improper production practices usually resulted in low yields and poor quality nuts. However, peanut has good potential as a food crop in Minnesota and Wisconsin and could be an alternative cash crop to soybean, corn, potato, or fieldbean (Robinson, 1984, and Pendleton, 1977).

II. Uses:

All parts of the peanut plant can be used. The peanut, grown primarily for human consumption, has several uses as whole seeds or is processed to make peanut butter, oil, and other products. The seed contains 25 to 32% protein (average of 25% digestible protein) and 42 to 52% oil. A pound of peanuts is high in food energy and provides approximately the same energy value as 2 pounds of beef, 1.5 pounds of Cheddar cheese, 9 pints of milk, or 36 medium-size eggs (Woodroof, 1983).

Peanuts are consumed chiefly as roasted seeds or peanut butter in the United States compared to use as oil elsewhere in the world. Americans eat about 4 million pounds (unshelled weight) of peanuts each day. Approximately two-thirds of all U.S. peanuts are used for food products of which most are made into peanut butter. Salted and shelled peanuts, candy, and roasted-in-shell peanuts are the next most common uses for peanuts produced in this country. The remaining one-third of annual production is used for seed, feed, production of oil, or exported as food or oil. The large nuts sold as in- and out-of-shell are supplied by Virginia (confectionery or cocktail) and Runner ("beer nuts") types. Spanish varieties supply small shelled nuts, "redskins", and the Valencia type is used for medium-size nuts in the shell. Runner and Spanish are made into peanut butter while all types are used for peanut products that do not require a specific seed size.

Nonfood products such as soaps, medicines, cosmetics, and lubricants can be made from peanuts. The vines with leaves are an excellent high protein hay for horses and ruminant livestock. The pods or shells serve as high fiber roughage in livestock feed, fuel (fireplace "logs"), mulch, and are used in manufacturing particle board or fertilizer.

III. Growth Habits:

Peanut is a self-pollinating, indeterminate, annual, herbaceous legume. Natural cross pollination occurs at rates of less than 1% to greater than 6% due to atypical flowers or action of bees (Coffelt, 1989). The fruit is a pod with one to five seeds that develops underground within a needlelike structure called a peg, an elongated ovarian structure.

Peanut emergence is intermediate between the epigeal (hypocotyl elongates and cotyledons emerge above ground as in soybean) and hypogeal (cotyledons remain below ground as in fieldpea) types. The hypocotyl elongates but usually stops before cotyledons emerge. Leaves are alternate and pinnate with four leaflets (two pairs of leaflets per leaf). The peanut plant can be erect or prostrate (6 to 24 in. tall or more) with a well developed taproot and many lateral roots and nodules. Plants develop three major stems, i.e., two stems from the cotyledonary axillary buds equal in size to the central stem during early growth.

Bright yellow flowers with both male and female parts are located on inflorescences resembling spikes in the axils of leaves. One to several flowers may be present at each node and are usually more abundant at lower nodes. The first flowers appear at 4 to 6 weeks after planting and maximum flower production occurs 6 to 10 weeks after planting.

Eight to 14 days after pollination aerial pegs will grow 2 to 3 in. into the soil and then turn to a horizontal orientation to mature into a peanut pod. Pods reach maximum size after 2 to 3 weeks in the soil, maximum oil content in 6 to 7 weeks, and maximum protein content after 5 to 8 weeks. The peanut crop matures after 7 to 9 weeks in the soil, which is indicated by maximum levels of protein, oil, dry matter, and presence of darkened veining and brown splotching inside the pod. Peanuts usually require a minimum of 100 to 150 days from planting to maturity depending on the variety planted.

Flowering continues over a long period and pods are in all stages of development at harvest. Pegs will eventually rot in the soil (25% after 12 weeks in the soil) and the resulting loose pods are lost during the harvest. Since the pod wall is needed to protect the seed, as it is moved through the various markets from producer to processor or consumer, yields and farm prices are based on a pod rather than seed basis.

IV. Environment Requirements:

A. Climate:

Temperature is the major limiting factor for peanut yield in northern states since a minimum of 3,000 growing degree-days (with a base of 50°F) is required for proper growth and development (Robinson, 1984). A peanut crop will not reach optimum maturity for a marketable yield to justify commercial production in areas with fewer heat units during the growing season. This eliminates some of Minnesota and most of Wisconsin as practical production areas. Little if any growth and development occur at temperatures below 56°F (Emery et al., 1969) and 86°F is reported to be optimal (Ketring, 1984).

Rainfall distribution varies greatly from western Minnesota to south eastern Wisconsin and irrigation may be a yield-stabilizing factor. University of Minnesota studies over a six-year period indicated that irrigation of sandy soil increased average yield by 1,000 to 1,450 lb/acre. However, in some years it did not increase yields appreciably, and irrigation expenses and lower land values may give an economic advantage to dryland production over use of irrigation. Research in Ontario, Canada indicated that the most critical time to apply water was during the flowering period.

B. Soil:

Soil for peanut production should be a light-colored, light textured with good drainage, and moderately low amounts of organic matter. Such soil is preferred since it is usually loose and friable, permitting easier penetration of roots and pegs, better percolation of rainfall, and easier harvesting. Light-colored soils reduce staining of pods which ensures greater eye appeal when the crop is used for unshelled nuts. Well-drained soils provide proper aeration for the roots and nitrifying bacteria that are necessary for proper mineral nutrition of the plant. Medium to heavy soils or those with a high clay content should also be avoided due to excessive loss of pods when harvesting peanuts.

Organic matter should be maintained at a level of 1 to 2% to improve water-holding capacity of the soil and supply plant nutrients. Peanut grows best in slightly acidic soils with a pH of 6.0 to 6.5, but a range of 5.5 to 7.0 is acceptable. Saline soils are not suitable since peanut has a very low salt tolerance (Weiss, 1983).

C. Seed Preparation and Germination:

Poor stand is perhaps the most common cause of low yields. To obtain a full stand, use undamaged seed with intact seed coats and treat shelled seed with an approved seed protectant prior to planting. Planting seeds rather than pods allows for easier machine planting and more uniform stands. Robinson (1984) reported higher yields when seed was used because planting pods delayed emergence due to slower absorption of moisture into the shells.

V. Cultural Practices:

A. Seedbed Preparation:

Peanut should not be grown in the same fields for successive years, but should be produced in a crop rotation plan. Soil samples should be taken before pre-plant field preparation to determine nutrient needs. Fertilizer, if needed, may be broadcast prior to plowing. Plow 8 to 9 in. deep to completely cover plant residues, which reduces losses from stem- and peg-root diseases (*Sclerotium rolfsii*) and weeds. The operations necessary to produce a seedbed for corn or soybean are suitable for peanut.

B. Seeding Date:

Planting in early June was originally favored in Minnesota due to the warm temperature required for optimal growth of peanut. However, planting in early May gave higher yields, larger seeds, and higher shelling percentage (Table 1). Peanut planted in early May required 9 more days to emerge and had a slower development than a crop planted in June. However, the planting in early May flowered earlier which allowed more pods to reach maturity before frost.

Table 1. Yields of early-, medium-, and late-planted peanut on different soil types in Minnesota, 1981 - 1982[1].

Planting Dates	Silt Loam	Dryland Sand	Irrigated Sand	All 3 Soils (Avg.)
	lb Pods/acre			
April 29 - May 6	1290	1000	1940	1380
May 14 - May 21	1260	860	1540	1220
June 1 - June 2	1060	590	1170	940

[1]From R.G. Robinson (1994).

C. Method and Rate of Seeding:

Plant seeds on smooth, uniform, well-prepared seedbeds with planting equipment properly adjusted to prevent damage to the fragile seed. Seed that splits will not germinate and grow. The short plant height of Spanish varieties results in them not filling 30 in. rows, yet other varieties may fill them by midsummer. Spanish and Valencia varieties had greater yields with 18 in. row spacing than in 30 in. rows, except on dryland sand (Table 2). The narrow 18-inch row spacing is about minimum for tractor wheels when cultivating (due to crop damage and yield reduction), and 22 in. is often better. Peanut planted in narrow row spacing appears to result in greater yields, yet the row spacing used for planting will largely depend on the type of planting and harvesting equipment available.

Table 2. Effects of different row spacings and soil types on yields of peanut in Minnesota, 1981 - 1992[1].

Soil Type	Row Spacing (in)	
	18	30
	lb Pods/acre	
Silt Loam	1580	1370
Dryland Sand	1210	1250
Irrigated Sand	1870	1680

[1]Data from R.G. Robinson (1984).

Comparison of ridge- and level-planted peanut in Minnesota indicated that ridge planting resulted in earlier flowering by 1 to 2 days but had no other advantages. Ridge planting might be better for some harvesting machinery. A late hill-up cultivation showed no advantage over level cultivation. For once-over harvesting, researchers from Ontario, Canada recommend planting on level fields parallel to the direction of plowing in rows spaced 24 in. apart.

Planting rates should be expressed in seeds per acre rather than pounds per acre since varieties and seed lots vary greatly. The highest yields were produced in 18 in. rows planted with 105,000 seeds per acre while highest yields from 30 in. row spacing resulted from only 70,000 seeds per acre. Seventy-thousand seeds per acre produced highest yields on drylands and where row spacing had no effect. A seeding rate of 90,000 seeds per acre is recommended in Minnesota and Wisconsin with adjustments for germination below 90%, soil texture, and seed price-

Seed should be planted 1 to 2 in. deep since at greater depths, slower and poorer emergence results. However, planting 2 to 4 in. deep to reach moisture in sandy soil is successful in late May or early June in Minnesota. Time to emergence varies with seed quality, and soil temperature, moisture, and texture. It is typical for peanut to have a slower emergence than soybean in Minnesota.

D. Fertility and Lime Requirements:

Peanut responds well to residual soil fertility from previous crops in the rotation, but usually has a low response to fertilizer in soils with medium to high fertility levels. When nutrients are needed (low or very low soil test levels) broadcast applications are recommended especially of potash due to the low salt tolerance of peanut. Rates should be similar to those used for soybean. Since it is a legume, peanut can biologically fix its own nitrogen. The adequacy of farm soils for fertility for peanut should be checked with soil tests. Optimum pH levels of 6.0 to 6.5 will usually result in adequate calcium being present, however on lighter soils especially where long term applications of potash have been made, Ca may be limiting pod formation. Soil test Ca should be above 600 to 800 ppm. Although plant analysis may be useful for micronutrient levels, it does not detect Ca shortages in storage organs such as peanut pods. The severe calcium and micronutrient deficiencies that occur in the major peanut production areas are not likely here. Nitrogen fertilizer or seed inoculation with the proper *Rhizobium* strain is needed for a crop on irrigated sandy soil (Table 3). One-hundred-fifty pounds of nitrogen per acre were required to equal the yield produced with seed inoculation alone. An alternative to seed inoculation is to place granular inoculants in the seed furrow with a planter attachment.

Table 3. Yield response of Valencia and Spanish peanut to rhizobial inoculation or nitrogen fertilizer on dryland and irrigated sandy soil in Minnesota, 1982[1].

Treatment	Dryland	Irrigated
	lb Pods/acre	
Untreated	570	930
Inoculation	490	1380
N, 50 lbs/acre, 6/2	610	1050
N, 150 lbs/acre (50 lbs. each on 6/2, 7/1, 7/28)	480	1390

[1]Data from R.G. Robinson (1994).

E. Variety Selection:

The variety selected will depend largely on soil type and length of growing season. The Spanish type will mature sooner (90 to 120 days) than Runner or Virginia types. Most Valencia varieties mature in 90 to 110 days while Runner and Virginia types require 130 to 150 days to reach maturity. Previous attempts to raise peanut in Minnesota and Wisconsin usually involved Spanish and occasionally Runner and Virginia varieties. Only earlymaturing varieties of the Valencia type are grown commercially in Ontario, Canada.

Field trials in Minnesota and Wisconsin indicated that Valencia and Spanish varieties with shorter maturity were most promising (Tables 4 and 5). These types initiate pegs from leaf axils on the main stem, and consequently, some pods mature sooner than those of Virginia and Runner types that do not produce pegs on the main stem. Valencia varieties produced much cleaner pods than Spanish varieties that required washing after harvest, especially when grown in nonsandy soil.

Table 4. Yields of peanut varieties in Minnesota on three soils, 1981 ö 1993[1].

Variety	Market Type	Soil Type		
		Silt Loam	Dryland Sand	Irrigated Sand
		lb Pods/acre		
Minnesota X52	Vallencia-Spanish	1580	1320	1820
McRan	Valencia	1540	1210	1700
Valencia C	Valencia	1480	1250	1590
Pronto	Spanish	1450	1210	1420
Valencia A	Valencia	1490	1180	1370
Early Spanish	Spanish	1260	1260	1000
Delhi	Spanish	1200	1130	1100
NC 7	Virginia	540	390	410
Florunner	Runner	480	330	390

[1]Data from R.G. Robinson (1984).

Table 5. Yield and agronomic characteristics of peanuts grown at Hancock, Wisconsin, 1976.[1]

Variety	Type	Yield[2]	Shelling	Seed Weight	Height[3]

			%	(g/100 Seeds)	(in.)
1. Delhi	Spanish	2770	64.3	30.5	16
2. A-114	Spanish	3100	66.3	28.5	12
3. Comet	Spanish	2657	64.5	30.4	16
4. Trifspan	Spanish	2746	67.6	30.6	12
5. Tamnut	Spanish	2323	64.6	31.2	15
6. Valencia	Valencia	2653	70.2	36.6	21
7. Tennessee Red	Valencia	2536	69.8	37.1	21
Average		2684	66.7	32.1	16
LSD 0.05			4.8	3.6	2

[1]Data from Pendleton and Weis, (1977). Planted May 15; harvested October 7
[2]Pounds of dry pods/acre
[3]9/9/76

Growers should also consider varieties developed in Ontario at the University of Guelph (i.e., OAC Garroy, OAC Tango, or OAC Ruby.). Garroy is a red-seeded Valencia type with an erect plant habit that yields consistently higher than U.S. varieties. Ruby is a higher-yielding replacement for Garroy. Ontario varieties are usually planted at the same time as soybeans and should mature in 110 to 120 days. Seed for these varieties can be obtained from Department of Crop Science, University of Guelph, Guelph, Ontario N1G 2W1.

E. Weed Control:

Weeds can lower yields significantly and make harvesting difficult. Peanut plants grow more slowly than soybeans and take almost three months to achieve a complete ground cover. As a result the combination of cultivation and herbicides is usually necessary. In major peanut production states, crop rotation is the first step in a sound weed management program.

1. Mechanical: Cultivation requires the use of sweeps to skim just beneath the soil surface or use of carefully adjusted rotary gangs (rolling cultivator). Precise depth and lateral control of either cultivator is necessary to avoid making preemergence herbicide (if applied) ineffective or causing peanut injury with an accompanying reduction in yields and quality. Improper cultivation will damage plants and provide an entry point for disease organisms. Soil thrown on plants by cultivation will inhibit flower, peg, and pod development. When preemergence or preplant herbicides have not been used, mechanical weeding is possible prior to emergence of seedlings, which is usually about 7 days after planting. Two weeding operations are usually sufficient, the first performed at 14 to 20 days after planting. The second cultivation is dependent on weed growth, but it is not recommended to delay it later than 60 days after planting (1983, Weiss).

2. Chemical: Many herbicides are registered for use in peanut. These include Balan (PPI), Basagran (POST), Blazer (POST), 2,4-DB (POST), Dual (PPI or PRE), alachlor (Lasso and other names) (PPI, PRE), POAST (POST), PROWL (PPI), and SONALAN (PPI). Tank mixes of several of these products can be applied to broaden the spectrum of weeds controlled. Consult the product label for information on rates, tank mixes, harvest intervals, etc.

G. Disease and Their Control:

Research plots in Minnesota or Wisconsin did not have serious injury from diseases. Leaf spot diseases were observed in August. Disease problems may appear with continued peanut production in northern states.

H. Insects and Other Predators and Their Control:

Injury from insects occurred rarely in Minnesota or Wisconsin research plots. Potato leafhopper was controlled in a few trials. Birds were a problem in eating peanut left in windrows to dry. Insects, nematodes, and diseases that are a problem to peanut production are controlled by crop rotation and/or pesticides in southern states.

I. Harvesting:

The optimum time for harvesting is when most pods have a veined surface, seed coats are colored, and 75% of pods show darkening on the inner surface of the hull. However, peanut does not reach this stage in Minnesota, so immature pods are removed in the threshing, drying, and cleaning operations. Harvesting in northern areas should begin after the first killing frost if soil moisture is at a level suitable for cultivation since wet soil sticks to pods.

Harvesting usually starts with clipping or coultering. Rotary mowers remove up to half of the top growth when plant growth is too great for efficient harvesting. A killing frost may make this step unnecessary, since most of the leaves may have already fallen off the plant. Varieties with prostrate growth may overlap between rows and a coulter makes the vertical cut between rows. The next operation frequently uses a digger-shaker-windrower. Dig deep enough to prevent cutting pegs. Windrow-inverting attachments orient plants as they leave the shaker so pods are primarily on the top of windrows to permit more air circulation and exposure to sunlight for a shorter drying time.

Windrowed peanut may be combined-harvested wet (35 to 50% moisture), semidry (18 to 25%), or dry (8 to 10%). These peanuts may reach the semidry condition (seeds rattle in pods) 1 to 3 days after digging. Drying in the windrow to a moisture level of 8 to 10% requires 5 to 10 days of good drying weather. However, peanut remaining in windrows for several days is more susceptible to weather damage than when freshly dug.

Combining wet (green) or preferably semidry peanut, followed by artificial drying, may result in better quality nuts. Adjust combines regularly to give more picking action when vines are tough, and reduce picking action when vines are dry, to obtain good picking efficiency and minimize mechanical damage to peanut hulls.

White and Roy (1982) reported that a once-over harvester used for peanut variety Valencia gave 50% more total harvested yield than conventional digging and combining methods. Percentage of loose, shelled seeds was reduced from 10 to 1%, and subsequent germination improved from 45 to 86%. A once-over harvester developed in Canada had less than 3% loss and 1% mechanical damage while maintaining high viability of seed. Certain cultural practices were recommended to make once-over harvesting easier and more efficient than use of a digger-shaker-windrower.

J. Drying and Storage:

The two most important operations in handling peanut after harvest are cleaning and drying to a safe moisture content (5 to 10%). Pods should be kept dry and protected against infestation from insects or rodents, as well as from loss of natural color and flavor, and prevention of the development of off-flavors and rancidity. Artificial drying of wet or semidry peanut should start immediately after combining to prevent mold growth and aflatoxin formation. Presence of aflatoxin is a concern in peanut production states with warmer climates. However, cool September and October temperatures in Minnesota should minimize this problem when proper drying and storage practices are followed.

Unheated air may be used for drying when relative humidity is below 65%. Besides removal of water, drying causes physical and biochemical changes that can be harmful or beneficial to flavor and quality. Peanut seed should not be heated above 95°F to avoid off-flavors, and the drying rate should not exceed 0.5% per hour. Safe storage of peanut requires an atmosphere with low relative humidity (60 to 70%). Robinson (1984) reported that peanut maintains a moisture content of about 7% at a relative humidity of 65 to 70%. The National Peanut Council has published detailed information on the proper handling, storage, processing, and testing of peanuts.

Peanut saved for seed must be protected from insect pests and rodents as well as from high temperatures and high relative humidities (70%). Peanut is usually stored in the form of unshelled nuts. Seven to eight month storage is usually required for peanut used as seed, and those intended for food uses can be stored until the start of next harvesting season. Seed harvested from Minnesota research plots usually tested over 90% germination. Seed retained viability longer when stored in the pod than when shelled. Seed stored with 5% moisture content lost viability more slowly than seed with 8% moisture, but relative humidity must be less than 50% to maintain such a low moisture level. In a storage trial in Minnesota, shelled seed maintained viability for three years when kept frozen (32°F) and for one year in a heated (68°F) office.

Most seed sold to growers is treated with fungicides to prevent damage from seed-rotting and damping-off fungi in the soil. Germination and emergence of hand-shelled seed was also improved when treated with fungicides. Seed satisfactory for planting can be produced in Minnesota.

VI. Yield Potential and Performance Results:

Previous attempts to raise peanut in Minnesota and Wisconsin usually involved Spanish and occasionally Runner and Virginia varieties. Few of the many peanut varieties and introductions have been grown in the Upper Midwest, but field trials indicated that Valencia and Spanish types were most promising due to shorter crop times. Average yields in Minnesota trials ranged from 400 to 1800 lb/acre (Table 4) while a trial conducted in Wisconsin had yields ranging from 2300 to 3100 lb/acre. OAC Garroy, a Valencia-type variety, yielded 2400 lb/acre in Ontario, Canada. The varieties developed in Ontario should also be considered for use in Minnesota and Wisconsin.

VII. Economics of Production and Markets:

Peanut markets are well established and shortages of this protein-rich crop have occurred. Acreage allotments in the U.S.A. were discontinued in 1981 so anyone can grow peanut, but only previous growers were given allotments for quota-peanut poundage that are eligible for quota-peanut price support. Peanut production in the U.S. during 1982 was limited by legislation at 1,614,000 acres for quota-peanut price supports. Quota peanuts have a higher price support ($642.79/short ton or 32 cents/lb in 1990-1991) than non-quota or additional peanuts ($149.79/short ton or 7.5 cents/lb) whether grown by quota or non-quota producers.

Peanuts from new growers, the third category of production, can only be sold for export or crushed for oil at the additional peanut price (minimum of 7.5 cents/lb). Allotments for quota-peanut poundage would not apply for peanut grown in the Midwest. Higher prices on the world market would encourage production by new growers. However, the lower quality peanut produced due to a shorter growing season (lack of uniform maturity of a crop) would be used for oil and meal production, and realize a much lower return for the farmer. If commercial peanut production will be extended to the Upper Midwest, additional research is needed to develop varieties that are earlier maturing and require fewer heat units to produce a good crop. Peanut production in the Upper Midwest at this time is economically inefficient until earlier maturing varieties become available.

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Popcorn

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I. History:

Popcorn is a special kind of flint corn that was selected by Indians in early western civilizations. Although U.S. commercial popcorn production has always been centered in the Corn Belt, the major growing areas within this region have shifted over the years. Up to the mid 1940s, Iowa was the number one producer, with both production and processing plants concentrated in the western part of the state. Then, as popcorn hybrids began replacing open-pollinated varieties, production shifted eastward, first to Illinois and then to Indiana. Another major shift occurred in the mid 1970s when production jumped back to the west, so that Nebraska is now the leading popcorn producer.

Total U.S. popcorn acreage over the 5-year period 1977-81 averaged 189,000 acres per year, with 55% of that total in Nebraska and Indiana, and another 25% in Iowa, Ohio and Illinois.

II. Uses:

Popcorn is sold either as a plain or flavor-added popped product, or as an unpopped product in moisture-proof containers ranging from plastic bags and sealed jars to ready-to-use containers both for conventional and microwave popping. Popcorn flavor is enhanced to individual tastes with the addition of salt and butter. There is no end to the uses of popcorn. One recipe book lists 200 different recipes.

Nutritionally, it is one of the best all-around snack foods, providing 67% as much protein, 110% as much iron and as much calcium as an equal amount of beef. An average 1.5-ounce serving of popcorn supplies the same energy as two eggs; and a cup of unbuttered popcorn contains less calories than half a medium grapefruit. In addition, hull is excellent roughage, comparing favorably with bran flakes or whole wheat toast.

III. Growth Habits:

Popcorn moves through commercial channels primarily in three kernel types: white, small yellow and large yellow. White popcorn characteristically has a rice-shaped kernel, while yellow popcorn kernels are pearl-shaped. The three kernel types meet different needs within the industry, and growers and/or processors must take that into consideration when selecting hybrids. Kernel color of specialty popcorn may also be blue, red, black, or brown.

The popped appearance may resemble either a butterfly or a mushroom. The butterfly type is preferred for eating; while the mushroom type is used in confectionery products.

In performance trials, a hybrid is usually identified as one of the above types, although some medium-kernel yellows are now available that meet either the small- or large-kernel requirements after grading. No industry standards have been developed for kernel size determinations; but a commonly used measure is based on number of kernels in 10 grams and defines kernel size as follows:52-67 = large, 68-75 = medium and 76-105 small.

Popcorn hybrids generally have smaller plants and about 2/3 the yield per plant than dent corn. Stalk strength is relatively poor compared to dent corn hybrids.

IV. Environment Requirements:

A. Climate:

Popcorn growth requirements are similar to those for dent corn, with less adaptability to environmental extremes. Popcorn seed germinates more slowly than dent corn, and seedling growth is also slower. Although popcorn varieties are available with maturities as early as 90 days, extensive development of top performing hybrids is limited to those with maturities of 110-days or later.

B. Soil:

Although there is little experimental data regarding effects of soil type on popcorn production, grower experience has shown that any soil type suitable for dent corn should produce a good popcorn crop. However, experience also indicates that popcorn is likely to perform better on medium- to coarse-textured soils (coupled with adequate rainfall or supplemental irrigation) than on fine-textured, poorly drained soils for at least two reasons:

- Popcorn seed germinates more slowly than dent corn, and the seedlings grow more slowly; thus, medium- to coarse-textured soils, which warm slightly faster than fine-textured soils, should improve germination, emergence and seedling establishment.
- The popcorn root system is less extensive than that of dent corn; thus, high-clay-content and/or poorly drained soils foster weak, shallow rooting that reduces yields and increases lodging.

V. Cultural Practices:

A. Seedbed Preparation:

Careful seedbed preparation is important because seed size is small. A clod-free seedbed with good tilth will ensure coverage of the seed placed just deep enough (1 -2 inches) to be in contact with moist soil.

B. Seeding Date:

Timely planting of popcorn is very important because of its slow germination and seedling growth and because it must reach harvest maturity (see Harvesting section) for maximum popping expansion. Planting should not occur until early-May when soils warm to temperatures conducive to rapid germination and emergence. Planting delays after mid-May need to be balanced with popcorn maturities and the length of growing season.

C. Method and Rate of Seeding:

For plate planters, special popcorn plates are required, and recommendations of the equipment manufacturer should be followed. Both seed size (number of kernels per pound) and grade should appear on the popcorn seed bags.

Little information is available concerning the effects of plant density on the performance of popcorn hybrids. Commonly, seeding rates for popcorn are higher than for dent corn because of its smaller plant size and lower yield per plant. However, if plant populations are too high, the relatively poor stalk strength of popcorn hybrids can result in severe lodging. Generally, a 5 to 25% increase over the recommended dent corn plant densities should be considered for most soils and cultural practices.

D. Fertility and Lime Requirements:

A pH of 6.0 is adequate for popcorn. Test the soil and apply the amount of lime recommended to achieve this pH. Thorough incorporation and mixing are important.

Nutrient requirements for popcorn are estimated to be 85% of those for field corn. Soil P and K should test in the medium to high range (30 to 75 lbs of P and 160 to 240 lbs K per acre). Apply any corrective phosphate or potash recommended on the soil test report.

Maintenance fertilizer equivalent to crop removal should be applied to maintain soil test P and K levels. Nitrogen requirements and maintenance recommendations for phosphate and potash are given in Table 1.

Table 1: Annual nitrogen, phosphate and potash recommendations for popcorn.

Yield goal	Soil organic matter, T/a					Soil Test P			Soil Test K		
	0-20	21-35	36-75	76-100	>100	H or below	VH	EH	H or below	VH	EH
bu/A	lbs N/a					lbs P_2O_5/a			lbs K_2O/a		
80-100	100	80	60	30	20	30	15	0	20	10	0
101-120	120	100	80	40	30	35	20	0	25	15	0
121-140	140	120	100	60	40	40	20	0	30	15	0
141-160	160	140	120	80	60	45	25	0	35	20	0

Credits for a preceding legume crop and use of manure should be subtracted from these recommendations.

Dent corn fertilizer programs adapted to popcorn production should take into consideration popcorn's relatively poor standing ability. Very high rates of N can compound lodging problems, especially if soil test K levels are low. Also, because popcorn seedlings grow more slowly than dent corn, the application of starter fertilizer is probably of greater importance.

E. Variety Selection:

Popcorn growers shifted from open-pollinated varieties to hybrids for some of the same reasons that dent corn growers did -improved yield and better standing ability. Also, hybrids have better popping expansion and more uniform kernel type and maturity.

A major consideration in hybrid selection is maturity. Maximum popping potential of a hybrid can be achieved only if it reaches full maturity. Any factor that prematurely terminates plant development (e.g., drought stress, disease, frost, etc.) reduces popping potential, and may result in a crop not marketable as popping corn. Therefore, growers should select hybrids that will usually mature before frost in their area. If planting must be delayed much past normal dates, consider an earlier-maturing hybrid or an alternative crop.

Some popcorn hybrids are dent-sterile and cannot be pollinated by ordinary types of dent or sweet corns. In popcorn *seed fields* (where the harvested crop is to be used as seed for the following year's crop), dent sterility is important because it prevents cross pollination with dent corn. Corn harvested from plants grown from outcrossed seed has very poor popping ability. Thus, if the ears from these outcrossed plants are not sorted out before shelling, it is virtually impossible to remove all kernels from these ears in the cleaning and grading operation. This adversely affects the quality and appearance of the total crop. For this reason, dent-sterile hybrids are especially desirable where popcorn is to be field-shelled.

In popcorn *production fields* where the harvested crop is to be used for popping, isolation from other types of corn is unnecessary, even if the popcorn is not dent-sterile. Pollen from other corn does not have any effect on the popping ability of popcorn hybrids.

The "right" popcorn hybrids must meet the needs of both grower and consumer. The grower wants high yields, strong stalks and good disease resistance; the consumer wants popped corn that's tender, good tasting and free from hulls. Current commercial hybrids involve some compromise among these requirements.

A large portion of commercial popcorn acreage is contracted with growers by popcorn processors. In most instances, the contracts specify that the processor will determine the hybrids to be used. Growers producing uncontracted popcorn may, of course, grow any hybrid they choose. Sources of information about hybrids include state Extension Services, popcorn seed companies or the current "Hybrid Popcorn Performance Trials" from the Agricultural Experiment Station, Purdue University, West Lafayette, IN 47907.

F. Weed Control:

The same weeds that commonly infest dent corn fields are also found in popcorn fields. Yield losses will occur when popcorn has to compete with weeds for the nutrients, light and moisture essential to maximum growth and development. Also, certain weed species may serve as alternate hosts for disease and insect pests of popcorn.

Cultural mechanical, and chemical methods for weed control in popcorn are similar to those used for dent corn. For chemical control methods, consult your county Extension office or popcorn company agronomist. Follow recommendations, and apply as directed on the herbicide label. Neither Banvel nor 2,4-D are registered for use in popcorn.

G. Diseases and Their Control:

As with weeds and insects, popcorn is subject to the diseases common to dent corn. Fortunately, not all of these diseases are of economic importance and may pass from year-to-year without notice. A few, however, are widespread and can substantially reduce yield and quality if conditions are optimum for infection.

Stalk and root rot diseases are often the most destructive in popcorn. Symptoms are usually first noted when the crop nears physiological maturity. The disease complex is generally caused by several fungal and/or bacterial pathogens rather than by a single causal agent. Yield losses are the result of infected plants having poorly filled ears or lodged plants and dropped ears that escape harvest.

Satisfactory control of popcorn diseases involves a combination of sound cultural practices, which include crop rotation, proper fertilization, proper management of crop residue, use of disease-resistant hybrids and appropriate applications of chemical treatments. Consult state recommendations for specific practices tailored to fit local situations.

H. Insects and Their Control:

Most, if not all, insects that attack dent corn also can attack popcorn. Follow state recommendations and the specific information on the product labels regarding application, safety, and restrictions.

I. Harvesting:

Much popcorn acreage today is harvested by combine, despite the fact that there is likely to be more kernel damage, and thus a reduction in popping volume. Processors who want maximum popping volume may contract with farmers to harvest their popcorn on the ear. While this usually increases production costs, it also results in a higher quality popcorn with more potential popping volume. Combined popcorn can give satisfactory popping volumes if it is harvested at the correct moisture content by a properly adjusted combine.

Shelled Grain-harvesting. Popcorn shelled with a combine in the field should have a field moisture of between 14 and 18%. with the optimum being 16-17%. Above 18% moisture, shelling losses are high and there is much **physical damage** to the kernels. Below 14%, the kernels are too susceptible to **impact damage** from combining and associated handling operation; and as already mentioned, kernel damage lowers popping volume.

Combine settings are different for popcorn than for dent corn, and adjustments must be made when switching to popcorn. The cylinder speed, concave clearance and other adjustments should be set to provide a balance between shelling efficiency, machine losses and degree of physical damage to the popcorn. Slower cylinder speeds and wider concave clearances reduce kernel damage. A combine operated at or near its rated capacity will produce less kernel damage than when operated at relatively low levels of throughput. Further "fine tuning" will also likely be needed to account for specific harvest conditions, harvest moisture and popcorn hybrid.

Ear-harvesting. With a heated forced-air system to dry the ears promptly to a safe storage moisture, popcorn can be harvested at 25% moisture. Such a system must be so designed that the drying process does not affect the potential popping volume of the popcorn. With an unheated forced-air system or naturally ventilated storage, ear-harvested popcorn should field-dry to at least 20 (preferably 18) % moisture and then be harvested promptly to minimize field losses.

Like combines, ear pickers can also damage popcorn kernels if not operated properly. Special rubber snapping rolls are available for ear harvesting of popcorn; they cause less damage than the steel ones used for dent corn picking.

Hand-harvesting. The home gardener or small, noncommercial producer can hand-harvest popcorn anytime after it reaches physiological maturity (approximately 35% moisture). Well-ventilated storage must be available to allow the ears to dry without molding. They can be dried by spreading them on covered concrete floors for several weeks.

Factors other than moisture content can influence when to harvest a given popcorn crop. These include incidence of disease, insect and bird damage and freezing temperatures. Popping volume is not affected by a light frost once moisture content drops below 30%; but it could be significantly reduced by a hard freeze when kernel moisture is above 20%. On this basis, it may sometimes be better to harvest and artificially dry popcorn than risk a hard freeze. Below 20% moisture, freezing apparently has little or no effect on popping volume.

J. Conditioning:

To be high-quality, popcorn must be free of microbial contamination and insect and rodent damage. Aside from that, the most important factor influencing the economic value of popcorn is popping volume - i.e., the volume of popped corn produced from a given weight of unpopped kernels. Processors may reject popcorn that does not meet specified minimum popping volume.

Popping volume is affected somewhat by harvesting and handling practices, and by the moisture history of the popcorn prior to popping; but the primary factor is the moisture content of the kernels when popped. Studies have shown that maximum popping volume is produced at moistures ranging from 13.0 to 14.5%, with 13.5% being optimum. Data also indicate that popcorn must be initially dried to at least 13.5% moisture before it attains maximum popping volume. After that, moisture can increase to 15% without significantly decreasing popping volume. Overdried popcorn (11% or below) can be rewetted to 13.5% moisture, but it will not recover the maximum popping volume it had on initial drydown to 13.5%.

Conditioning shelled grain popcorn. Popcorn with less than 18% moisture and combine-harvested can usually be conditioned (i.e., dried down to the proper moisture) without spoilage by using an in-bin forced-air drying system. Such a system should supply approximately 2 cubic feet of drying air per minute per bushel of stored grain. This will not overdry the popcorn, unless the season is unusually dry - i.e. relative humidity (RH) often below 60%.

In areas where RH above 80% is expected for extended periods, a minimum amount of supplemental heat (producing no more than a 7-9°F temperature rise) can be provided, if it can be controlled by a reliable humidistat set at 60% RH and activated only when the outside RH exceeds 80%.

In areas where outside RH is consistently below 60%, it may be advantageous to condition popcorn in unheated air portable-batch- or continuous-flow-type dryers before storage. If operated and monitored properly, this type of system prevents the overdrying problems that can occur with an in-storage drying unit.

Conditioning ear-harvested popcorn. Popcorn mechanically harvested on the ear at 20-25% moisture content must be dried promptly to prevent mold growth in storage. Storage structures should incorporate high-volume forced-air ventilation systems to insure uniform drying in all areas of the crib. The high volume of uniform air flow is the key to preventing mold growth; but provision for supplemental heat during periods of higher humidity, as was recommended for shelled popcorn, is also desirable.

Ear popcorn conditioned by heated forced air needs to be monitored frequently to prevent overdrying or too rapid drying, which would reduce potential popping volume. Moisture content can be checked using a commercially available electronic moisture tester either calibrated for popcorn or supplied with a conversion chart for popcorn.

Ear popcorn harvested at 20% or less moisture can usually be stored in naturally ventilated cribs. Natural ventilation should dry the popcorn to a moisture content near that desired for popping without any overdrying problems. To insure that air will move freely through the stored popcorn, cribs should be no more than 3-4 feet wide, and the popcorn itself clean and free of husks and other residue. Once ear popcorn has dried to below 16%, it can be shelled and conditioned to the correct popping moisture. This may be done with a forced-air system similar to that previously described.

Re-conditioning overdried popcorn. If popcorn has been overdried, it can be rehydrated to the desired mois. ture content but, as mentioned above, it will not fully recover its initial popping volume. Usually the best way is to move 70-85% RH air through it over a long period (i.e., from a week to several months, depending on air flow rate and amount of rehydration needed). Another way is to blend the over-dried popcorn with high-moisture popcorn to produce a desired "average" moisture.

Blending, however, does not always provide satisfactory results. One requirement in blending is an accurate knowledge of both the moisture contents of the lots being blended and the blending flow rates to insure that the desired average moisture content of blended popcorn is attained. Even then, the moisture levels of the blended grains will not be exactly the same at equilibrium. The higher-moisture grain will always maintain a slightly. higher moisture content than the lower-moisture grain in the blend. However, a difference of less than I% will not have a measurable effect on popping volume.

Heated-air drying is generally not recommended for popcorn because of problems with overdrying, non-uniform drying and occurrence of stress cracks from too rapid drying. Its use, however, may be necessary to prevent spoilage or speed the drying process. If so and to minimize the amount of stress cracking, drying air temperatures should be in the 90-100°F range, with 120°F being the maximum.

Higher quality popcorn can be expected if drying is done in several stages, with a 12-24 hour tempering period between stages to allow for moisture redistribution within the kernels. An alternative to this is a twostage combination drying system where a heated-air dryer is used to reduce moisture content to approximately 17-18%, then a natural-air or low-temperature drying system finishes the conditioning process.

K. Storage:

For best storage, the moisture content of popcorn must be low enough to prevent significant fungal and microbial activity, but not so low as to adversely affect its popping volume. Popcorn at 14.5% moisture can be safely stored over winter and into early spring. For longer term storage, it should be dried to 13.5-12.5%.

Aeration systems similar to those systems used for dent corn should be provided for shelled popcorn storage bins to prevent moisture migration and help maintain grain quality during storage. Ear popcorn cribs must allow good natural ventilation and be designed to prevent rain and snow from getting into the popcorn.

Before storing a new crop, all bins and cribs should be cleaned and treated for insects; the grain can also be treated as it is put into storage. Use only those insecticides approved for this type of application, and apply according to manufacturer's recommendations. Popcorn that has not been treated with any insecticide must be watched carefully for any sign of insect activity, particularly if it is to be stored after the weather warms up in the spring. An aeration system will tend to reduce insect activity in the winter by keeping the grain near the average outside temperature. Storage in refrigerated warehouses will prevent damage by stored grain insects. All cribs and bins for popcorn storage should also be rodent proofed. To do this, keep the surrounding area free of weeds and trash, which can harbor rats and mice, and apply an approved rodenticide as necessary to prevent problems from developing in the storage facility.

VI. Yield Potential and Performance Results:

In the major commercial production regions, popcorn yields (measured as pounds of shelled corn per acre) for the years 1977-1981 averaged nearly 2900 pounds which, at 65 pounds per bushel, is equivalent to about 44 bushels per acre. Nebraska usually reports the highest yields because of its high proportion of irrigated acres.

On a weight basis, popcorn hybrids can be expected to yield a little less than half as much as dent corn hybrids. No popcorn yield trials have been conducted in Wisconsin or Minnesota in recent years.

VII. Economics of Production and Markets:

As with any specialty crop, marketing and economics are extremely important considerations in profitable popcorn production. The grower considering a large acreage must be familiar with marketing outlets for the crop and the economics involved.

Generally, three markets are available for good-quality popcorn: processor-contracted acreage, open-market sales, and local sales. However, since not all harvested popcorn may be marketable as popping corn, thought should be given to alternative uses or outlets.

Processor-contracted acreage. Most popcorn is grown under contract to processors. This acreage is adjusted annually to the processors' estimated needs as determined by market analysis. Normally, these estimates are very close to actual demands, which tends to stabilize the popcorn market.

Most contracts specify that a grower plant a given number of acres with a certain hybrid for a fixed price per 100 pounds of delivered popcorn. As an alternative to fixed pricing, some processors write contracts using the commodity price of popcorn on the Board of Trade on a given day, thus allowing the grower some flexibility in the system. By keeping abreast of popcorn supply and demand as well as the price of dent corn and soybeans, processors are able, under normal growing conditions, to contract popcorn at prices that provide a reasonable profit for the successful grower. Hence, growing contracted popcorn is-generally competitive with dent corn.

Open-market sales. A popcorn grower who plans to sell on the open market assumes the risk of fluctuations in price. A year or so of high popcorn prices relative to dent corn not only tempts regular popcorn growers to increase their acreage, but also attracts new growers, the result often being over-production, low prices and financial loss. Thus, it is unwise, especially for the novice, to plant a large acreage of popcorn immediately following a year of high prices.

An open-market grower must be aware of current acreage and crop conditions, as well as probable market demand and carryover. The grower should be prepared, financially and storage facility-wise, to hold the crop for an extended length of time. Good-quality popcorn stored under good conditions will keep indefinitely, allowing the grower to wait for a price that ensures a profit.

Local sales. This market alternative requires a longer-term commitment to popcorn production. Depending on the level of involvement, it can entail becoming a popcorn processor on a small scale. Success in the local sales market depends on the ability of the grower, as both producer and merchant, to grow and process a high-quality product and utilize proper packaging. Growers lacking in any of these areas will likely not fully satisfy their direct sales customers, and sales will drop rapidly, especially in light of the number of competitive popcorns readily available in stores.

Alternative outlets. If the crop is not marketable as popping corn, it can be ground and fed to livestock or poultry. Any outlet for unmarketable popcorn that provides some monetary return on the crop will lessen the extent of the financial loss.

Home Garden Production. All that is required to grow popcorn for home use is adequate space and a little gardening know-how. Most seed catalogs list popcorn varieties for home gardeners. To find one that grows best under your conditions, try several over a couple of years; and keep testing new ones as they come on the market. Maturity is important in variety selection because popcorn that does not reach full maturity before frost will have very poor quality.

Plant popcorn according to package directions. It is better to plant several short rows side by side than one long row. Also, do not plant sweet corn and popcorn in the same garden; if they happen to shed pollen at the same time, the sweet corn quality might be reduced. Popcorn requires adequate nitrogen and should be fertilized accordingly.

Harvest popcorn only after the kernels are hard and the husks completely dry. After picking, remove the husks and store the ears in bags that allow air movement so ears can dry. Each week, shell a few kernels and try popping them. When they pop well, shell the remaining ears and store in moisture-proof containers. Because popcorn can become infested with several types of insects, refrigeration is the best long-term storage.

Determining if moisture content is optimum for the best popping volume is a difficult problem. If the popcorn is "chewy" after popping, it is probably still too wet; so allow the kernels to dry some more, popping a sample every couple of days until the flakes are no longer chewy.

Popcorn that pops poorly with many unpopped kernels is probably too dry and needs moisture. Start by adding one tablespoon of water to a quart of popcorn, mix well a couple of times that day, then after 2-3 days try popping another sample. Continue this procedure until the popcorn pops well.

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References to pesticide products in this publication are for your convenience and are not an endorsement of one product over other similar products. You are responsible for using pesticides according to the manufacturer's current label directions. Follow directions exactly to protect the environment and people from pesticide exposure. Failure to do so violates the law.

Quinoa

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I. History:

Quinoa or quinua (*Chenopodium quinoa* Willd.) is native to the Andes Mountains of Bolivia, Chile, and Peru. This crop (pronounced KEEN-WAH), has been called 41 vegetable caviar" or Inca rice, and has been eaten continuously for 5,000 years by people who live on the mountain plateaus and in the valleys of Peru, Bolivia, Ecuador, and Chile. Quinua means "mother grain" in the Inca language. This crop was a staple food of the Inca people and remains an important food crop for their descendants, the Quechua and Aymara peoples who live in rural regions.

This annual species is in the goosefoot family and is related to the weed, common lambsquarters (*Chenopodium album* L.), canahua (*C. pallidicaule Aellen*), and wormseed (*C. ambrosiodes* L. *anthelminticum*). Possible hybrids between quinoa and common lambsquarters have been observed in Colorado. Quinoa is also in the same botanical family as sugarbeet, table beet, and spinach, and it is susceptible to many of the same insect and disease problems as these crops. Quinoa is sometimes referred to as a "pseudocereal" because it is a broadleaf non-legume that is grown for grain unlike most cereal grains which are grassy plants. It is similar in this respect to the pseudocereals buckwheat and amaranth.

II. Uses:

Quinoa is a highly nutritious food. The nutritional quality of this crop has been compared to that of dried whole milk by the Food and Agriculture Organization (FAO) of the United Nations. The protein quality and quantity in quinoa seed is often superior to those of more common cereal grains (Table 1). Quinoa is higher in lysine than wheat, and the amino acid content of quinoa seed is considered well-balanced for human and animal nutrition, similar to that of casein (Table 2).

Quinoa is used to make flour, soup, breakfast cereal, and alcohol. Most quinoa sold in the United States has been sold as whole grain that is cooked separately as rice or in combination dishes such as pilaf. Quinoa flour works well as a starch extender when combined with wheat flour or grain, or corn meal, in making biscuits, bread, and processed food.

Seed coats (pericarp) are usually covered with bitter saponin compounds that must be removed before human consumption. Saponins may also be toxic to fish. Deresination (removal of the pericarp and the saponins by mechanical or chemical means) does not affect the mineral content of the seed (Johnson and Croissant, 1990). The marketable seed is usually white in color. The leaves are frequently eaten as a leafy vegetable, like spinach. Seed imported from growers in South America is sold in the United States in health-food stores and gourmet food shops at high prices.

Quinoa grain has a lower sodium content and is higher in calcium, phosphorus, magnesium, potassium, iron, copper, manganese, and zinc than wheat, barley, or corn (Table 3). The determination of the mineral content from Colorado quinoa trials showed a similar relationship, but differences from other grains were less conspicuous.

Table 1. Comparisons of the nutritional quality (% dry weight) of quinoa with various grains.

Crop	% dry weight					
	Water	Crude Protein	Fat	Carbohydrates	Fiber	Ash
Quinoa	12.6	13.8	5.0	59.7	4.1	3.4
Barley	9.0	14.7	1.1	67.8	2.0	5.5
Buckwheat	10.7	18.5	4.9	43.5	18.2	4.2
Corn	13.5	8.7	3.9	70.9	1.7	1.2
Millet (Pearl)	11.0	11.9	4.0	68.6	2.0	2.0
Oat	13.5	11.1	4.6	57.6	0.3	2.9
Rice	11.0	7.3	0.4	80.4	0.4	0.5
Rye	13.5	11.5	1.2	69.6	2.6	1.5
Wheat (HRW)	10.9	13.0	1.6	70.0	2.7	1.8

Source for quinoa: Cardoza, A. and M. Tapia. 1979. Valor nutrivia. In: *Quinoa y Kaniwa.* M. Tapia (ed.), Serie Libros y Materiales Educativos No. 49. Reported by J. Risi and H. W. Galwey. 1994. Analyses of the remaining crops reported by: Crampton, E. W. and L.E. Harris. 1969. *Applied Animal Nutrition,* 2nd ed., W. H. Freeman and Co., San Francisco.

Table 2. Essential amino acid pattern of quinon compared to wheat, soy, skim milk, and the FAO reference pattern (1973) for evaluating proteins.

Amino Acid	Amino Acid Content (g/100g protein)				
	Quinoa	Wheat	Soy	Skim Milk	FAO
	%				
Isoleucine	4.0	3.8	4.7	5.6	4.0
Leucine	6.8	6.6	7.0	9.8	7.0
Lysine	5.1	2.5	6.3	8.2	5.5
Phenylalanine	4.6	4.5	4.6	4.8	-
Tyrosine	3.8	3.0	3.6	5.0	-
Cystine	2.4	2.2	1.4	0.9	-
Methionine	2.2	1.7	1.4	2.6	-
Threonine	3.7	2.9	3.9	4.6	4.0
Tryptophan	1.2	1.3	1.2	1.3	1.0
Valine	4.8	4.7	4.9	6.9	5.0

Source: Johnson, R. and R. Aguilera. 1980. Processing Varieties of Oilseeds (Lupine and Quinoa), *In: Report to Natural Fibers and Foods Commission of Texas, 1978-1980* (Reported by D. Cusack, 1984, The Ecologist 14:21-31).

Table 3. Comparisons of the mineral content In quinoa grain with barley, yellow corn, and wheat. Quinoa data are based on the average of 15 cultivars.

Crop	Ca	P	Mg	K	Na	Fe	Cu	Mn	Zn
	%				PPM				
Quinoa	0.19	0.47	0.26	0.87	115	205	67	128	50
Barley	0.08	0.42	0.12	0.56	200	50	8	16	15
Corn	0.07	0.36	0.14	0.39	900	21	-	-	-
Wheat	0.05	0.36	0.16	0.52	900	50	7		14

Source: E. Ballon (1987), personal communication, reported by Johnson (1990).

III. Growth Habit:

Plants grow from 1 1/2 to 6 1/2 ft in height, and come in a range of colors that vary from white, yellow, and pink, to darker red, purple, and black. Quinoa has a thick, erect, woody stalk that may be branched or unbranched, and alternate, wide leaves that resemble the foot of a goose. Leaves on younger plants are usually green; but as the plant matures, they turn yellow, red, or purple. The root

system develops from a tap root to form a highly branched system that makes plants more resistant to drought. Varieties of quinoa mature in 90 to 125 days after planting in southern Colorado. Early-maturing varieties are recommended because of the short growing season at these high elevations.

Quinoa is usually self pollinated, but cross pollination does occur at rates of up to 10 to 15% (Risi and Galwey, 1989). Seed is produced in large clusters on a panicle that resembles that of sorghum. The seed is similar in size to millet (0.8 to 0.11 in. in diameter) and has two flat surfaces and rounded sides, which resembles an aspirin tablet. Seeds can be black, red, pink, orange, yellow, or white in color. The seed color is due to a resinous coating that contains two to six percent saponin. The embryo comprises 60% of the volume within the pericarp, and this results in the higher protein content of the seed in comparison to cereal grains.

IV. Environment Requirements:

A. Climate:

Quinoa requires short daylengths and cool temperatures for good growth. Areas in South America where it is still produced tend to be marginal agricultural areas that are prone to drought and have soils with low fertility. Cultivated quinoa will flower and produce seed at high elevations between 7,000 and 10,000 ft in Colorado since it requires a cool temperature for good vegetative growth. Research conducted in Colorado reported that temperatures which exceeded 95°F tended to cause plant dormancy or pollen sterility. In several years of trials near the Twin Cities, Minnesota, quinoa plants have failed to set seed; probably due to high temperatures.

Quinoa plants are usually tolerant to light frosts (30° to 32°F). Plants should not be exposed to temperatures below 28°F to avoid the 70 to 80% loss that occurred in Colorado during 1985 when plants were in mid-bloom (Johnson and Croissant, 1990). However, plants are not affected by temperatures down to 20°F after the grain has reached the soft-dough stage. Quinoa will flower earlier when grown in areas with shorter daylengths.

Quinoa is generally not a widely adapted crop due to temperature sensitivity. Farmers should experiment first before planting large acreages.

B. Soil:

This crop grows well on sandy-loam to loamy-sand soils. Marginal agricultural soils are frequently used in South America to grow quinoa. These soils have poor or excessive drainage, low natural fertility, or very acidic (pH of 4.8) to alkaline (8.5) conditions.

C. Seed Preparation and Germination:

Quinoa prefers cool soil conditions (45° to 50°F). Germination occurs within 24 hours after planting when adequate moisture is present, and seedlings emerge in three to five days. Quinoa seeds, like those of spinach, may not germinate if conditions are warm and may need to be refrigerated for a week (vernalized) to obtain adequate germination.

V. Cultural Practices:

A. Seedbed Preparation:

Quinoa requires a level, well-drained seedbed in order to avoid waterlogging.

B. Seeding Date:

Robinson (1986) planted quinoa in mid-May at Rosemount, Minnesota that emerged about June 1, but earlier dates are also appropriate. Seed is planted in late April to mid - May in southern Colorado.

C. Method and Rate of Seeding:

Seeds should be planted at a depth of 1/2 to 1 in. depending on soil type and available soil moisture. Ile small size of the seed makes it susceptible to both dehydration and waterlogging when planted too shallow, or deep, respectively. Row width can vary, but rows should be spaced by a minimum of 14 in. Varieties in Colorado have been grown in rows 20 to 30 in. apart. Stands of 130,000 plants/acre appear to be optimal for growing conditions in Colorado. A stand of this density would require 1/2 to 3/4 lb of seedlacre. Seeding rates are usually doubled when growing conditions are not optimal. Better stands are obtained when seed is planted in a moist soil, instead of irrigating after planting prior to emergence. Field trials in Great Britain indicated that increasing plant density resulted in a slightly earlier maturity, greater seed yield, and less -branching of plants.

D. Fertility Requirements:

Quinoa responds well to nitrogen fertilizer. In the first year of trials in Colorado, the variety Linares and others responded favorably to application of nitrogen fertilizer (Table 4). Research on nitrogen and phosphorus requirements conducted for three years by D. L. Johnson of Colorado State University found that maximum yields are possible when 150 to 180 lbs N/acre are available. Yields declined when greater levels of available nitrogen were present due to a slower maturity and more intense lodging. No effect on yield was observed when 30 lb of phosphorus (as phosphate acid) per acre was applied, in comparison to an untreated field plot.

Table 4. Effect of nitrogen on quinoa yields in Colorado during 1983 for the variety Linares[1]. Other varieties have responded In a similar fashion.

Nitrogen lb/a	Yield lb/a
15	950
65	991
125	1,378

[1]Source: Johnson and Croissant (1990).

E. Water Requirements:

This crop is somewhat drought tolerant with a water requirement of 10 to 15 in. per year (precipitation and irrigation combined on sandy-loam or loamy-sand soils). Studies on crop water use conducted during 1987 in Colorado found that the application of lower amounts of water reduced plant height by 50% with only an 18% reduction in yield. Crops planted during late April to mid-May in Colorado did not usually need irrigation until mid-June when the soil was near field capacity at planting time. Plants should not be irrigated until the two- or three-leaf stage. Rainfall in July has usually been sufficient during Colorado research trials to supply the crop until August. Excessive irrigation after stand establishment usually produces tall, lanky plants with no yield improvement. Damping off and severe stunting of plants will occur with excessive irrigation in the seedling stages.

F. Variety Selection:

The Agricultural Experiment Station at Colorado State University has developed a yellow-seeded variety, CO407, which is the only registered variety that is available (Table 5). This variety was derived from plants that came from Chile and was released in 1987. 'CO407' typically has a short height, early maturity (100 days after planting), compact seed head, and resists grain shattering. This variety has a rich, nutty flavor and 16.5 to 18% protein, which is higher than other types that have averaged 12.5 to 14%. The nutty flavor of the flour made from this variety complements those of other grain flours when it comprises as little as 15 to 30% of a product. The pericarp with its coating of saponins is removed effectively by abrasion rather than washing. Three other varieties, CO409, Cahuil, and CO407 Black, have good yield potential based on field performance in southern Colorado.

G. Weed control:

Weed control in quinoa fields is difficult since plants grow slowly during the first two weeks after emergence. In commercial fields of southern Colorado, pigweed, kochia, lambsquarters, and sunflower have been the most common weeds. Wild mustard and sunflower can be a problem since it is not possible to separate them from quinoa seed. There are no registered herbicides for quinoa at this time. Preemergence herbicide trials have been conducted in field and greenhouse locations in Colorado. Several herbicides were used safely on quinoa, but were variable in weed control.

Competition from weeds is greater when quinoa is planted later in the growing season. Kochia and lambsquarters numbers can be reduced when field irrigation is followed by cultivation before seeding. Pigweed emerges too late in the growing season to depend on cultivation for weed control. Early planting may be the most effective means to control pigweed since the quinoa will have a good start in growth before the pigweed emerges.

H. Diseases:

Disease and pest problems may arise after a crop like quinoa is introduced to a new production area. Viruses found on spinach or beets have been observed in quinoa fields. Many of these viruses are transmitted by aphids or leafhoppers. Several of the viruses tested produce symptoms, yet research needs to be conducted to determine if any cause significant damage. Diseases such as damping off (*Sclerotium rolfsii*), downy mildew (*Peronospora farinosa*), stalk rot (*Phoma exigua* var. *foveata*), leaf spot (*Ascochyta hyalospora*), grey mold (*Botrytis cinerea*), and bacterial blight (*Pseudomonas* sp.) have also caused significant losses in South America, North America, and Great Britain.

I. Insects and Other Pests:

A wide variety of insect pests can damage quinoa during seed germination up through harvest and seed storage in production areas of South America. Insect pests observed in North America include flea beetles and a wide variety of caterpillars (insect larvae). Flea beetles and aphids caused damage in quinoa trials conducted in Minnesota (Robinson, 1986). The sugarbeet root aphid (*Pemphigus populivenae*) has significantly reduced yields in isolated research fields of Colorado. Since this crop requires little water, the soil will crack and allow aphids access to the roots. There are no pesticides cleared for use on quinoa. The best control method for this aphid is to irrigate fields when winged forms appear in leaf-petiole galls of cottonwoods and poplars (overwintering habit) in early summer. The "quinoa plant bug" *(Melanotrichus* sp.) and the beet armyworm (*Spodoptera exigua*) have also reduced yields in some research fields. *Bacillus thuringiensis,* a naturally occurring bacterium that controls certain insect larvae, can be used to control the defoliating caterpillars. Entomologists at Colorado State University, do not consider insect problems to be a yield-limiting factor for quinoa production at this time.

Seed in the panicle is subject to feeding losses by birds. Quinoa, like some other grains, evolved a chemical defense against the feeding activity of insects and animals with the production of bitter saponins in the pericarp. However, saponins are easily washed out by rain and may not totally prevent feeding losses.

J. Harvesting:

Plants have a sorghum-like seed head at maturity. Harvest usually begins when the seed can barely be dented with a fingernail and plants have dried, turned a pale yellow or red color, and leaves have dropped. The seed should thresh easily by hand at this time. Field dry down is usually acceptable and plants are harvested easily with a combine. A sorghum header attachment is recommended for quinoa, although platform headers can usually be used as well, without a large crop loss. Cylinder speed and air flow of combines are usually greatly reduced. Smaller screens are used than with cereal grains due to the small size and lighter weight of quinoa seed. A fanning mill and gravity separator is usually necessary to remove trash from the seed after combining. Grain must be dry before storage. Quinoa stover contains little fiber and subsequently provides little crop residue.

Rain during harvest will cause problems since mature seed will germinate within 24 hours after exposure to moisture.

K. Drying and Storage:

The seed must remain dry during storage. Prior to using quinoa in food processing, the saponins in the pericarp are removed by soaking them in water or by mechanical methods, such as with a rice polisher or a machine similar to those used to remove wheat bran.

VI. Yield Potential and Performance Results:

Most quinoa used in North America is imported from South America. Research on developing quinoa as a crop for North American agriculture is being conducted in Colorado. The first commercial crop was produced in Colorado in 1987. Average yields were about 1,000 lb/acre, produced on fields that ranged from 10 to 80 acres in size. The variety CO407 has given consistent yields of 1,200 lb/acre in Colorado field trials, while other lines have yielded from 1,421 to 1,739 lb/acre (Table 5). Yields that exceed 1,800 lb/acre in research trials are possible with adequate stands, fertility, moisture, and weed control. This crop has the potential to be produced on 6,000 acres in Colorado at elevations above 7,000 ft (Robinson, 1986). Quinoa planted by Robinson in Minnesota grew about two feet tall but did not flower and produce seed, as high summer temperatures probably caused the plants to become dormant. Quinoa lines grown in 1991 at Rosemont also did not set seed (Putnam, D.H., pers. com.).

Table 5. Performance of selected quinoa varieties in research trials conducted during 1987 in south central Colorado[1].

Landraces/Lines	Yield lb/acre	Panicle color	Plant height ft
Cahuil	1,739.8	mixture	4.3
C0407-78	1,692.3	yellow	4.3

C0407-06	1,690.6	yellow	5.9
C0407-260	1,6903	yellow	4.6
Milahue	1,634.6	red, white	6.9
Isluga	1,499.0	mixture	5.6
Faro	1,421.6	mixture	6.6
CO407	1,206.2	mixture	4.3

[1]Source: Johnson and McCamant (1988), Johnson and Croissant (1990).

Quinoa should be considered a future crop for most North American farmers. This crop is not recommended for growers except on an experimental basis in Minnesota or Wisconsin at this time, since there are no varieties that will produce well under the environmental conditions in these areas. Hot summer temperatures, precipitation greater than 10 to 15 in. per year, and wet conditions during seed maturation, prevent growing the available varieties in the Upper Midwest. Areas located in southern Colorado and northern New Mexico at an elevation of 7,000 ft, northward from central California along the Pacific Coast, the eastern side of the Cascade Mountains., in northern Washington, and locations in the Canadian;' Prairie provinces (especially Saskatchewan) at 2,000 to 3,000 ft, may be the best production areas in the future.

VII. Economics of Production and Markets:

The current market for quinoa in North America is limited. A widespread effort is necessary to educate people in the United States about what quinoa is and how to cook it before the market will expand a great deal. Five farms in Colorado started to grow quinoa as a commercial crop in 1987 after a processing facility was provided by the Pillsbury Company to remove saponins from the pericarp. The North American Quinoa Producers Association was organized in 1988 and a small processing plant was started for the crop produced in Colorado. Costs of production for Colorado growers decreased from $1.00/lb in 1984 to $0.35/lb in 1987 as they became more familiar with the crop and obtained higher yields (Johnson, 1990). Prices to producers have currently (1991) ranged from S.80/lb to over $1.00 lb.

In the United States this crop has been available in health food stores and more recently (1988), in grocery stores of the western United States for prices that range from $2.50 to $3.40/lb. The high nutritional quality, good flavor, and many uses in food products, give quinoa a good potential market. The market for quinoa has continued to grow in North America since 1984, yet the acreage planted has declined since 1985 due to crop losses from adverse environmental conditions such as insect, disease, and weed problems. Prospective growers from areas with suitable environmental conditions should contact a marketing group about contracts for quinoa seed before raising the crop. The quinoa market in 1987 for the United States was approximately 500,000 lbs.

The food industry is ready to make quinoa products due to the current market and its good growth potential. These companies have a disincentive to make quinoa products until the cultural problems have been reduced and yields have improved so there is a larger, more reliable supply available to processors. Future varieties will have a white pericarp (low or no saponin content), grow well at lower elevations, and have better yield, plant height and form, seed size, and resistance to pest, disease, and other environmental factors. A low saponin content would avoid some processing costs, a larger seed would reduce the proportion of fibrous pericarp in the grain, and a white pericarp would give a colorless, versatile product for the food processing industry. However, the elimination of saponins in future varieties may also increase feeding losses by birds and other pests.

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Rye

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I. History:

Cultivated rye (*Secale cereale*) is believed to have originated from either *S. montanum*, a wild species found in southern Europe and nearby parts of Asia, or from *S. anatolicum*, a wild rye found in Syria, Armenia, Iran, Turkestan, and the Kirghis Steppe. Rye was found as a weed widely distributed in wheat and barley fields in southern Asia. It apparently had coevolved with wheat and barley for over 2,000 years until its value as a crop was recognized. Rye was brought to the western hemisphere by the English and Dutch who settled in the northeastern areas of what is now the United States. The average production in the United States in 1987-89 was about 15.9 million bushels on some 2.3 million acres. The leading states in rye production are South Dakota, Georgia, Nebraska, North Dakota, and Minnesota. In 1930 Minnesota grew 7.2 million acres of rye for grain, while in 1989 there were 32,000 Minnesota acres harvested and Wisconsin harvested rye from 6,000 acres. The average yield in 1920 was 17 bushels per acre, while in 1989 it was 34 bushels in the Upper Midwest.

II. Uses:

Less than 50% of the rye grown in the U.S. is harvested for grain, with the remainder used as pasture, hay, or as a cover crop. About half of the amount harvested for grain is used for livestock feed or exported, and the remainder is used for alcoholic beverages, food, and seed. In the Midwest, rye is primarily grown for grain, but occasionally for hay or pasture. It can also be grown as a cover or green manure crop. In addition to contributing organic matter, rye reduces soil erosion and enhances water penetration and retention. Furthermore, due to its allelopathic effect, some evidence suggests that rye could be exploited for weed control. It has been widely reported that residues of fall-planted, spring-killed rye reduces total weed biomass by 60% to 95% when compared to controls with no residue. Rye residue which remains at the soil surface can potentially modify the physical and chemical environment during seed germination and plant growth.

A. Human food:

Although rye flour does not develop true gluten, it has proteins which give it the capacity for making a nutritious leavened bread. Rye is usually mixed with 25 to 50% wheat flour for bread making.

B. Livestock feed:

Grain: Rye grain has a feeding value of about 85 to 90% that of corn, and contains more digestible protein and total digestible nutrients than oat or barley. Rye is most satisfactorily used when mixed with other grains at a proportion less than a third, because it is not highly palatable and is sticky when chewed.

Forage: Rye makes excellent forage especially when combined with red or crimson clover and ryegrass. For best quality, cut rye between early heading and the milk stage of growth. Yields and quality of rye harvested as forage compared to winter wheat and winter triticale are shown in Table 5. Rye matures earlier than wheat or triticale and has the highest crude protein levels. However, forage yields are lower than for the other two small grains, resulting in somewhat lower crude protein yields and overall lower relative feed values. Thus, the main advantages winter rye has as a forage as compared to winter wheat or winter triticale, is that it is more winter hardy and reaches optimum harvest maturity 7 to 10 days earlier.

Pasture: Rye generally provides more forage than other small grains in late fall and early spring because of its rapid growth and its adaptation to low temperatures. Although rye is a less palatable pasture crop, it is readily grazed when other green forages are not available. In the Upper Midwest, care must be taken not to overgraze rye in the spring or fall due to the short growing season.

C. Cover and green manure crop:

Fall sown rye holds more snow and rainfall than does a bare field. It also preserves soil moisture in the spring, since there is no spring seedbed preparation. It provides fall, winter, and spring soil cover when the potential for wind and water erosion losses are substantial in plowed fields. Rye as a cover crop fits well into many erosion control programs. Land going into potatoes, soybean, or corn can be protected over winter by a rye cover crop. Rye can be also used as an emergency cover to fill gaps between other crops, or if a crop is removed early because of failure, rye can be seeded to protect the soil until time to plant the next crop. It can also be used as a winter cover crop for continuous minimum tillage corn when the corn crop is harvested early. When corn or soybean are sod-planted, rye can be seeded in the fall and then killed with herbicides prior to planting. Rye should not be grown between crops of wheat or barley, unless it is completely killed before wheat or barley are planted in the spring.

As a green manure crop, rye is particularly suitable because of its winter hardiness and its rapid growth early in the spring. It should be plowed or disked when about 20 in. tall.

III. Growth Habits:

Winter rye generally overwinters; in the tillering stage. The winter temperatures near freezing satisfy the vernalization requirement and allow the plants to initiate reproductive development the following spring. Rye varieties are long day plants, but they do not have an absolute requirement for a specific day length. Rye is cross pollinated, and relies on wind-borne pollen. The florets remain open for some time, but if conditions are not favorable for cross-pollination, rye spikes may have several empty florets. The inflorescence is a spike with one sessile spikelet per rachis node. Spikelet initiation begins in the middle of the spike and proceeds toward the tip and base. Only the two basal florets in each spikelet produce seed. Spring rye does not require vernalization to induce flowering. Varieties of spring rye in general are less productive than winter rye in the Upper Midwest.

IV. Environment Requirements:

A. Climate:

Rye can be grown in a wider range of environmental conditions than any other small grain. Winter rye is the most winter hardy of all cereals. Rye will usually make considerable growth during the cool temperatures of late fall, and resumes growth very quickly in the early spring. However, rye cannot survive the winter in pot holes or other wet areas where water collects or ice sheets form.

B. Soil:

Winter rye is more productive than other cereals on infertile, sandy, or acid soils, as well as on poorly prepared land. For best results however, rye should be planted on well prepared, fertile, well drained soils, having a pH of 5.6 to 5.8 or higher. Rye grows better on light loams and sandy soils than on heavy clay soils. It is also able to germinate in relatively dry soils, and is fairly tolerant to droughty conditions.

C. Seed Preparation and Germination:

Seed should be free of weeds and ergot bodies, and have at least 85% germination. Stored rye seed loses its ability to germinate more rapidly than do other cereals. It is recommended to buy Certified seed, that has proven adaptation to local conditions. Fungicide seed treatments used for other small grains are suitable for use on rye, and often can improve stands.

V. Cultural practices:

A. Seedbed Preparation:

For best results, plant rye in a firm, well prepared seedbed. On fall plowed ground, disk and harrow and then drill rye. If fall plowing is not possible, particularly after corn harvesting, disk and drill the rye into the soil. Rye is sometimes drilled into small grain stubble without previous preparation. This practice is economical and satisfactory in reasonably weed-free land. In addition to the economy of labor, it also leaves the stubble to hold the snow and protect the rye plant from winter killing.

B. Seeding Date:

The time of seeding depends on the use of the crop. Winter rye can be generally seeded from late summer to late fall. However, when grown for grain, rye should be seeded at about the same time as winter wheat, but can be seeded safely as much as 2 weeks later. The best time to seed winter rye is from August 15 to September 10 in northern Minnesota and Wisconsin, and from September 5 to September 30 in southern areas of the two states. If winter rye is planted in August, cattle can lightly graze the crop, but enough vegetation must remain standing to control soil erosion. When rye is grown for pasture, cover crop or green manure, seeding date should be 2 to 8 weeks earlier than for a grain crop to insure a heavy blanket of growth for protection over winter. However, rye is also successfully planted the first two weeks of October after harvesting potatoes to provide winter cover and a green manure crop.

C. Method and Rate of Seeding:

Plant rye in 6 or 7 in. rows at a rate of 60 to 90 lb/acre, and to a depth of 1 to 2 in. with a grain drill. Higher seeding rates might be needed when planting later than desired or when perennial weed control is important.

D. Fertility:

Winter rye and winter wheat respond similarly to nutrient additions. Soil tests are the best guide on which to base fertilizer rates. Phosphorus and potash should be applied in the fall although improved efficiency can be achieved by banding phosphate directly below the seed at planting, especially on high pH soils. The nitrogen application should be split, especially on lighter soils with one part applied at planting, and the rest by topdressing in the spring.

Rye should be fertilized when grown for pasture or as a cover crop. Fall application of nitrogen and phosphorus increases fall growth, which improves winter ground cover. A spring top dressing with nitrogen is desirable where rye is pastured. Heavy nitrogen applications promote lodging in rye grown for grain. A moderate rate (about 10 ton/acre) of manure is a good general fertilizer.

Table 1: Recommended fertilizer applications for a goal of 30 to 50 bu/acre rye yield.

Soil test	N[1]	P_2O_5	K_2O
	lb/acre		

Very low or low	40	40-50	50-80
Medium	40	20-30	30-60
High	40	15-20	0-30
Very high or excessively high	40	0	0

[1]Recommended nitrogen rate ranges from 20 to 60 lb N/acre depending on cropping history and soil organic matter level. If the previous crop was alfalfa, red or sweet clover, no supplemental N is recommended.

E. Variety Selection:

Several winter rye varieties have been developed and are recommended for planting in Minnesota and Wisconsin.

Recommended Varieties

Hancock: High yield, fair winter hardiness, medium late, medium height, and good lodging resistance. Large seed of predominantly tan color and high test weight. Originated by Wisconsin Agricultural Experiment Station from crosses involving Von Lochow and Wisconsin synthetics of tan seed color. Released in 1979.

Muskateer: High yield, good winter hardiness, medium late, medium height, and poor lodging resistance. Large seed of green color and medium test weight. Originated by Agriculture Canada, Swift Current, from crosses to Harrach, Petkus, and Dakold. Licensed in 1980. Production of certified seed limited to Canada.

Rymin: High yield, fair winter hardiness, medium late, medium height, and good lodging resistance. Large seed of predominantly greenish-gray color and high test weight. Originated by Minnesota Agricultural Experiment Station from a cross of Von Lochow and WR5. Released in 1973.

Other Varieties

Aroostook: Low yield, good winter hardiness, very early, tall, and poor lodging resistance. Small seed of brown and tan color, and low test weight. Selected from Balbo by USDA Soil Conservation Service in New York. Released by USDA, Cornell University, and Maine Department of Agriculture in 198 1.

Cougar: Medium yield, winter-hardy (only fair hardiness in eastern Minnesota trials), late, medium height. Fair lodging resistance. Small green and tan seed, medium test weight. Originated by University of Manitoba from an open-pollinated selection in a composite cross of European and Canadian varieties. Licensed 1967.

Dankowski Nowe (Danko): Medium yield, poor winter hardiness, late, medium height, and good lodging resistance. Very large predominantly green seed, high test weight. Developed by Dankow-Laski and Choryn experiment stations. Reported to be the leading variety in Poland.

Frederick: Medium yield, good winter hardiness, medium late, medium height, and poor lodging resistance. Medium size seed of predominantly tan color and high test weight. Selected from Von Lochow by South Dakota Agricultural Experiment Station. Released in 1984.

Metzi: Medium yield, medium late, tall with average lodging resistance. The seed is predominantly green and high test weight. Released by Nutriseed Company.

Puma: Medium yield, good winter hardiness, medium late, medium height, and poor lodging resistance. Small predominantly green seed, medium test weight. Winter-hardy selection from Dominant by University of Manitoba. Licensed 1972.

Von Lochow: Medium yield, fair to poor winter hardiness, medium late, medium height, and good lodging resistance. Large seed of predominantly green color and high test weight. Obtained from F. Von Lochow-Petkus Ltd. of Germany in 1958. Released by Minnesota Agricultural Experiment Station in 1964.

F. Weed Control:

1. Cultural and Mechanical: Winter annuals and/or perennials are usually the major weed problem in fall sown cereal grains. Perennial weeds should be controlled by tillage or herbicides before or during seedbed preparation. Establishment of dense stands before winter will enable the rye to compete well with weeds.

2. Chemical: Rye competes well with weeds, and herbicides are generally not needed. Bromoxynil (Buctril), MCPA, and 2,4-D are the only herbicides labeled for broadleaf weed control in rye, These herbicides are applied in the spring. Roundup can be applied preplant prior to tillage to control perennial weeds. While there are no post emergent herbicides registered for grass weed control in rye, these weeds are generally not a problem with vigorous, dense rye stands.

G. Diseases and Their Control:

Fewer diseases attack rye than other cereals. Ergot is the most serious disease in rye.

1. Ergot:
Rye is more sensitive to ergot than other cereals. When rye contains 0.5% or more of ergot, it is considered unfit for food or feed. The ergot disease is characterized by large spur-like purplish-black bodies (*sclerotinia*) that replace the kernel in the rye spikelet. Ergot bodies over-winter in the field, or with the seed in storage, and germinate under favorable conditions in the spring. The disease can be partly controlled by sowing ergot-

free seed or year old-seed on land where rye has not been grown for 1 or 2 years previously. The mowing of ergot infested grasses adjacent to rye fields is also helpful. Resistant varieties are not yet available. Ergot bodies can be removed by immersing infested rye in a 20% salt solution. The grain is stirred, and ergot bodies float to the surface where they can be skimmed off. The salt must be washed from the seed, and the seed partly dried before it is sown.

2. Stem or stalk smut:
This is a very common disease on rye, particularly in Minnesota and nearby states. The symptoms appear first, as lead gray, long narrow streaks on the stems, sheaths, and the blades. These streaks later turn black. Infected plants are darker green than normal and somewhat dwarfed. The stems usually are twisted or distorted, and the heads fail to emerge from the sheath. Spores can be carried both on the seed and in the soil. Disease control could be achieved by seed treatment and crop rotation where the spores are soil-borne. Resistant varieties are also available.

3. Anthracnose:
This common rye disease is especially prevalent in the humid and subhumid eastern United States. Infected tissues are stained brown on the leaf sheath that surrounds the diseased stem. Head infections cause shriveled, light brown kernels. Infected plants often ripen or die prematurely.

4. Rusts:
Leaf rust: Severe infections of leaf rust are largely confined to the southern range of U.S. rye production, and cause a reduction of tillering and grain yield. Ile disease overwinters in the leaves of rye as dormant mycelium. Destruction of volunteer rye in stubble fields will aid in control of this disease.
Stem rust: The early maturity of rye usually enables it to escape serious damage from stem rust. Common barberry is the alternate host.

H. Insects and Other Predators and their Control:

Rye is attacked by many of the same insects that attack other small grains. Serious losses on rye are not common. Early sown winter rye provide a favorable environment for the deposition of grasshopper eggs, which may promote grasshopper injury to other crops.

I. Crop Rotations:

Rye is useful in rotations designed to control certain hard-to-control weeds. Alternating intensive summer fallow with winter rye and repeated summer tillage after rye harvest is effective against troublesome annual and perennial weeds such as quackgrass, sowthistle, Canada thistle, and wild oats. In rotations that include a small grain, rye may replace wheat, oats, or barley. Winter wheat should not follow rye in a rotation because of volunteer rye.

J. Harvesting:

Rye can be harvested and threshed in one operation with a combine, or swathed and later threshed. To reduce shatter loss when direct combining, begin harvest at about 22% moisture and follow by drying. Moisture content needs to be below 15% to avoid discounts at elevators. Sprout damage can occur during harvest or storage in some years. Some buyers have used the "falling number" test to check for sprouted grain and have discounted grain with a low value.

K. Drying and Storage:

Many rye producers will store grain and sell at peak markets. Grain moisture should be 12% for long term storage. During storage, the grain needs to be aerated to control the temperature of the stored grain to avoid moisture buildup in bins during changing outdoor temperatures.

VI. Yield Potential and Performance Results:

State average yields of rye are commonly only 20 to 40 bu/acre. Yields of 70 to 80 bu/acre can be obtained with good management.

Table 2: Yields of winter rye varieties in Minnesota.

Variety	Rosemount 1981-85	Becker 1982-85	Morris 1982-86	Crookston 1982-86	Grand Rapids 1982-86	Average 5 locations
	bu/acre					
Hancock	59	46	57	62	48	54
Musketeer	58	47	60	72	47	57
Rymin	58	50	60	67	50	57
-LSD 5%	2	4	3	5	4	2

Table 3: Yields of winter rye varieties in Wisconsin.

Variety	Arlington	Madison	Hancock	Spooner	Mean
1989 Yields	bu/acre				
Hancock	65	61	26	19	43
Metzi	53	62	25	15	39
LSD 5%	8	7	4	4	3
1987-89 Yields		(1986,89)		(1986,87,89)	
Hancock	83	70	22	19	55

VII. Economics of Production and Markets:

Production costs for rye would be similar to those for wheat and barley with somewhat reduced herbicide and fertilizer costs. Rye straw can often be sold at a premium for bedding or to fruit and vegetable producers who prefer rye straw as mulch.

The price of rye will fluctuate during the year and growers need to market at peak prices for maximum profit. Most local grain elevators will purchase rye.

Table 4: Characteristics of winter rye varieties in Minnesota averaged over five locations and five years.

Variety	Winterkill %	Heading date May	Mature date July	Lodging score[1]	Height inches	Seeds no./lb	Test weight lb/bu
Hancock	9	30	23	2.9	53	15,600	55
Musketeer	4	29	22	3.1	53	16,200	56
Rymin	6	30	23	2.7	52	16,200	56

[1] 1 = erect, 9 = flat.

Table 5: Performance of winter cereals harvested at early heading from the boot at Arlington, Wisconsin, 1986-88.[1]

Crop	Harvest date	Height at harvest date in	Forage yield ton/acre	Crude %	Protein lb/acre	ADF %	NDF %	Relative feed[2] value
Winter wheat	5/31	33	3.67	11.8	872	35.9	63.8	89
Winter rye	5/19	37	IN	13.8	833	37.6	65.1	85
Winter triticale	6/2	37	3.56	12.4	879	36.1	64.2	88

[1]From M.A. Brinkman, A.B.G. Mostafa, and K.A. Albrecht, Department of Agronomy, University of Wisconsin-Madison.
[2]Corn = 100

VIII. Information Sources:

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Reference to seed dealers and pesticide products in this publication are for your convenience and are not an endorsement of one product over other similar products. You are responsible for using pesticides according to the manufacturer's current label directions. Follow directions exactly to protect people and the environment from pesticide exposure. Failure to do so violates the law.

Safflower

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I. History:

Safflower (*Carthamus tinctorius* L.) is an annual, broadleaf oilseed crop adapted chiefly to the small-grain production areas of the western Great Plains. Evaluations of safflower in the Great Plains states began in 1925, but the seed had an oil content that was too low for profitable oil extraction. In the following years the Nebraska Agricultural Experiment Station developed varieties with about 35% oil compared to older varieties with less than 30%.

Commercial production became concentrated in western Nebraska and eastern Colorado, but is now located in several Western states and Canadian Prairie provinces. California grows approximately 50% of the safflower in the U.S.A., while North Dakota and Montana, grow most of the remaining domestic production. South Dakota, Idaho, Colorado, and Arizona also produce safflower, but with much smaller acreages.

There are two types of safflower varieties, the type that produces oil which is high in monounsaturated fatty acids (oleic acid), and those with high concentrations of polyunsaturated fatty acids (linoleic acid). Either type of safflower raised in the Northern Great Plains is very low in saturated fatty acids when compared to other vegetable oils. Only the linoleic safflower is being grown commercially in the Upper Midwest. Varieties with a high content of oleic acid may soon be grown more widely.

II. Uses:

Safflower was originally grown for the flowers that were used in making red and yellow dyes for clothing and food preparation. Today this crop supplies oil, meal, birdseed, and foots (residue from oil processing) for the food and industrial products markets, although this crop is now primarily grown for the oil.

The oil in linoleic safflower contains nearly 75% linoleic acid, which is considerably higher than corn, soybean, cottonseed, peanut or olive oils. This type of safflower is used primarily for edible oil products such as salad oils and soft margarines. Researchers disagree on whether oils high in polyunsaturated acids, like linoleic acid, help decrease blood cholesterol and the related heart and circulatory problems. Nonetheless, it is considered a "high quality" edible oil and public concern about this topic made safflower an important crop for vegetable oil.

Varieties that are high in oleic acid may serve as a heat-stable, but expensive cooking oil used to fry potato chips and french fries. As an industrial oil, it is considered a drying or semidrying oil that is used in manufacturing paints and other surface coatings. The oil is light in color and will not yellow with aging, hence it is used in white and light-colored paints. This oil can also be used as a diesel fuel substitute, but like most vegetable oils, is currently too expensive for this use.

The meal that remains after oil extraction is used as a protein supplement for livestock. The meal usually contains about 24% protein and much fiber. Decorticated meal (most of hulls removed) has about 40% protein with a reduced fiber content. Foots are used to manufacture soap. The birdseed industry buys a small portion of the seed production. Sheep and cattle can graze succulent safflower and stubble fields after harvest.

III. Growth Habit:

Safflower is an annual species in the same plant family as sunflower. This crop is adapted to dryland or irrigated cropping systems. Each seed germinates and produces a central stem that does not elongate for two to three weeks, and develops leaves near the ground in a rosette, similar to a young thistle. The slow growth of seedlings in early spring often results in a weedy crop. The strong central stems, with variable numbers of branches, grow to between 12 to 36 in. depending on environmental conditions. Safflower can compensate for hail damage with little yield loss once branches have developed. This crop is more drought tolerant than small grains since it has a taproot that can grow to 8 to 10 ft. if subsoil temperature and moisture allow. Stiff spines develop on leaf margins of most varieties at about the flower bud stage and make it difficult to walk through the fields.

Branches usually produce one to five flower heads. Flower heads, about one inch in diameter, are usually yellow or orange in color, although some varieties have red or white flowers. Flower buds form in late June and flowering starts in mid- to late July, and continues for two to three weeks depending on environmental conditions, stand density, and varietal differences. Each flower head produces 15 to 30 seeds with a seed oil content usually between 30 to 45%. Seeds are enclosed in the head at maturity, which prevents shattering before harvest and delays somewhat the feeding loss from birds. Seeds usually mature in September, which is about four weeks after flowering ends. This crop usually needs 110 to 140 days to mature in the Upper Midwest.

IV. Environment Requirements:

A. Climate:

Safflower production is not recommended for areas with more than 15 in. of annual precipitation or growing seasons with fewer than 120 frost-free days and less than 2,200 growing degree days. Temperatures as low as 20°F are tolerated by plants while in the rosette stage, but safflower is very sensitive to frost injury after stem elongation until crop maturity. This crop does best in areas with warm temperatures and sunny, dry conditions during the flowering and seed-filling periods. Yields are lower under humid or rainy conditions since seed set is reduced and the occurrence of leaf spot and head rot diseases increases. Consequently, this crop is adapted to semiarid regions. Most areas of Minnesota and Wisconsin are not well suited for safflower.

B. Soil:

Deep, fertile, well-drained soils that have a high waterholding capacity and high level of stored moisture are ideal for safflower. This crop is also productive on coarse-textured soils with low water-holding capacity when adequate rainfall or moisture distribution is present. Soils that crust easily can prevent good stand establishment. High levels of soil salinity can decrease the frequency of seed germination and lower seed yield and oil content. Safflower has approximately the same tolerance to soil salinity as barley.

C. Seed Preparation and Germination:

Seed should be treated with a registered fungicide to reduce losses due to seed-borne rust and damping-off organisms. Germination will not begin until soil temperature exceeds 40°F.

V. Cultural Practices:

Safflower gives farmers some options in a dryland crop rotation with respect to weed and disease control, and in using soil moisture available to its deep taproot. This crop is usually grown in rotation with small grains or fallow. Safflower can be severely injured by soil residues of broadleaf herbicides that were used on small grains earlier in the rotation. Caution must be used when growing safflower after small grains.

Safflower should not follow safflower in rotation or in close rotation with crops susceptible to *Sclerotinia* head rot (white mold), such as sunflower, mustard, canola (oilseed rape), or dry bean. A crop following safflower should be grown only if there has been a significant recharge of soil moisture. Very little crop residue remains after harvesting safflower. Therefore, reduced tillage or chemical fallow after safflower may help reduce wind and water erosion of the soil. The production practices and equipment needed for safflower are similar to those used for small grains.

A. Seedbed Preparation:

Volunteer small grain may be a problem when safflower follows small grain. Fall tillage and rains should reduce this problem. A moist, firm seedbed should be prepared to help establish a good stand.

B. Seeding Date:

Safflower is usually planted in late April or early May. This crop may not mature if planted after mid-May. Planting dates recommended for North Dakota are between April 20 to May 10. Seedlings emerge in 8 to 15 days. Sowing the crop after mid-May increases the possibility of lower seed yield and quality due to injury from fall frost and disease. Late planting usually results in shorter plants, less branching, and lower seed yield and oil content, even if damage from frost or disease does not occur.

C. Method and Rate of Seeding:

Use a grain drill to plant seed at depths of 1 to 1 1/2 in. at a rate of 20 to 25 lb/acre. A shallow planting depth promotes a uniform emergence that is important when planting early. Dryland rows are usually spaced at 6 to 7 in. with about 6 plants/ft^2; however, rows spaced up to 14 in. apart are sometimes used. Wider row spacing may decrease disease incidence, but can promote more weed competition, less branching, delayed maturity and lower oil content of seed. Seeding rates for irrigated crops should be 25 to 35 lb/acre. Seed is similar in size to barley and weighs about 38 lb/bushel. Drill settings for planting safflower usually agree with settings for similar seeding rates of barley.

D. Fertility Requirements:

Soil tests are necessary to correctly determine whether any additional soil nutrients are required. The amount of fertilizer needed for safflower production depends on the yield goal, its position in the rotation, and the other crops used in the rotation. Safflower has deeper roots than small grains or flax, and can effectively use nitrogen remaining in the soil from previous crops to a depth of 7 ft. As a result, soil samples should be collected at depths from 2 to 4 ft to increase the accuracy of fertilizer recommendations.

High yields can be obtained when 100 to 120 lb/acre of nitrogen are available. A limited amount of nitrogen may be required for yield goals of 1,000 lb/acre, unless a similarly deep-rooted crop such as safflower or sunflower was grown during the previous three to five years. More fertilizer may be necessary if safflower follows a deep-rooted crop in the rotation. Use of a phosphorus fertilizer does not consistently improve seed yield and quality unless applied on soils testing low or very low. Potassium fertilizer (K_2O) is applied primarily when very low levels are present. Check the soil test data and fertilizer recommendations for safflower in your area, or consider those from North Dakota (NDSU Extension Circular SF-727, Fertilizing Safflower) if none are available.

Common rates include about 20 lb P_2O_5/acre for soils testing in the medium range or below. Soil pH of 6.0 appear to be adequate. Nitrogen fertilizer can be band applied as anhydrous ammonia, or broadcast as urea or another dry or liquid form, and incorporated shortly after application. Banding or drill application of phosphorus or potassium fertilizer is more effective than broadcast application due to better availability of nutrients. To avoid seedling injury, as with other oilseed crops, do not apply more than 20 lb/acre of nitrogen or potassium fertilizer in drill rows. Urea should not be applied with the drill.

E. Variety Selection:

Only varieties that are tolerant to *Alternaria* leaf spot and bacterial blight are recommended. Descriptions of recent cultivars that were evaluated in North Dakota should be useful to prospective growers (Table 1). Do not mix the seed of linoleic and oleic safflower in planting a crop or at harvest.

F. Weed Control:

Weeds can be a major problem for safflower crops by reducing potential crop yields. Protection from weed competition during the early portion of the growing season is very important. A dense canopy of vegetation forms as the plants grow, which allows safflower to compete successfully with late-emerging weeds. Safflower with a combination of tillage and herbicides inappropriate for use on cereal grains, can be used to reduce numbers of grassy weeds in a small grain rotation.

1. Mechanical: Timely and thorough cultivation can provide initial weed-free conditions for the emerging crop. Weeds frequently emerge before safflower and can be controlled in wider rows by a spike-tooth or coil-spring harrow. Harrowing may control some weeds, but damage to the emerging safflower seedlings can occur if the soil is ridged and some plants are buried too deeply.

2. Chemical: Dual (metolachlor) and Treflan (trifluralin) are labeled for use on safflower. Dual is applied as either a preplant or preemergence herbicide. Treflan is used as either a fall or spring preplant incorporated treatment. Treflan is primarily used to control grasses, but will control some broadleaf weeds. If there are large numbers of broadleaf weeds, consider not growing safflower in that field. Wild mustard, kochia, and Russian thistle are difficult weeds to control in safflower. The herbicide rate applied will vary with the soil type and organic matter content, and the species of weeds that need to be controlled. Check the label for the correct rate to use on your fields.

Table 1. Description of several safflower varieties.

Variety	Origin[1]	Hull type[2]	Oil type[3]	Relative performance[4]					Disease tolerance[5]	
				Yield	TWT	Oil	Height	Maturity	Alt.	BB
S-541	ST	STP	Lino	v. good	m. high.	v. good	m. tall	mod.	S	MS

S-208	ST	N	Lino	good	med.	good	med.	m. early	S	S
Hartman	MT. ND	STP	Lino	fair	med.	fair	med.	m. late	T	T
Oker	MT, ND	STP	Lino	poor	low	good	m. short	early	T	MT
Girard	MT. ND	STP	Lino	good	med.	good	m. tall	m. late	T	T
Finch	MT. ND	N	Lino	v. good	v. high	fair	med.	med.	MT	T
Saffire	Can.	N	Lino	poor	med.	poor	short	v. early	S	S
Centennial	MT. ND	STP	Lino	v. good	med.	v. good	m. tall	med.	MT	MT
C/W 4440	CalWest	STP	Lino	v. good	med.	fair	tall	m. early	NA	NA
S-317	ST	STP	Oleic	v. good	med.	good	m. tall	med.	MS	MS
MT 3697	MT. ND	STP	Oleic	good	high	good	med.	med.	MT	MT
Montola 2000	MT. ND	N	Oltic	good	med.	good	short	early	NA	NA

Source: Safflower Production, March 1991. A-870, Cooperative Extension, North Dakota State University, Fargo, ND.
[1]ST=SeedTec International, MT=Montana, ND=North Dakota, Can.=Canada.
[2]STP=purple or white stripes, N=normal or white.
[3]Lino=high linoleic acid content, Oleic=high oleic acid content.
[4]Yield=seed yield, TWT=seed test weight, Oil=oil content, v.=very, m. and med.=medium.
[5]Alt.=alternaria leaf spot, BB=bacterial blight, S=susceptible, MS=moderately susceptible, MT=moderately tolerant, T=tolerant, NA=not available.
Relative performance for seed yield, test weight, and oil can vary with a severe disease infestation.

G. Diseases and Control:

Diseases have caused economic losses in years with above normal rainfall and prolonged periods of high humidity. *Alternaria* (*Alternaria carthanti*) leaf spot and bacterial blight (*Pseudomonas syringae*) are the most serious disease problems under these conditions. *Alternaria* leaf spot has symptoms of large, brown irregular spots on leaves and flower bracts. Varieties vary in the degree of resistance they have to leaf spot, and severe losses may occur. Bacterial blight has symptoms similar to those of *Alternaria* leaf spot that usually appear during periods of heavy rainfall. These leaf lesions have yellow-green margins. Using disease-free seed of a variety with some resistance, and the proper seed treatment before planting, should reduce these disease problems. Rust (*Puccinia* *carthand*) is usually not a problem in safflower since it is easily controlled by seed treatment.

There are other diseases that can cause economic losses which have not been a problem in North Dakota during recent years. Flower head rots caused by *Sclerotinia* and *Botrytis,* root rots produced by *Phytophthora* and *Pythium* fungi, and wilts from *Verticillium* or *Fusarium* are included in this list of potential disease problems. A four-year crop rotation should separate safflower from safflower, sunflower, canola, mustard, dry bean, soybean, or lentils so that common disease problems are reduced. Disease problems with safflower have historically been worse in regions east of the Dakotas, where humidity and rainfall are higher.

H. Insects and Other Predators:

Safflower can compensate well for insect damage. Economic losses do not usually occur unless the stands are greatly reduced. Growers must consider the effect of any insect control measure on beneficial insects, such as bees, since they are attracted to safflower during the flowering period and improve seed set with their pollination activity.

Wireworms, cutworms, and seed corn maggots can be harmful to germinating seeds and seedlings. Seed treatment is an effective control measure. Wireworms can be controlled with Lindane at seeding time or in combination with seed-treatment fungicides. The safflower crop may be damaged later by thrips, lygus bugs, grasshoppers, and sunflower moths. These pests should be controlled only if they reach population levels that can cause serious losses. Severe insect damage that occurs early in the flowering period may cause premature senescence of Rower heads (bronzebeads) with a possible 20 to 30% loss of the crop. Producers should consider the full range of possible cultural and chemical control measures for insect pests. Contact your local county Extension Agent for current control measures.

I. Harvesting:

Safflower is ready to harvest when most of the leaves turn a brown color and very little green remains on the bracts of the latest flowering heads. The stems should be dry, but not brittle, and the seeds should be white and hand thresh easily. This crop should be harvested as soon as it matures in order to avoid the seed discoloration or sprouting in the head that can occur with fall rains.

Safflower is an excellent crop for direct combining since it stands well and does not shatter easily. Direct combining may require artificial drying or waiting until green weeds are killed by frosts. The Crop can be windrowed to dry green weeds when moisture content of seed is as high as 25%. The time for harvesting safflower in North Dakota and similar areas of the Upper Midwest can vary from early to late September due to the environmental conditions during the growing season.

The combine cylinder speed should be set low at 550 RPM for a 22 in. cylinder to avoid cracking seed. Peripheral speed should be approximately 3,000 ft/minute. Concave clearance should be set at approximately 5/8 in. at the front and 1/2 in. at the back. The reel speed should be about 25% faster than the ground speed. To prevent clogging of the machine from plant residue, the shaker speed must be greater than speeds used for small grains. Air speed should be sufficient to remove most unfilled seeds, straw, and bulls. The combine radiator and air intake should be checked regularly to avoid blockages from the white fuzz of seed heads. Accumulations of this white fuzz can be a fire hazard.

J. Drying and Storage:

Quality safflower seed should have a white seed coat, a bushel weight over 38 lb, no uncleanable admixtures, and no sprouting, heated seeds. Safflower seed has recently been purchased on a clean basis with a desired oil content of 34 to 36%. Oil content above or below this level results respectively, in a premium or dockage on prices paid to growers. Moisture content of the cleaned seed should not exceed 8% for safe, long-term storage.

VI. Yield Potential and Performance Results:

Seed yields from research trials in North Dakota have varied from less than 500 lb/acre with limited moisture or acute weed and disease problems, to greater than 1,900 lb/acre with adequate moisture and few weed, disease, and insect problems (Table 2). Irrigated fields in California have produced yields with a range of 2,000 to 3,000 lb/acre. Yield trials in western North Dakota and Montana indicated that safflower will produce greater yields than other alternative crops, such as mustard, sunflower, and rapeseed, by 10 to 30%. Evaluations of safflower conducted in Minnesota during the 1950s and 1960s showed yield and oil content to be extremely variable. Seed yields for the best variety in each trial varied from 5 to 1,248 lb/acre with oil contents ranging from 8 to 34%. This great variation in safflower productivity might be due to cool temperatures during the flowering period, which may cause poor seed set and grain filling. These older varieties were also susceptible to diseases enhanced by heavy rainfall and high humidities that can occur in Minnesota.

Table 2. Average yield, test weight, and oil content for three varieties of safflower in 22 trials conducted by North Dakota State University during 1987-1990.

Variety	Yield (lb/acre)	Test weight (lb/bu)	Oil content[1] %
Girard	841	37.6	37.8
Carmex	888	39.3	37.8
S-541	991	37.8	41.0

Source: Cooperative Extension Service, North Dakota State University, Fargo, ND.
[1]Oil content calculated at 8% moisture.

VII. Economics of Production and Markets:

Safflower gives farmers cash income and may increase flexibility in dryland crop rotations. Safflower is grown usually under contract on a per acre basis. That is, the grower buys seed from the contracting firm and agrees to sell the entire crop for a set price. Contracts are negotiated before spring planting. Farmers are paid based on percentage of oil in the seed and/or test weight at an 8% moisture level. A recent contract price for safflower in western North Dakota and northeastern Montana was an average of 90/lb within a range of 8 to 10 cents/lb. Growers were given a 2% price bonus for each percent oil content greater than 36%. Birdseed contracts have slightly higher prices than safflower raised for oilseed. Contracts should also cover payment provision, storage payments and provisions, bonuses and discounts for moisture content and dockage, freight charges, and a clause to cover a crop disaster if it is damaged by environmental conditions, insects, or diseases. Due to recent changes in the Federal farm program, contracts are less common, and marketing loans are encouraging production for the cash or open market.

Good seed production requires hot, dry conditions during the periods of flowering, seed set, and maturation. Cool summer temperatures in parts of Minnesota and Wisconsin at these times may cause poor yields. The effect of high humidity and rainfall in promoting disease problems, such as *Alternaria* leaf spot, also make this crop questionable for production in this area of the Upper Midwest. Other minor oilseed crops may be more economically viable in most parts of Minnesota and Wisconsin.

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for one product over other similar products is implied by the Minnesota and Wisconsin Extension Services.

Sesame

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I. History:

Sesame (*Sesamum indicum* L.) is one of the oldest cultivated plants in the world. It was a highly prized oil crop of Babylon and Assyria at least 4,000 years ago. Today, India and China are the world's largest producers of sesame, followed by Burma, Sudan, Mexico, Nigeria, Venezuela, Turkey, Uganda and Ethiopia. World production in 1985 was 2.53 million tons on 16.3 million acres.

Sesame was introduced to the United States in the 1930s. Domestic production has been limited because of the lack of cultivars that can be harvested mechanically. In 1987, the sesame acreage in this country was less than 2,500 acres, about half of which were in Texas. The U.S. imports about 40,000 tons of seed and 2,200 tons of sesame oil annually, primarily from South America.

Upon ripening, sesame capsules split, releasing the seed (hence the phrase, "open sesame"). Because of this shattering characteristic, sesame has been grown primarily on small plots that are harvested by hand. The discovery of an indehiscent (nonshattering) mutant by Langham in 1943 began the work towards development of a high yielding, shatter-resistant variety. Although researchers have made sign)ficant progress in sesame breeding, harvest losses due to shattering continue to limit domestic production.

II. Uses:

Sesame seeds (approximately 50% oil and 25% protein) are used in baking, candy making, and other food industries. Oil from the seed is used in cooking and salad oils and margarine, and contains about 47% oleic and 39% linoleic acid. Sesame oil and foods fried in sesame oil have a long shelf life because the oil contains an antioxidant called sesamol. The oil can be used in the manufacture of soaps, paints, perfumes, pharmaceuticals and insecticides. Sesame meal, left after the oil is pressed from the seed, is an excellent high-protein (34 to 50%) feed for poultry and livestock.

III. Growth Habits:

Sesame is an erect annual (or occasionally a perennial) that grows to a height of 20 to 60 in., depending on the variety and the growing conditions. Some varieties are highly branched, while others are unbranched. Leaves are variable in shape and size and may be opposite or alternate. The bellshaped white to pale-rose flowers begin to develop in the leaf axils 6 to 8 weeks after planting and this continues for several weeks. Multiple flowering is favored by opposite leaves.

Sesame is normally self-pollinated, although cross pollination by insects is common. The fruit is a deeply grooved capsule (1 to 3 in. in length) that contains 50 to 100 or more seeds. The seeds mature 4 to 6 weeks after fertilization. The growth of sesame is indeterminant; that is, the plant continues to produce leaves, flowers and capsules as long as the weather permits. Sesame seeds are small and vary in color. One thousand seeds weigh about one ounce. The lighter colored seeds are considered higher quality.

IV. Environment Requirements:

A. Climate:

Commercial varieties of sesame require 90 to 120 frostfree days. Daytime temperatures of 77°F to 80°F are optimal; below 68°F, growth is reduced, and at 50°F germination and growth is inhibited.

Sesame is very drought-tolerant, due in part to an extensive root system. However, it requires adequate moisture for germination and early growth and a minimum rainfall of 20 to 26 in. per season is necessary for reasonable yields. Moisture levels before planting and flowering have the greatest impact on yield. Sesame is intolerant of water-logging. Rainfall late in the season prolongs growth and increases shattering losses. Wind can cause shattering at harvest and is cited as one reason for the failure of commercial sesame production in France.

Initiation of flowering is sensitive to photoperiod and varies among varieties. The oil content of the seed tends to increase with increased photoperiod. Because protein content and oil content are inversely proportional, seed with an increased oil content has a decreased protein content.

B. Soil:

Sesame is adaptable to many soil types, but it thrives best on well-drained, fertile soils of medium texture and neutral pH. Sesame, which has an extensively branched feeder root system, appears to improve soil structure. Sesame has a very low salt tolerance and cannot tolerate wet conditions.

C. Seed Preparation and Germination:

Seed should be cleaned thoroughly and treated with one ounce of 75% Captan per 100 lb of seed to prevent damping off. This treatment is especially important for nonshattering varieties because they are slower to emerge than the shattering varieties. Because the seeds of the nonshattering varieties spend more time in the soil before germination, they need more protection from fungal pathogens in the soil.

V. Cultural Practices:

A. Seedbed Preparation:

Sesame requires a warm, moist, weed-free seedbed. Good drainage is important, because the plant is extremely susceptible to waterlogging at any stage of growth. Since sesame is planted late, several generations of weeds can be killed by repeated tillage before planting.

B. Seeding Date:

Sesame should not be planted before the soil reaches a temperature of about 70°F—roughly one month after the last killing frost.

C. Method and Rate of Seeding:

Sesame can be seeded with a row crop planter equipped with vegetable planter boxes. Populations of 250,000 to 300,000 plants/acre in 18 to 30 in. rows have given the highest yields. This is about 1 lb/acre for 30 in. rows.

Depth of planting varies with soil type and soil moisture from 1 to 2 in. Uniform depth and seed rate are essential for stand establishment resulting in maximum yield.

D. Fertility and Lime Requirements:

Fertility requirements for sesame are similar to millet: 80 lb N, 20 lb P_2O_5 and 20 lb K_2O per acre. The N recommendation is for soils with less than 2% organic matter. Reduce the N to 60 lb/acre for soils with 2% to 5% organic matter and to 40 lb/acre if the soil has more than 5% organic matter. The P_2O_5 and K_2O recommendations are for soils testing in the "optimum" range. A pH of 5.6 or above is satisfactory. Lime and fertilizer recommendations are not presently available for sesame in Wisconsin or Minnesota. Specify "millet" on the Soil Information Sheet to obtain recommendations suitable for sesame. The P_2O_5 and K_2O and up to half of the recommended N could be applied in a band alongside the row at planting if desired. There is not likely to be a "starter" effect, however, if the crop is planted after the soil temperature reaches 70°F, as recommended.

E. Variety Selection:

There is great diversity within the several hundred varieties of sesame. However, the sesame varieties are usually divided into two types: shattering and nonshattering.

Shattering varieties: Most of the shattering varieties grown in the United States have been produced from the variety Kansas 10, or K 10. The seeds of this unbranched variety have a high oil content—over 50%—but their bitter flavor limits their value on the whole-seed market. Some shattering varieties grown in the U.S. include: Margo, Oro, Blanco, Dulce, and Ambia.

Nonshattering varieties: Nonshattering varieties have been developed to allow mechanical harvesting. Though these varieties usually contain somewhat less than 50% oil, their seed is used for oil production only. Some nonshattering varieties include: Baco, Paloma, UCR3, SW-16 and SW-17.

Mechanical harvesting is more successful with varieties that have minimal branching and a height from the soil surface to the first capsule of about 12 in. See Table 1 for the results of test crops of sesame varieties

Table 1: Yield and varietal characteristics of sesame, Lubbock, Texas, 1977–79.

	Yield (lb/acre)	Seed color	Height[1]	Maturity[2]
Shattering varieties:				
Margo	1,697	Tan	Medium	Medium
Oro	1,762	White	Medium	Medium
Blanco	1,274	Tan	Medium	Medium
Dulce	737	White	Medium	Early
Ambia	1,210	White	Tall	Medium
Nonshattering varieties:				
Baco	1,570	Brown	Medium	Medium
Paloma	1,178	Tan	Medium	Medium
UCR-3	865	Tan	Short	Early
SW-16	1,855	Tan	Medium	Medium
SW-17	1,125	Tan	Medium	Medium

[1]Short c 36 in.; Medium = 36 to 60 in.; Tall > 60 in.
[2]Early = 90 to 105; Medium = 106 to 120; Late = 120+ days.

F. Weed Control:

Because of their slow early growth, sesame plants are poor competitors against weeds. Select fields with low weed densities.

1. Mechanical: Cultivate sesame fields early and as close to the rows as possible. Shallow cultivation is recommended, because the fine, fibrous sesame roots grow close to the surface and are easily damaged. Early cultivation causes seedlings to grow faster, possibly as a result of improved soil aeration. After the plants reach a height of 3 or 4 in., they grow rapidly. Cultivate only as necessary to control weeds.

2. Chemical: No herbicides are currently registered in Wisconsin or Minnesota for use on sesame. In other areas the pre-emergence herbicides alachlor (Lasso) and trifluralin (Treflan) have been used successfully for weed control in sesame. Growers should check current labels for use of these or other products in their growing area.

G. Diseases and Their Control:

The most common sesame diseases are leaf spot, leaf and stem blights, Fusarium wilt, charcoal rot and root rot. Some of the disease organisms are carried on the seed. It is advisable to use disease-free seed and treat it with a fungicide before planting.

H. Insects and Other Predators and Their Control:

Sesame plants are often attacked and damaged by aphids. Thrips will stunt seedlings and injure developing flower buds so that capsules do not set. The gall midge (*Asphondylia sesami* Felt.) and various caterpillars have been important in some countries. Green stink bugs, red spiders, grasshoppers, cut.worms, armyworms and bollworms also attack sesame, but do not cause extensive damage. Check with your county extension office, crop consultant or chemical dealer about insecticides registered for sesame.

I. Harvesting:

Sesame is ready for harvesting 90 to 150 days after planting. In general, the unbranched varieties mature earlier. The crop must be harvested before the first killing frost to obtain high quality seeds. At maturity, leaves and stems tend to change from green to yellow to red in color. The leaves will begin to fall off the plants. The shattering and nonshattering types require different harvesting techniques. Caution is recommended to minimize seed damage and loss.

Shattering sesame varieties are usually swathed green and placed upright in small shocks, about 8 bundles per shock. Tighten the strings on the shocks in 2 or 3 days. In 2 weeks the crop will be ready to thresh. Light rains during this time will not seriously damage seed. Sesame should be threshed using a low cylinder speed (450 to 500 rpm). Screens may need to be adjusted (1/8 in. round perforations) for the small seed size. Nonshattering types can be combined directly at low cylinder speed.

J. Drying and Storage:

Sesame may be stored at room temperature for approximately 5 years without loss of viability. Freezing temperatures damage seed and make them less marketable.

VI. Yield Potential and Performance Results:

Domestically sesame is a relatively high risk crop. Sesame yields in test plots average 1,000 to 1,500 lb/acre, though as much as 2,300 lb/acre have been produced under irrigation in California. Commercial yields are usually lower.

The introduction of the nonshattering characteristic into high-yielding, normally shattering varieties carried with it a reduction in yield and/or seed quality. The development of higher-yielding nonshattering varieties is necessary for sesame to compete with other crops. Performance of shattering and nonshattering lines of sesame in trials conducted in Texas are summarized in Table 1.

VII. Economics of Production and Markets:

Currently sesame is being imported at a price of 43 cents/lb. This relatively high price reflects a world-wide shortage. Though the market for sesame seed is strong, domestic production awaits the development of high-yielding nonshattering varieties. It is advisable to establish a market before planting.

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Grain Sorghum (Milo)

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I. History:

Farmers on the hot, dry plains from Texas to South Dakota grow and use grain sorghum like Corn Belt farmers use corn. Large acreages of grain sorghum are also grown in Africa and Asia in areas where the climate is too hot and dry for corn.

During the past 25 years, the grain sorghum acreage in the U.S. has ranged from 15 to 18 million acres per year. Grain sorghum acreage is somewhat greater than acreages for oats and barley, but considerably less than the land area planted to corn, wheat, and soybeans.

In cooler, more humid regions, corn is usually a better choice than grain sorghum, but renewed interest in grain sorghum occurs whenever hotter and drier than normal growing seasons are experienced.

II. Uses:

Worldwide, sorghum is a food grain for humans. In the United States, sorghum is used primarily as a feed grain for livestock. Feed value of grain sorghum is similar to corn. The grain has more protein and fat than corn, but is lower in vitamin A. When compared with corn on a per pound basis, grain sorghum feeding value ranges from 90% to nearly equal to corn. The grain is highly palatable to livestock, and intake seldom limits livestock productivity. However, some sorghum varieties and hybrids which were developed to deter birds are less palatable due to tannins and phenolic compounds in the seed. The grain should be cracked or rolled before feeding to cattle; this improves the portion digested.

Pasturing cattle or sheep on sorghum stubble, after the grain has been harvested, is a common practice. Both roughage and dropped heads are utilized. Stubble with secondary growth must be pastured carefully because of the danger of prussic acid (HCN) poisoning.

Grain sorghum may also be used as whole-plant silage, however another sorghum, sweet sorghum, was developed as a silage crop. Sweet sorghum produces much higher forage yields than grain sorghum, but feed quality will likely be lesser because there is no grain. Some growers mix grain sorghum with soybeans to produce a higher protein silage crop.

III. Growth Habits:

Grain sorghum is a grass similar to corn in vegetative appearance, but sorghum has more tillers and more finely branched roots than corn. Growth and development of sorghum is similar to corn, and other cereals. Sorghum seedlings are smaller than corn due to smaller seed size. Before the 1940s, most grain sorghums were 5-7 feet tall, which created harvesting problems. Today, sorghums have either two or three dwarfing genes in them, and are 2-4 feet tall. While there are several grain sorghum groups, most current grain sorghum hybrids have been developed by crossing Milo with Kafir. Other groups include Hegari, Feterita, Durra, Shallu, and Kaoliang.

The grain sorghum head is a panicle, with spikelets in pairs. Sorghums are normally self-fertilized, but can cross pollinate. Hybrid sorghum seed is produced utilizing cytoplasmic male sterility. Sorghum flowers begin to open and pollinate soon after the panicle has completely emerged from the boot. Pollen shedding begins at the top of the panicle and progresses downward for 6-9 days. Pollination normally occurs between 2:00 and 8:00 a.m., and fertilization takes place 6-12 hours later.

Sorghum can branch from upper stalk nodes. If drought and heat damage the main panicle, branches can bear panicles and produce grain.

The grain is free-threshing, as the lemma and palea are removed during combining. The seed color is variable with yellow, white, brown, and mixed classes in the grain standards. Brown-seeded types are high in tannins, which lower palatability. Percentages of the seed components, endosperm (82%), embryo (12%), and seed coat (5-6%) are similar to corn.

IV. Environment Requirements:

A. Climate:

Low temperature, not length of growing season, is the limiting factor for production in most of the Upper Midwest. **Average** temperatures of at least 80°F during July are needed for maximum grain sorghum yields, and **day-time** temperatures of at least 90°F are needed for maximum photosynthesis. For example, normal average temperatures for July are about 75°F in southern Wisconsin. Night temperatures below 55°F for a week at the heading and pollination stage may result in heads with very little grain. Normal night temperatures during August range from about 65°F in southern to 60°F in central Wisconsin. In September, the range is from 55°F in southern to 50°F in central Wisconsin. In southern and central Minnesota, July and August temperatures are similar to those for southern Wisconsin. Therefore, low temperatures may prevent successful production of grain sorghum in central and northern Wisconsin and Minnesota or as a late-planted emergency grain crop in southern Wisconsin and Minnesota. Plants should complete heading by early August to insure excellent grain set.

Soil temperature at planting time is critical for grain sorghum. Sorghum seed needs soil temperatures of 60-65°F for good emergence.

Three characteristics of sorghum give it a potential advantage over corn in dry areas:

1. Corn is cross-pollinated. Severe drought at silking time may cause barren ears (no kernels). Sorghum is self-pollinated and produces heads over a longer time period because tillers develop over several weeks. Consequently, short periods of drought do not seriously damage pollination and fertilization. In a longer drought, sorghum produces fewer and smaller heads but they are rarely without kernels.
2. An optimum relationship between plant population and moisture supply is often critical with corn but unimportant with sorghum. When soil moisture is plentiful, sorghum heads grow large and tillers produce heads. But if drought occurs, heads are small and fewer tillers develop. Consequently, sorghum growers can plant high populations for potentially high yields. Corn growers can choose between high populations for maximum yields or lower populations with less chance of serious loss from drought.
3. Sorghum foliage resists drying. At equal moisture stress, corn leaves lose a greater percentage of their water content than do sorghum leaves. The waxy coating on sorghum leaves and stems may be an important cause. This coating often gives the leaf sheaths a sticky, frosty appearance.

B. Soil:

Sorghum is more tolerant of wet soils and flooding than most of the grain crops-an interesting phenomenon in relation to its drought tolerance. However, most of the poorly drained, wet soils in Wisconsin and Minnesota are too cold for grain sorghum.

V. Cultural Practices:

A. Seedbed Preparation:

A seedbed similar to the one prepared for corn is also good for grain sorghum. The use of a cultipacker or corrugated roller after seeding often gives better stands. In warmer regions, reduced- and no-tillage systems are used for grain sorghum. Soil temperatures may be too cold for these systems in much of the Upper Midwest.

B. Seeding Date:

Grain sorghum should be planted when soil temperatures reach 60 to 65°F. Generally this is 15 to 20 days after corn planting or between May 15 and early June. Grain yields decrease as planting is delayed after early June. Most hybrids require 90-120 days to reach maturity, therefore late-planting as an emergency crop is not recommended.

C. Method and Rate of Seeding:

1. **Method of Planting:** Plant grain sorghum in rows at a depth of 1 inch in heavy soil and 1 1/2 to 2 inches in sandy soil. Corn planters are probably the most common seeding equipment. It is important to place the seed in moist soil to obtain fast emergence of the seedling. A grain drill can also be used to plant the seed in narrow rows. Some adaptations in the grain seedbox may be necessary to isolate the seed above the hole. Some growers have attached small gas funnels above the holes in the seedbox and place the seed in the funnels. Commercial equipment is also available for most newer drills.
2. **Rate of Planting:** Seed size will influence the pounds of seed to plant per acre. As a general rule, there are approximately 16,000 sorghum seeds per pound. Most sorghum hybrids average about 75% emergence. On soils of good fertility and adequate moisture, the recommended rate of seeding is 8- 10 pounds of seed in rows of 30-40 inches in width. At this rate of planting, seeds will be I to 1 1/2 inches apart in the row with a population of 100,000 to 120,000 plants per acre. On soils that are less fertile or more droughty, the seeding rate should be 5-6 pounds per acre.
3. **Row Width:** The row width used will likely depend on the equipment available. During the last few years, there has been considerable interest in planting grain sorghum in narrow rows to boost grain yields. With narrow rows, greater distance between plants in the row must be planned in order to get the optimum plant population per acre. The main advantage of narrow rows is to attain more efficient use of moisture, soil fertility, and sunlight. Grain yields in Minnesota studies were 10-15% higher in 10-inch rows than in 40-inch rows. The primary disadvantage is that cultivation is not possible and weed control is dependent entirely on chemical herbicides.

D. Fertility and Lime Requirements:

Nutrient needs of sorghum closely resemble those of com in that sorghum uses relatively large amounts of nitrogen and moderate amounts of phosphorus and potassium. The grain in a 100-bushel per acre grain sorghum crop removes about 100 lbs. of nitrogen, 14 lbs. of phosphorous, and 14 lbs. of potassium.

A soil test is the most practical method of determining fertilizer needs. Apply phosphate and potash according to soil test recommendations where soil tests for P and K are low (L) or very low (VL). Use the nitrogen and maintenance phosphate and potash recommendations shown in Table 1. Lime soils to a pH of 6.0 to 6.5.

Nitrogen can be applied in the spring as a preplant application, at planting, or as a side dressing at cultivation. Appropriate N credits should be taken for manure and previous legumes to reduce N fertilizer rates. A starter fertilizer may be beneficial.

Table 1: Annual nitrogen, phosphate, and potash recommendations for grain sorghum.

Yield level	Nitrogen recommendation				Phosphate and Potash recommendation[1]	
	Organic matter %					
	< 2	2-5.0	5.1-10	> 10	P_2O_5	K_2O
bu/a	lb/a					
50 to 100	120	100	80	60	30	30

[1]Amounts shown are for medium (M) soil test levels. Apply 50% of this r ate if soil test is high (H) and omit if sod test is excessively high (EH).

E. Variety Selection:

Improved short-season grain sorghum hybrids are available, but most of the breeding is for the major grain sorghum production areas, which have warmer, longer growing seasons.

Hybrid trials are not conducted in Wisconsin, but results of limited Minnesota trials are reported in Miscellaneous Report 24. Hybrids listed in this publication may be of acceptable maturity for southern Wisconsin and sandier, warmer soils in central Wisconsin. Hybrid trials are also conducted in Iowa, but these focus on the drier, warmer western and southern portions of that state.

F. Weed Control:

Early spring seedbed preparation followed by one or two shallow cultivations, just before planting sorghum will kill several generations of weed seedlings and give sorghum a chance to get ahead of the weeds. Timely cultivations of sorghum planted in 20-inch or wider rows during the early growing stages are highly important. Sorghum planted in narrow rows can not be cultivated, but it is a highly competitive crop and can dominate many weeds. Several herbicides are available to compliment cultural and mechanical practices. Quackgrass can be controlled with I qt/A of Roundup applied when the weed is actively growing and has 3 to 4 leaves. Other perennial weeds such as Canada thistle, milkweed and hemp dogbane should be suppressed the year before sorghum is planted.

Several selective herbicides can be used in sorghum. Atrazine can be applied as a preplant incorporated, preemergence or postemergence herbicide. Application rates are similar to those used in com, as are the concerns of atrazine carryover. If crops other than com will be planted next year, do not use atrazine in sorghum. On the other hand, sorghum could be safely planted in fields with atrazine residues from previous years.

Dual and Lasso can be used as a preplant or preemergence treatment **only when sorghum seed is treated with a safener**. Your seed dealer may be able to obtain safener-treated seed for you. Dual and Lasso are excellent annual grass herbicides and could be used in combination with atrazine. If incorporated into the upper 2 inches of soil, they suppress yellow nutsedge.

Ramrod is chemically related to Lasso and Dual but can be used preemergence in sorghum without a chemical safener applied to the seed. It controls many annual grasses and can be mixed with atrazine to control a broader spectrum of weeds.

Buctril, Banvel and 2,4-D are labeled for use in grain sorghum for postemergence broadleaf weed control. Their use directions and rates are similar to those for corn.

G. Diseases and their Control:

A seed treatment such as Captan should be used to control seed rots and seedling blights. Leaf diseases can be problems in areas with high rainfall and humidity, but generally do not cause serious losses. Planting resistant hybrids, providing optimum growing conditions, rotating with other crops, removing infested debris, planting disease-free seed are all methods which can be used to minimize losses from disease.

H. Insects and Other Predators and their Control:

Under Minnesota and Wisconsin conditions, the most serious pest problem for grain sorghum growers is likely to be bird damage. Planting larger fields in one block and locating, these away from urban areas or farm buildings may help reduce the problem.

Grain sorghum is resistant to corn rootworms, but may be attacked by corn earworms, aphids, and greenbugs.

I. Harvesting:

Nearly all grain sorghum is harvested as a standing crop with a combine. Combining time will depend on the fall weather and the availability of grain drying facilities. Sorghum grain can be threshed free of the head when the seed Moisture is 20-25 percent. The seed is physiologically mature at even higher moisture levels. Frost will generally kill the top of the plant and help to lower the moisture content. Some hybrids have a loose, open type head which hastens field drying.

Sorghum seed is easily damaged in the threshing operation, especially when the grain is dry. The combine platform should be operated as high as possible to minimize the mass of stems entering the combine. If necessary, the cylinder speed can be reduced to one-half that used for wheat to prevent cracking the seed. However, grain moisture will normally be higher and faster cylinder speeds can be used. The recommended cylinder speed is 750-1300 R.P.M. but loss determinations should be made to refine the combine adjustments. An average loss of 19-22 kernels per square foot is equal to one bushel per acre loss.

The grain sorghum crop can be harvested for high-moisture grain silage. When fed to livestock, its digestibility will be increased by grinding or rolling. High moisture grain sorghum can be combined and ensiled when the grain is about 25-30% moisture.

J. Drying and Storage:

Grain sorghum can be dried with corn drying equipment. However, because the grain is smaller in size, fans may need to be operated at higher static pressure than used for corn. Also, grain sorghum needs to be somewhat drier than corn for safe storage since there is less air movement through the grain. Grain should be stored at 13% moisture and in clean bins. The grain should not be heated over 200°F since feeding values are reduced by high temperature.

VI. Yield Potential and Performance Results:

Grain sorghum yields exceeding 100 bushels per acre have been obtained in Wisconsin (Table 2). Yield potential and economics of grain sorghum must be compared to corn to determine whether or not grain sorghum offers an advantage.

On very droughty soils, or if subsoil moisture is very low, grain sorghum may out yield corn. This occurred at the Hancock Research Station in 1971 and 1972 (Table 2). However, when conditions are more favorable for corn production, corn yields will probably be at least 15-20% higher than for grain sorghum. This assumes

that planting dates and hybrid maturities are optimum for both crops, with the optimum date for grain sorghum being later than for corn.

Table 2: Performance of grain sorghum compared to corn at three Wisconsin locations, 1971-1972.

	Hancock (sand)	Janesville (silt loam)	Lancaster (silt loam)
	Bushels/acre		
Corn	53	111	118
Grain Sorghum	75	93	105

When expected corn yields are less than 50-75 bushels per acre, and the reason for the low yields is moisture stress, grain sorghum may equal or exceed corn grain yields. However, if corn yields greater than 75 bushels per acre are anticipated, grain sorghum is unlikely to be competitive.

VII. Economics of Production and Markets:

The cost of grain sorghum production is about the same as for similar grain-yield production levels for corn. Therefore decisions to grow grain sorghum depend primarily on relative yield potential compared to corn, and the ability to obtain markets. Since market outlets for grain sorghum are not established in most areas of Minnesota and Wisconsin, local elevators will probably not buy it. On-farm utilization as feed is the most likely alternative available to most growers.

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Sorghum—for Syrup

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I. History:

Sorghum (*Sorghum bicolor* L. Moench) is native to Africa, and many of today's varieties originated there. Sorghum was also grown in India before recorded history and in Assyria as early as 700 BC. The crop reached China during the thirteenth century and the Western Hemisphere much later.

Sorghum was introduced to the United States from Africa in the early part of the seventeenth century. It was not grown extensively in this country until the 1850s, when the forage variety Black Amber (also called "Chinese sugarcane") was introduced from France. Since then many other varieties have been introduced from other countries or developed domestically.

Sorghum was grown primarily for syrup until the settlement of the semiarid West created a demand for drought-resistant forage crops. By the 1950s, about 90% of the acreage of sweet sorghums in the United States was grown for forage. Interest in sorghum syrup is renewed whenever a shortage of sugar results in higher sugar prices.

Sorghum production is concentrated in areas where the rainfall is insufficient and the temperatures are too high for profitable corn production. Thus most of the domestic sorghum acreage is in the southern Great Plains states, with Texas, Kansas and Nebraska the leading producers. However, some sweet sorghum has been grown for syrup or silage in Wisconsin and Minnesota.

II. Uses:

Sorghum syrup is extracted from the plant by crushing the stalk. The syrup is produced primarily in the United States and is used by the food industry as a substitute for sugar. Recent research has evaluated sorghum as a feed stock for production of ethanol. The grain from sorghum can be used as feed for poultry and livestock.

III. Growth Habits:

Sorghum is a coarse grass that grows as an annual in the Upper Midwest. Stems are erect and solid and reach a height of 2 to 12 ft. Syrup varieties grow to be 6 to 9 ft tall. In many respects, the structure, growth, and general appearance is similar to corn: stalks have a groove on one side between the nodes; grooved internodes alternate from side to side; a leaf is borne at each node on the grooved side, with the leaf sheath and blade arrangement also much like that of corn.

The buds that form at the nodes often develop into branches. Buds that form near the crown develop into grain-producing tillers. The tillers develop their own roots but remain attached to the old crown. The culms or stalks of some varieties and types of sorghum are juicy. If the pith is not juicy, the midrib of the leaf is white in color because of the air spaces in the tissues; when the air spaces are filled with juice, the color is more neutral. Because of this difference, the plants will be at different stages of maturity at the optimum time for harvest for syrup.

Another variation between varieties is the sweetness of the juice within the stalk. Sweetness is not related to juiciness; a dry-stalked sorghum can be either sweet or non-sweet, as can a juicy-stalked sorghum. Sugar content of the juice can range from 2 to 20%.

Sorghum leaves tend to fold rather than roll, as do corn leaves when subject to moisture stress. A heavy white wax (called "bloom") usually covers sorghum leaf blades and sheaths, protecting them against water loss under hot, dry conditions.

In contrast to corn, both the male and female flowers of sorghums are in a panicle at the tip of the culm with about 95% of the flowers being self-pollinated. The inflorescence ranges from loose and open to a dense closed panicle.

Seed color varies among the sorghum varieties from white to dark brown. The endosperm is white, and the sorghums have the same vitamin A deficiency as white corn. Seed size varies considerably among the varieties, typically ranging from 1,000 to 2,000 seeds/lb.

IV. Environment Requirements:

A. Climate:

Sorghums are fast-growing, warm weather annuals. They are best suited to warm, fertile soils, as cool, wet soils limit their growth. Therefore, their production in the Upper Midwest may be limited to the warmer regions and soils of Wisconsin and Minnesota. The crop tolerates drought relatively well, although it responds to adequate fertility and soil moisture with faster growth. It also tolerates short periods of flooding better than corn. The plant will stop growing in the absence of adequate water, but it won't wilt. It will start growing again when conditions improve.

B. Soil:

Sorghums need a warm, fertile soil for optimum growth. They are suitable for planting on a wide range of soil types. Because sorghum tolerates droughty conditions, it is suited for planting on coarser textured soils if fertility requirements of the plant are met. Sorghum also grows well on loam and clay loam soils.

C. Seed Preparation and Germination:

Seed should be treated with a fungicide, such as Captan, to control seed rots and seedling blights. The effectiveness of the seed treatment will be reduced if germination and emergence are delayed due to cold, wet soil conditions. Once the seed germinates growth is normally slow for two to three weeks until the plants become established.

V. Cultural Practices:

A. Seedbed Preparation:

A firm, well-prepared seedbed is essential for a full stand. Moldboard plowing in the fall or just before planting is recommended where a heavy residue crop such as corn precedes the sorghum. If soybeans or another low residue crop precedes sorghum, fall or spring chisel plowing or disking will prepare an adequate seedbed. Tillage used should be based on soil type and erosion potential.

B. Seeding Date:

Sorghums are generally sown between May 20 and June 5. However, research at the University of Minnesota found that early planting resulted in excellent yields during 1987 and 1988 when temperatures were above normal and rainfall was below normal. The top four inches of the soil should be warm (65 to 70°F at planting. This gives quick germination and promotes early growth. Rapid early growth is essential since weeds may severely compete with small sorghum plants if growth is slowed by cool weather.

C. Method and Rate of Seeding:

The seeding rate and method depend on the use for the crop and the equipment available. Minnesota research shows little response to planting rates of 20,000 to 80,000 plants/acre for sugar yield. Sorghum for syrup can be planted with a corn planter or with a grain drill at a rate of 10 to 15 lb/acre. Seeding depth should be 1 in. in medium or heavy soil or 1 1/2 in. in sandy soil.

D. Fertility and Lime Requirements:

Soil fertility requirements are somewhat similar to those of corn, although sorghums are usually more efficient in their use of soil phosphorus and potassium. Balanced fertilization, with ample amounts of nitrogen and adequate phosphorus and potassium, is essential to get high yields. A 5 to 7 ton/acre sorghum crop will remove about 100 lb N, 40 lb P_2O_5 and 180 lb K_2O /acre. Follow soil test recommendations to determine phosphorous and potassium nutrient requirements. Under dryland conditions, 60 to 120 lb N/acre is recommended, with soils higher in organic matter requiring the smaller amounts. Recent Minnesota research indicates no response to N on soils with 5 to 6% organic matter with corn treated with 50 lb N/acre as the previous crop. On sandy soils apply about 20% of the nitrogen at planting (not seed placed) and the remainder within 30 days after emergence. Where the sorghum is planted in rows, the nitrogen may be sidedressed when the crop is 8 to 16 in. tall.

Sorghum seed is sensitive to fertilizer. Therefore, for row planting place fertilizer 2 in. to the side and at or slightly below seed depth. For broadcast stands, work fertilizer well into the soil before sowing. A soil pH of 6.0 or higher is adequate for sorghum production.

E. Variety Selection:

Rox Orange, or **Waconia**, is a medium-early maturing variety that was developed for syrup production by the Wisconsin Agricultural Experiment Station. (It has also been grown for silage in the Upper Midwest.)

Leoti Red is about the same in maturity as **Rox Orange** and can be grown for syrup, but it is prone to lodging.

Other varieties have been tested at the University of Minnesota, Southern Experiment Station. Yield data are shown for different varieties in Tables 1 and 2. The primary purpose of this research was to evaluate sweet and semisweet sorghum as a feed stock for ethanol production. **Keller**, **Dale**, and **M81E** competed favorably with corn in theoretical ethanol production based on amount of sugar produced. However, these varieties lodged severely both years, which would have made mechanical harvest difficult.

Table 1. Varietal differences in total dry matter yields, percent stalk, stalk moisture, Brix, fermentable carbohydrate yield, ethanol yield and stalk lodging of sorghum and corn grown at Waseca, MN, 1987 and 1988.

Varieties	Total dry matter (ton/a)	Percent stalk[1] %	Stalk moisture %	Brix[2]	Fermentable carbohydrate yield[3] (ton/a)	Calculated ethanol yield[4] (gal/a)	Stalk lodging[5] (%)
	Average of 2 years						
Corn							
Dekalb 524	8.2	--	46	--	--	332	15
Sorghum							

Northrup King 301	9.4	52	68	13.2	1.81	247	47
Rox Orange	10.6	46	75	10.3	1.84	250	33
Northrup King 405	11A	60	70	7.3	1.25	170	70
Keller	10.1	70	72	13.4	2.96	403	97
Dale	10.0	70	74	12.3	3.00	408	98
Northrup King 8361A	11.7	67	70	8.9	1.85	252	72
M81E	10A	66	73	12.7	2.83	385	96
Northrup King 8361	13.1	68	73	7.4	1.96	267	93
LSD (.05)	1.5	3	3	1.7	0.49	66	18
	Sorghum varieties grown only in 1988						
Cargill Mor-Cane	8.6	40	76	8.9	1.19	161	13
DeKalb FS 5	9.2	41	73	10.0	1.25	171	8
NC +940	9.2	51	70	13.2	1.83	248	15
LSD (.05)	2.0	4	3	1.9	0.56	74	17

[1]Dry matter basis.
[2]Brix is approximately equivalent to percent sugar.
[3]Brix multiplied times stalk sap yield.
[4]Assuming 2.5 gal of ethanol/bu of corn grain and 14.7 lb fermentable carbohydrate/gal of ethanol.
[5]Stalk lodging: percent of plants lodged at least 450or more at harvest. Lodging was much more severe in 1987 than 1988 due to two wind storms.
Source. Putnam, Lueschen, Kanne and Harverstad. University of Minnesota. A Comparison of Sweet Sorghum Cultivar and Corn for Ethanol Production. Submitted for publication in the Journal of Production Agriculture.

Table 2. Effect of planting date and variety on dry matter yield, percent stalk, stalk moisture, Brix, fermentable carbohydrate yield and ethanol yield of sorghum harvested at Waseca, MN in mid-October 1987 and 1998.

	Total dry matter (ton/a)	Percent stalk[1] %	Stalk moisture %	Brix	Fermentable carbohydrate yield[2] (ton/a)	Calculated ethanol yield[3] (gal/a)
Date of Planting Means						
April 26	9.3	66	68	11.3	1.71	232
May 5	8.6	66	69	10.8	1.60	217
May 15	8.4	65	69	10.4	1.46	199
May 25	8.2	66	70	10.4	1.52	206
LSD (.05)	1.0	2	1	0.6	0.18	24
Variety Means						
8361A	9.2	70	70	9.1	1.49	101
405	8.7	69	67	9.2	1.26	86
301	8.2	53	68	11.4	1.22	83
Keller	8.4	71	70	13.2	2.32	158
LSD (.05)	0.8	2	1	0.6	0.18	12

[1]Dry matter basis.
[2]Brix multiplied times stalk sap yield.
[3]Assuming 2.5 gal of ethanol/bu of corn grain and 14.7 lb fermentable carbohydrate/gal of ethanol.

F. Weed Control:

1. Mechanical: Sorghums planted in a well-prepared, warm seedbed germinate and grow rapidly and can compete well with most annual weeds. Weeds can usually be controlled with rotary hoeings and cultivations between rows.

2. Chemical: If weed problems are anticipated, it may be necessary to use herbicides to control them until a full leaf canopy is formed. The herbicides registered for use in grain or forage sorghums may not be approved for use in syrup sorghums. Check with your local extension office, crop consultant or the herbicide manufacturer if information on herbicides is needed.

G. Diseases and Their Control:

A seed treatment, such as Captan, should be used to control seed rots and seedling blights. Leaf diseases, including northern corn leaf blight, maize dwarf mosaic (MDM) and anthracnose, can be problems in areas with high rainfall and humidity. Charcoal rot, which develops under hot, dry conditions after the plants have bloomed, occasionally causes serious lodging problems. Losses due to disease can be minimized by selecting resistant hybrids, planting disease-free seed, providing optimum growing conditions (soil fertility and pH), rotating with other crops and removing infested debris.

H. Insects and Other Predators and Their Control:

Sorghums are attacked by wireworms, seed beetles, cutworms, aphids (especially greenbugs), sorghum midge, chinch bugs, spider mites, armyworms and earworms. Some of these pests can be controlled with insecticide seed treatments in the planter box.

Greenbugs are probably the most damaging sorghum insect pest. Colonies of these aphids feed on the underside of leaves and inject toxins that destroy leaf tissue. Some sorghum varieties are resistant to greenbugs, except when attacked by large numbers of the pests while still in the seedling stage.

In the Upper Midwest the most serious pest problem for sorghum may be bird damage. Birds will eat the grain, but have less effect on syrup production. Planting larger fields in one block and locating these away from urban areas or farm buildings may help reduce the problem.

I. Harvesting:

Sorghum grown for syrup should be harvested when the seeds are fully in the dough stage. Harvesting should be done before a killing frost if possible; if not, the crop should be harvested immediately after the freeze. Strip off the leaves before the freeze to lessen the damage.

The leaves should be stripped by hand while the stalks are still standing. Stalks should be tied into bundles for easier handling. The heads can be removed either before cutting the stalks or after they have been bundled and before they are taken to the mill.

The grain of sweet sorghum can be harvested, cured and used as feed for poultry and livestock.

J. Drying and Storage:

Syrup production will be reduced if stalks are stored longer than 7 to 10 4ays or subjected to freezing temperatures.

VI. Yield Potential and Performance Results:

In general it takes 8 gal of juice to produce I gal of molasses syrup. A realistic syrup yield of 75 to 80 gal/acre can be expected from a good sorghum crop.

VII. Economics of Production and Markets:

The marketability of sorghum syrup depends on the availability of other sugars and syrups and the development of niche markets. It is advisable to identify a sorghum mill and secure a contract, if possible, before planting sorghum for syrup.

VIII. Information Sources:

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Spelt

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I. History:

Spelt (*Triticum aestivum* var. *spelta*) is a sub-species of common wheat. It has been grown in Europe for about 300 years. Spelt was introduced to the United States in the 1890s.

Most of the nation's spelt acreage is in Ohio. That state grows between 100,000 and 200,000 acres of spelt annually, about 10 times more than any other state. A few varieties of spelt were developed in the early part of this century. They are no longer identifiable, and spelt has been considered an undeveloped crop. In 1986, The Ohio State University released an improved winter variety, named 'Champ'.

Spelt is often erroneously called "speltz." Sometimes emmer, another subspecies of wheat that includes dururn wheat, is incorrectly called spelt.

II. Uses:

Ground spelt is used primarily as an alternative feed grain to oats and barley. Its nutritional value is close to that of oats. The protein content of the Champ variety of spelt is about 11.7%, compared to 12% to 13% for oats. The spelt hull has nearly as much feeding value as the kernel.

Spelt can also be used as a food grain after removal of the hulls. It is popular in Europe, particularly in Germany. American food manufacturers in this country have begun to use spelt to meet the nation's increasing demand for pasta and high fiber cereals. Spelt can also be used in flour and baked goods to replace soft red winter wheat.

III. Growth Habits:

The growth habits of spelt are similar to those of winter wheat. Spelt generally lodges less than soft red wheat, but more than semi-dwarf hard red spring or winter wheat. Under conditions where soft red wheat tends to lodge, spelt has produced more grain. Spelt has large pithy stems. As with oats, the hulls remain on the grain in threshing and comprise 20% to 30% of the grain weight. No official test weight has been established for spelt, but recent tests show that unhulled it averaged 28 lb/bu. The test weight of hulled seed is close to that of wheat (60 lb/bu).

IV. Environment Requirements:

A. Climate:

Spelt is generally more winter hardy than most soft red winter wheat, but less winter hardy than most hard red winter wheat varieties. There is very little evidence that any spring types of spelt exist. The new Champ variety from Ohio is a winter type.

B. Soil:

Spelt can be grown on poorly-drained, low-fertility soils. It grows well on sandy soils in the Midwest. Some growers claim it can produce more grain than oats on a bushel basis on these soils. However, the test weight of spelt is often less than that of oats.

C. Seed Preparation and Germination:

Seed should be cleaned and tested for germination before planting. Seed treatment with a fungicide, such as Vitavax, would prevent problems with bunts; however, the label should be consulted to see if the fungicide is cleared for use on spelt. Because the hulls are attached, germination is slower than for wheat.

V. Cultural Practices:

A. Seedbed Preparation:

Soil preparation is the same as that for winter wheat.

B. Seeding Date:

The seeding date is the same as that for winter wheat - mid-September in the Upper Midwest.

C. Method and Rate of Seeding:

Spelt should be seeded with a drill set as for oats to plant 80 to 100 lb/acre. When the seedbed is dry, spelt should be seeded slightly deeper than winter wheat. The grain drill should be calibrated to ensure that the desired seeding rate is obtained.

D. Fertility and Lime Requirements:

Requirements for fertilization are similar to those for winter wheat. On soils with optimum or lower soil tests, apply a complete fertilizer with a combination drill at seeding time. Avoid direct contact of the fertilizer with the seed. An additional topdressing of nitrogen in early spring may improve yields. The topdressing should contain 10 to 20 lb less nitrogen per acre than for wheat; the straw of spelt is tall, and excess nitrogen can cause lodging. Common rates of nutrients to be applied are 50 to 60 lb/acre N, 25 lb/acre P_2O_5 and 30 lb/acre K_2O. Apply lime to maintain soil pH at about 6.0.

E. Variety Selection:

Champ is the only improved variety that has been released (Ohio State, 1986) in recent decades. Champ is awnless, brown-hulled, and about the same maturity as common spelt. Although Champ is slightly taller than common spelt, its straw strength is considerably improved. Its winter hardiness is about equal to that of common spelt. Table 1 compares yields and other performance characteristics for Champ with common spelt from trials in Ohio. Champ has very good resistance to leaf rust but is only moderately resistant to powdery mildew. The protein content of champ has consistently been 1 to 1.5% higher than common spelt. Certified seed of this variety is available from Certified seed growers in Ohio.

Table 1. Comparative performance of Champ spelt and common spelt at three locations in Ohio, 1981-85.

Entry	Yield (lb/a)	Date headed (June)	Plant ht. (in.)	% lodged	Test wt. (lb/bu)	% protein
No. of Tests	(10)	(6)	(8)	(12)	(10)	(2)
Champ	3009	2	51	12	27.7	11.7
Common	2442	3	49	48	27.9	10.5

F. Weed Control:

The best weed control practices are tillage, establishment of a good stand, and weed control in previous crops. Since no chemicals are specifically cleared for use on spelt, all the recommended cultural practices for winter wheat need to be followed to assure a dense, vigorous crop that competes well with weeds.

G. Diseases and Their Control:

Spelt is not resistant to loose smut or stinking smut (bunt). Treatment of the seed with a fungicide prior to planting could help prevent a smut problem, but the label should be consulted for clearance for use on spelt. Stem or leaf rust also can be a problem for spelt.

Other foliage diseases can occur, but can be reduced by crop rotation. Avoid planting spelt after other cereal crops.

H. Insects and Other Predators and Their Control:

The Hessian fly, greenbug, and wheat stem sawfly are the primary insect pests that attack wheat fields. Spelt has the same susceptibility to the Hessian fly as wheat. Early fall seeding may result in weak plants with poor root systems that are more susceptible to the Hessian fly in some areas of the Midwest. However, these insects have not been a problem on wheat in the Upper Midwest and may not be a serious concern on spelt.

I. Harvesting:

Spelt can be direct combined or windrowed and threshed similar to winter wheat. For direct combining, the moisture content of the crop should be 14% or less. If there are many weeds, the crop should be windrowed and the windrow allowed to dry for a few days. The crop can then be picked up and threshed with a combine fitted with a pick-up attachment. The combine should be adjusted in a manner similar to that for harvesting oats.

J. Drying and Storage:

Follow same practices as for winter wheat.

VI. Yield Potential and Performance Results:

In plot yield trials in Ohio in the early 1980s, Champ produced an average of 3,009 lb/acre and common spelt produced an average of 2,442 lb/acre (See Table 1). Newly released soft red winter wheat varieties such as 'Cardinal' yielded 10% ' more than Champ in Ohio. No performance data are available for Minnesota or Wisconsin.

VII. Economics of Production and Markets:

The value of spelt for feed is similar to oats on a per pound basis. However, because the test weight of spelt can vary considerably, the feeding value could be lower than for oats. Hence, the demand for seed is limited.

The demand for spelt may increase in the coming decade, however, because of its recently developed uses in the food industry. Some acreage in Ohio is contracted for production of spelt for pasta. It is advisable to identify a market before growing spelt.

VIII. Information Sources:

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Sugarbeets

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I. History:

Sugarbeet (*Beta vulgaris*) growing for sucrose production became successful in the United States starting about 1870. Earlier attempts at sugarbeet production were not totally successful. Once a viable industry was established, sugarbeets were grown in 26 states. About 1,400,000 acres were produced in 14 states in 1990. Minnesota and North Dakota produced about 550,000 acres. Other leading sugarbeet states are Idaho, California, Michigan, Nebraska, Wyoming, Montana, Colorado and Texas. Canada produces sugarbeets in Manitoba and Alberta. Russia leads worldwide production of sugarbeets with nearly 8,500,000 acres followed by Poland, France, West Germany and Turkey with about 1,000,000 acres each. The United States beet sugar industry has experienced great change in the last three decades. A total of 10 beet processors operated 53 factories in 18 states in 1973 while nine companies operated only 36 factories in the United States in 1990.

II. Uses:

Sugarbeets are used primarily for production of sucrose, a high energy pure food. Man's demand for sweet foods is universal. Honey was the main sweetener for primitive man. Trade in sugar from sugarcane can be traced to primitive times too. The sugarbeet was recognized as a plant with valuable sweetening properties in the early 1700s.

A. Human Food:

Sucrose from sugarbeets is the principal use for sugarbeets in the United States. Sugarbeets contain from 13 to 22% sucrose. Sucrose is used widely as a pure high energy food or food additive. High fiber dietary food additives are manufactured from sugarbeet pulp and major food processors in the United States have used these dietary supplements in recently introduced new products including breakfast cereals.

B. Livestock Feed:

Sugarbeet pulp and molasses are processing by-products widely used as feed supplements for livestock. These products provide required fiber in rations and increase the palatability of feeds. Sugarbeet tops also can be used for livestock feed. Sheep and cattle ranchers allow grazing of beet fields in the fall to utilize tops. Cattle and sheep also will eat small beets left in the field after harvest but producers grazing livestock in harvested fields should be aware of the risk of livestock choking on small beets.

Beet tops (leaves and petioles) also can be used as silage. Sugarbeets that produce 20 tons/acre of roots also produce a total of about 5 tons/acre of TDN per acre in the tops. Tops are an excellent source of protein, vitamin A, and carbohydrates but are slightly inferior to alfalfa haylage or corn silage for beef cattle. Tops are equal to alfalfa haylage or corn silage for sheep. Beet top silage is best fed in combination with other feeds. Tops should be windrowed in the field and allowed to wilt to 60-65% moisture before ensiling. See Morrisons Feeds and Feeding Handbook for a detailed description of the nutrient content of sugarbeet tops and roots.

C. Industrial Uses:

Molasses by-products from sugarbeet processing are used widely in the alcohol, pharmaceuticals, and bakers yeast industries. Waste lime from the processing of sugarbeets is an excellent soil amendment to increase soil pH levels. Waste lime is a good source of P & K plant nutrients. Treated processing waste water also may be used for irrigation.

III. Growth Habit:

Sugarbeet is a biennial plant which was developed in Europe in the 18th century from white fodder beets. Sugar reserves are stored in the sugarbeet root during the first growing season for an energy source during overwintering. The roots are harvested for sugar at the end of the first growing season but plants which overwinter in a mild climate will produce flowering stems and seed during the following summer and fall. Sugarbeet roots win not survive the winter in North Dakota, Minnesota, and Wisconsin. Sugarbeet is a summertime crop in the northern United States and a winter or summer crop in more southern, semi-arid regions. Sugarbeet seed for the United States is produced in Oregon where the climate is cool enough for vernalization but warm enough for the roots to live through the winter.

The plant has a taproot system that utilizes water and soil nutrients to depths of 5 to 8 ft. As sugarbeet plants emerge, a pair of cotyledons unfold. Successive leaves develop in pairs throughout the growing season. The life expectancy of sugarbeet leaves varies from 45 to 65 days and is temperature dependent.

Photothermal induction is necessary to bring about complete reproductive development of the plant. The sugarbeet normally is a diploid plant. It is cross pollinated with wind being the effective agent.

IV. Environment Requirements:

A. Climate:

Sugarbeets have adapted to a very wide range of climatic conditions. Sugarbeets primarily are a temperate zone crop produced in the Northern Hemisphere at latitudes of 30 to 60°N. Sugarbeets can be produced in hotter and more humid environments, however, problems with insects, disease and low quality of the crop are more common in such geographical arm.

The sugarbeet plant grows until harvested or growth is stopped by a hard freeze. Sugarbeets primarily grow tops until the leaf canopy completely covers the soil surface in a field. This normally takes 70 to 90 days from planting. Optimal daytime temperatures are 60 to 80°F for the first 90 days of plant growth. Regions with long day length are most suitable for sugarbeet growth. The most favorable environment for producing a sugarbeet crop from 90 days after emergence to harvest is bright, sunny days with 65 to 80°F temperatures followed by nighttime temperatures of 40 to 50°F. These environmental conditions maximize yield and quality in a sugarbeet crop.

B. Soil:

Sugarbeets are well adapted to a wide range of soil types. In the United States, sugarbeets am produced on coarse textured sandy soils to high organic matter, high clay content, silty clay or silty clay loam soils. A soil free or nearly free of stones is particularly desirable. Stones cause problems for sugarbeet planting, thinning, harvesting and processing equipment. Dryland sugarbeet production generally is limited to soils with high water holding capacities in areas with 20 in. of rainfall or more. Sugarbeets are successfully produced under irrigation in regions with very low rainfall.

V. Cultural Practices:

A. Seedbed Preparation:

Field selection and seedbed preparation are critical to establishment of the sugarbeet crop. Objectives are to manage crop residues effectively, minimize erosion, improve soil structure to meet needs of the crop and eliminate early season weeds.

Fall tillage should be matched to soil type, amount and type of previous crop residue present, and be compatible with soil conservation requirements. Mold board plows, chisel plows, disks and field cultivators all have been successfully used for primary fall tillage. Fall tillage systems should maintain enough residue on the soil surface to prevent erosion or be compatible with cover cropping systems for erosion control. Spring tillage should be kept to an absolute minimum. Objectives are to preserve seedbed moisture, maintain enough crop residues on the soil to stop erosion, and reduce the chance of wind damage to weak sugarbeet seedlings as they emerge. The spring seedbed should be as level as possible and firm to well packed to allow good seed to soil contact when planting. Common spring tillage tools are light harrows, multiweeders, and combination Danish tine, harrow, rolling basket tillage tool systems. Spring tillage should be only 1 to 2 in. deep. Planting should be done as quickly as possible after spring tillage before seedbed drying can occur. Sugarbeets are planted only 0.75 to 1.5 in. deep.

Sugarbeets have been successfully planted with no-till, with strip tillage in previous crop residues, and other reduced tillage systems. These tillage alternatives often require specialized equipment, greater planning and better management to be successful.

B. Seeding Date:

Research in North Dakota, Minnesota, Michigan and other states indicates highest yields and crop quality are attained with early planting. Growers generally accept some risk of early frost damage and plant early. Optimum planting dates in Minnesota, North Dakota, and Wisconsin are from April 20 to May 10. Sugarbeets have been successfully planted as early as April 1st. They may be planted as late as June 10 and stiff produce a harvestable crop. Yields decline about 1.5 tons/week with each week delay in planting after May 10. Seedling sugarbeet plants have good tolerance to mild frosts and have survived temperatures in the mid-twenty degree range.

C. Method and Rate of Seeding:

Sugarbeets are planted with precision row crop planters. Plate and cell wheel planters or newer vacuum or air planters all work well. Sugarbeets may be planted to thin to a final stand or space planted to a desired final plant population. Seeding rates vary from 1 to 2 lbs of seed/acre. Sugarbeet planters should not be operated at more than four miles per hour. Planting speeds greater than four miles per hour result in increased skips, increased seed doubles or triples and seed damage. Sugarbeet seed should not be planted greater than 1.5 in. deep.

D. Row Width and Plant Populations:

Narrow row widths produce higher yields and quality than wide rows. Sugarbeets in narrow rows compete better with weeds also. Optimum row widths are 18 to 24 in., with 22 in. rows being most common. Sugarbeets may be planted in 30 in. rows for equipment convenience and compatibility with other row crops in rotation. However, sugarbeets planted in 30 in. rows commonly yield 400 to 600 lbs less recoverable sugar per acre than in 22 in. rows, with the same harvest populations. Also, higher more uniform plant populations, which will result in greater yield and quality, are easier to establish on narrow rows.

Sugarbeet plant populations should be from 30,000 to 40,000 uniformly spaced plants per acre at fiarvest. These populations should produce very good yields of easily harvested high quality sugarbeets. Growers can expect plants to be established from only 60 to 70% of the seed planted. Loss of 5 to 15% of established seedlings can be expected between planting or thinning and harvest depending on growing conditions.

E. Crop Rotations:

Yields and quality usually are highest when sugarbeets follow barley or wheat in the crop rotation. Yields usually are high when sugarbeets follow corn, potatoes or summer fallow in rotation, but higher than desirable residual soil nitrogen levels may follow these crops and reduce sugarbeet quality. Three years research in Minnesota indicated sugarbeet yielded significantly less when following soybeans versus barley in rotation. One year of research indicated sugarbeet yields also were reduced following dry edible beans in rotation.

F. Fertility and Cultural Practices:

Sugarbeets do not grow well on highly acidic soils and grow best on soils with a pH of 6.0 to 8.0. Sugarbeet culture on soils with pH lower than 6.0 should not be attempted until liming raises the pH to 7.0 or greater.

Profitable sugarbeet production depends largely on a high sucrose content/high tonnage crop. To accomplish this, growth-limiting factors such as soil fertility must be managed effectively.

Sugarbeets are unique in their nitrogen (N) requirements. Too little nitrogen results in poor leaf canopies, premature yellowing and reduced yields, while too much nitrogen leads to a reduced sucrose content, increased impurities and lowered sucrose extraction. For proper nitrogen management, pregrowing season soil nitrate-nitrogen (NO_3-N) should be determined in a reputable laboratory that uses appropriate procedures and interpretations. NO_3-N is mobile in the soil so residual nitrogen level should be determined annually. Phosphorus and potassium should be determined every three to four years.

Sugarbeet quality involves two concepts: the percent sucrose in the root and the level of impurities in the root, both of which affect sucrose extraction by the processor. Production of high quality sugarbeets is especially important to growers whose payment is based on the extractable sucrose content of their beets.

Proper nitrogen fertilizer use normally increases yield of both roots and sucrose and also may increase impurities and decrease the percent sucrose in the root. Use soil test information to select fields with nitrogen levels suited to expected yields, and to select fertilizer rates appropriate for expected yield goals. Excessive amounts of either residual or fertilizer nitrogen usually significantly lowers beet quality. Sugarbeets require 8 to 9 lbs of nitrogen/ton to produce a high quality, good yielding crop.

Table 1 shows the nitrogen, phosphate and potash recommendations for sugarbeets.

Table 1. Nitrogen, phosphate and potash recommendations for sugarbeets

Sugarbeet	Soil N plus	Phosphorus	

yield goal	fertilizer N needed*	P Soil test Levels lb/acre)				K Soil	
		L 0-9	M 10-19	H 20-29	VH Over 30	L 0-99	M 100
ton/acre	lb/acre/2 ft	P_2O_5 lb/acre					
16	95	60	35	10	0	85	50
17	100	60	35	10	0	90	55
18	110	65	40	15	0	95	55
19	115	70	40	15	0	100	60
20	120	75	45	15	0	105	6[illegible]
22	130	80	50	15	0	115	70

*Subtract amount of NO_3-N in top 2 feet of soil from these figures to determine the amount of N fertilizer to apply.
[1]All recommendations are for broadcast applications.

When selecting a sugarbeet yield goal and requesting fertilizer recommendations, remember that recoverable sugar is the product desired. **Over-fertilization, particularly with nitrogen, can result in poor quality beets and reduced net returns.** Therefore, judicious use of manageable factors such as nitrogen fertilizer, early planting, even spacing, adequate plant populations, weed control, timeliness of operations, disease and insect control all will improve recoverable sugar yield. A good method for selecting a yield goal is to use a yield approximately three tons/acre lower than the greatest yield produced on your farm or in your area.

Recent research in Minnesota and North Dakota indicated early season growth and/or yield responses to starter fertilizer occurred about 40% of the time. Significant responses are most likely to occur when soils test very low to low in phosphorus or have low levels of available nitrogen in the top 6 in. of soil.

Sugarbeet seeds and seedlings are sensitive to fertilizer salts. Germination damage may occur if excess nitrogen or potassium fertilizer is placed in direct contact with seed. In some areas, straight phosphate fertilizer materials may not be available in sufficient quantities. In this case, use monoammonium phosphate (11-48-0) or 10-34-0 liquid as a starter fertilizer. Seed germination reduction should be negligible from 5 or less pounds of nitrogen per acre in contact with beet seed and any slight effect would be more than offset by the improved yields from the banded phosphorus application on very low-testing soils. Do not apply more than 5 to 6 lbs/acre of nitrogen plus potassium as a starter in contact with the seed.

Sugarbeets growing on soils that test very low in phosphorus and/or potassium depend heavily on applied fertilizer. On soils testing medium or above, the crop is much less dependent on applied fertilizer. Fertilizer is applied on these soils to replace nutrients removed by the crop and/or as a starter to get the crop off to a fast start, especially in cool, cloudy springs. On very low testing soils where the plants depend largely on fertilizer for their needs, the method of application will influence the amount of fertilizer that plants can recover. Broadcast fertilizer is thoroughly mixed with the soil and, as a result, some is positionally unavailable to plant roots. Band or drill row fertilizer is applied closer to the seed and can be recovered more efficiently by the crop.

Sugarbeets are among the crops least susceptible to secondary and micronutrient deficiencies. The exception may be a susceptibility to boron and manganese shortages. Zinc deficiency has been reported on infrequent occasions in Minnesota. Responses to other micronutrients have not been reported or demonstrated. A soil test for these nutrients will answer questions that arise about possible needs for manganese, copper, or iron.

Calcium deficiency may be observed in sugarbeets in Minnesota and North Dakota. However, the deficiency apparently is a physiological problem. Soils in this area are high in calcium and application of calcium-containing fertilizers will not correct the deficiency. Yield losses due to this problem have not been documented.

G. Variety Selection:

Commercial sugarbeet variety development has been exclusively by private sugar and seed companies in the United States. American Crystal Sugar Company, Moorhead, Minnesota conducts the most comprehensive variety trials in the United States.

American Crystal's coded variety trials are designed to give an unbiased evaluation of the genetic potential of all sugarbeet variety entries while other variables (stand, fertility, moisture levels, etc.) are kept constant. These evaluations are used to establish a list of approved varieties which insures the use of the most productive varieties to maximize returns to the growers and sugar companies.

H. Weed Control:

Sugarbeets are poor competitors with weeds from emergence until the sugarbeet leaves shade the ground. Emerging sugarbeets are small, lack vigor, and take approximately two months to shade the ground. Thus, weeds have a long period to become established and compete. Sugarbeets are relatively short even after they shade the ground so many weeds that become established in a field prior to ground shading will become taller than the sugarbeets, shade the sugarbeets, and cause severe yield losses. To avoid yield loss from weed competition, weeds should be totally controlled by four weeks after sugarbeet emergence and weed control should be maintained throughout the season.

A combination of cultural, chemical, and mechanical weed control methods should be used to maximize weed control in sugarbeets. Some weed species such as kochia, common mallow, common milkweed, and velvetleaf are difficult or impossible to control selectively in sugarbeets with herbicides. These weeds in particular, and all weeds in general, should be effectively controlled in other crops in the rotation. Spot spraying or hand weeding small areas should be used to prevent establishment of problem weeds. Sugarbeets should not be planted on fields badly infested with problem weeds.

Cultivation with a row crop cultivator is a universal and essential weed control method in sugarbeets. Also, the rotary hoe or spring tine harrow can be used to remove small weeds from well rooted sugar beets. Hand weeding is still an important method of weed control in sugarbeets with 76% the acres in Minnesota and Eastern North Dakota receiving some hand weeding in 1989. Ile decision on using hand weeding or other methods of weed control should be based on expected economic returns. Generally herbicides will be more cost effective than hand weeding in moderate to heavy weed densities. Hand weeding may be more cost effective in low weed densities, especially if the target weed species are herbicide tolerant or too large for effective control.

1. Preemereence Contact or Tillage Substitution Herbicides. Glyphosate (several trade names) can be applied before sugarbeets emerge, to emerged weeds at 0.19 to 0.75 lb/acre (0.5 to 2 pt/acre). Use the higher rate on larger weeds, more resistant weeds, or if the plants are under moisture stress. Use 0.75 lb/acre to control living small grain cover crops. When low rates of glyphosate are used, apply in 3 to 10 gallons of water per acre by ground or in 3 to 5 gpa by air. Delay tillage for at least 3 days after treatment. Glyphosate is a non-selective translocated postemergence herbicide with no soil residual activity. A non-ionic surfactant should be used with glyphosate.

Paraquat (Gramoxone Extra) can be applied before sugarbeets emerge to emerged weeds at 0.62 to 0.94 lb/acre (2 to 3 pt/acre). Apply in 5 to 10 gpa of water by air or in 20 to 60 gpa by ground. Paraquat is a non-selective contact herbicide with no soil residual activity. A nonionic surfactant should be used with paraquat.

2. Soil-applied Herbicides: Good weed control with preemergence (non-incorporated) herbicides requires rainfall after application. Herbicides which are incorporated into the soil surface usually require less rainfall after application for effective weed control than unincorporated herbicides. Weeds emerging through a preemergence; herbicide treatment may be controlled by rotary hoeing or harrowing without reducing the effect of the herbicide unless the harrow or rotary hoe removes the herbicide from a treated band.

The reasons for using soil-applied herbicide in sugarbeets include the following:

1. To reduce early season weed competition.
2. To make postemergence herbicides more effective by increasing weed susceptibility and by reducing the total weed population.
3. To provide weed control if unfavorable weather prevents timely cultivations or postemergence herbicide applications.
4. A single herbicide treatment usually will not give total weed control. A preemergence or preplant incorporated herbicide followed by postemergence herbicides often will improve weed control compared to preemergence or preplant incorporated herbicides alone or postemergence herbicides alone.

Incorporation of Herbicides: Many herbicides applied before crop and weed emergence need to be incorporated to give optimum weed control. Included in this group are cycloate (Ro-Neet) and EPTC (Eptam). Weed control from ethofumesate (Nortron), pyrazon (Pyramin), and diethatyl (Antor) generally is improved by incorporation.

Cycloate (Ro-Neet) and EPTC (Eptam) should be incorporated immediately after application regardless of whether the liquid or granular formulation is used. Ethofumesate (Nortron), diethatyl (Antor), and pyrazon (Pyramin) may be used preemergence but incorporation usually improves weed control, especially on fine-textured soils or with limited rainfall after application. Incorporation may reduce weed control if heavy rains follow application and incorporation may increase sugarbeet injury compared to surface application. Experience indicates that lack of rainfall is more common than excess rainfall following planting.

An estimate of the efficiency of an incorporating tool can be obtained by operating the tool through flour or lime which has been spread thickly over the soil. A thorough incorporation should cover most of the flour or lime and give uniform mixing through the soil. Several tillage tools have been used successfully for the incorporation of herbicides. Some herbicides require more thorough incorporation than others and the incorporation method should be matched to the herbicide.

Cycloate and EPTC require a thorough incorporation and should be incorporated by one of the following methods or a method which will incorporate similarly.

a. A tandem disk should be set at a depth of 4 to 6 in. for EPTC or cycloate. Operating speed should be 4 to 6 mph. Tandem disks with disk blades spaced 8 in. or less and disk blade diameter of 20 in. or less have given good herbicides incorporation. Larger disks often give streaked incorporation and poor weed control.
b. Field cultivators of various types may be used. These should have overlapping sweep shovels with at least three rows of gangs and the operating depth should be 4 to 6 in. for EPTC and cycloate. A harrow should follow the field cultivator. The operating speed necessary to achieve a satisfactory incorporation will vary somewhat depending on the type of field cultivator but the speed usually will be 6 to 8 mph.
c. Field cultivators with Danish tines plus rolling crumblers behind have given good herbicide incorporation. These tools should be operated 4 in. deep and at 7 to 8 mph or faster. Adequate incorporation with one pass may be possible with these tools if soil conditions are ideal for herbicide incorporation. However, a second incorporation may be good insurance against poor weed control.
d. Power driven rototiller-type equipment will give adequate incorporation when set to operate at a depth of 2 to 3 in. at the manufacturer's recommended ground speed.

A single incorporation with a power driven rototiller is sufficient for cycloate or EPTC. However, a second tillage at right angles to the initial incorporation should be done if the disc or field cultivator is used. The second incorporation has two purposes:

a. Most of the herbicide left on the surface after the first incorporation will be mixed into the soil with the second tillage.
b. The second tillage will give more uniform distribution of the herbicide in the soil which will improve weed control and may reduce crop injury.

Ethofumesate, diethatyl, and pyrazon do not require deep incorporation. A tillage tool operating at a minimum depth of 2 in. will give adequate incorporation if the tool mixes the herbicide uniformly through the soil.

EPTC (Eptam) preplant incorporated in the spring at 2 to 3 lb/acre (2.3 to 3.4 pt/acre) or fall applied at 4 to 4.5 lb/acre (4.5 to 5.25 pt/acre) gives good control of annual grasses and certain broadleaf weeds. EPTC sometimes causes sugarbeet stand reduction and temporary stunting. However, no yield reduction will result if enough sugarbeets remain to obtain an adequate plant population after thinning. EPITC should be used with extreme caution on sugarbeets grown in loam or coarser-textured soils with low organic matter levels because a safe EPTC rate is difficult to predict on such soils.

Cycloate (Ro-Neet) spring applied at 3 to 4 lb/acre (4 to 5.3 pt/acre) or fall applied at 4 lb/acre (5.3 ptlacre) gives weed control similar to EPTC. EPTC tends to give better weed control than cycloate on fine-textured, high organic matter soils or under relatively dry conditions while cycloate gives better control than EPTC when spring rainfall is adequate to excessive. Cycloate causes less sugarbeet injury than EPITC and is thus safer for use on more coarse textured, low organic matter soils.

EPTC (Eptam) plus cycloate (Ro-Neet) has less potential for sugarbeet injury than EPTC alone and is less expensive per acre than cycloate alone. The rate of application of the mixture must be adjusted for soil texture and organic matter. Suggested fall applied rates are: cycloate alone at 4 lb/acre on soils with less than 3% organic matter, EPTC + cycloate at 1 + 3 lb/acre on loam or coarser soils with 3% organic matter, 1.5 to 2.5 lb/acre on loam to clay loam soils with 3 to 4% organic matter, 2 + 2 lb/acre on clay loam soils with 3.5 to 4.5% organic matter, and 2.5 + 2.5 lb/acre on clay or clay loam soils with over 4.5% organic matter. Suggested spring applied rates are: cycloate alone at 3 lb/acre on loam or coarser soils with 3 % or less organic matter, EPTC + cycloate at 1 + 2.5 lb/acre on loam or coarser soils with 3 to 3.5% organic matter, 1.5 + 2.5 lb/acre on loam to clay loam soils with 3.5 to 4.5% organic matter, and 2 + 2 lb/acre on clay loam or finer soils with 4% or more organic matter. These rates may need to be adjusted on certain fields or with certain incorporation tools based on individual experience. EPTC, cycloate, or EPTC + cycloate require immediate incorporation for best weed control.

Pyrazon (Pyramin) spring applied at 3.1 to 7.6 lb/acre (6 to 14.5 pt/acre) controls most broadleaf weeds. Pyrazon has been less effective on soils with more than 5% organic matter. Weed control from pyrazon generally increases as soil organic matter content decreases. Shallow incorporation generally improves weed control from pyrazon. High amounts of rainfall after application improves weed control from pryazon.

Ethofumesate (Nortron) at 3 to 3.75 lb/acre (16 to 20 pt/acre) gives good control of several broadleaf and grassy weeds, is especially effective on redroot pigweed, but is weak on yellow foxtail. Ethofumesate generally gives less sugarbeet injury than EPTC (Eptam) especially on more coarse textured, low organic matter soils. Ethofumesate may be applied preemergence but incorporation generally improved weed control in tests in North Dakota and Minnesota. Preemergence applications of ethofumesate will give good weed control when relatively large amounts of rain follow application. The exact amount of rain needed is not known but field observations indicate that at least I in. of rain is needed to give best results from preemergence ethofumesate. Coarse textured, low organic matter soils require less rain for activation than fine textured, high organic matter soils. Ethofumesate often has a residue the year following use on sugarbeets. Crops most likely to be damaged by ethofumesate residue are wheat, barley, and oats. Moldboard plowing usually eliminates carryover injury. Ethofumesate should be applied in a band to r6duce cost and reduce carryover.

Diethatyl (Antor) spring applied at 4 to 6 lb/acre (8 to 12 pt/acre) gives good to excellent control of redroot pigweed and prostrate pigweed. Diethatyl generally gives less sugarbeet injury than EPTC (Eptam) especially on coarse textured, low organic matter soils. Diethatyl may be applied preemergence but incorporation generally improved weed control in tests in North Dakota and Minnesota. Preemergence diethatyl will give good weed control if adequate rain follows application. Diethatyl needs amounts of rain similar to ethofumesate as discussed in the previous paragraph.

3. Postemergence Herbicides: Clopyralid (Stinger) at 0.09 to 0.25 lb/acre (0.25 to 0.66 pt/acre) postemergence controls several broadleaf weeds and volunteer crops. Clopyralid at 0.09 to 0.19 lb/acre is most effective when applied to common cocklebur, giant ragweed, marshelder, volunteer sunflower, wild sunflower, volunteer alfalfa, and volunteer soybeans up to the six-leaf stage, common ragweed up to the five-leaf stage and wild buckwheat in the three to five-leaf stage before vining begins. Clopyralid at 0. 19 to 0.25 lb/acre is most effective on Canada thistle in the rosette to pre-bud growth stage, but rosette application often gives better control than later application. Clopyralid must be applied to sugarbeets in the two to eight-leaf stage and at least 105 days prior to harvest. Clopyralid. is not registered for application by aircraft.

Clopyralid (Stinger) may have a herbicidally active residual in the soil following postemergence application. Wheat, barley, oats, grasses, corn and sugarbeets have good tolerance to clopyralid and can be planted any time following application. Other crops usually can be planted 12 months after treatment. Extreme conditions where topsoil remained cold or dry for extended periods after application may cause herbicidally active residual to persist for more than 12 months. In this case, small areas of lentils or peas should be planted as bioassay species prior to planting more extensive areas of lentils, peas, safflower, potatoes, alfalfa, sunflowers, edible beans, or soybeans. Time of clopyralid application during a season may influence the time of crop seeding the following year. For example, clopyralid applied June 15 would prevent seeding soybeans or edible beans until June 15 or later the following year.

Desmedipham (Betanex) and desmedipham + phenmedipham (Betamix) are posternergence herbicides for the control of annual broadleaf weeds. Sugarbeet injury occasionally occurs from desmedipham and phenmedipham. Sugarbeets with four true leaves are less susceptible to injury than smaller sugarbeets. Sugarbeets gain additional tolerance as they become larger than the four-leaf stage. Desmedipham at 0.25 to 0.5 lb/acre (1.5 to 3 pt/acre) or desmedipham plus phenmedipham at 0. 12 to 0.25 plus 0. 12 to 0.25 lb/acre (1.5 to 3 pt/acre) may be applied to sugarbeets with less than four leaves. Applications totaling 0.5 lb/acre or less should be followed by a second application in 5 to 7 days if living Weeds are present after 5 days. Split application with reduced rates has reduced sugarbeet injury and increased weed control compared to a single full dose application. Risk of sugarbeet injury is reduced by starting application in late afternoon so cooler temperatures follow application. Risk of injury is increased by factors such as recent flooding, high temperature, and a sudden change from a cool, cloudy environment to a hot, sunny environment. Sugarbeets and weeds in fields treated with a soil applied herbicide will be more susceptible to desmedipham and phenmedipham than untreated plants. Desmedipham and desmedipham plus phenmedipham vary in effectiveness on certain weed species.

Endothall (Herbicide 273) at 0.75 to 1.5 lb/acre (2 to 4 pt/acre) gives good control of wild buckwheat, and smartweed. Sugarbeets would have 4 to 6 leaves before application and should not be treated later than 40 days after emergence. Temperatures should be 60 to 80OF at application. Weed control may be poor when weeds are under even slight drought stress.

Sethoxydim (Poast) at 0.1 to 0.5 lb/acre (0.5 to 2.5 pt/acre) plus an oil additive will control annual grasses and suppress perennial grasses. An oil additive must be used for consistently good grass control. Tank mixing sethoxydim (Poast) plus oil additive with desmedipham, phenmedipham, or endothall often gives less grass control, especially of wild oats. Addition of ammonium sulfate at 2.5 lb/acre or 28% nitrogen solution at 0.5 to I gpa often will increase grass control especially when the water carrier has high levels of sodium carbonate or sodium bicarbonate. Application rates for several grass species are: 0. 1 lb/acre for wild proso millet; 0.2 lb/acre for green foxtail, yellow foxtail, giant foxtail, barnyardgrass, wooly cupgrass, wild oat, or volunteer corn; 0.28 lb/acre for volunteer cereals; and 0.25 lb/acre plus 0.2 lb/acre on regrowth for quackgrass.

Combinations of postemergence herbicides give more broad spectrum and greater total weed control compared to individual treatments. The risk of sugarbeet injury also increases with combinations so combinations should be used with caution. Ethofumesate (Nortron) in combination with desmedipham and desmedipham + phenmedipham has given improved weed control compared to desmedipham or desmedipham + phenmedipham used alone. These combinations increase the risk of sugarbeet injury. Endothall (H-273) has been used at 0.25 to 0.5 lb/acre in combination with desme4dipham or desmedipham + phenmedipham to give improved control of wild buckwheat compared to desmedipham or desmedipham + phenmedipham alone. Clopyralid plus desmedipham plus phenmedipham have given control of wild buckwheat, eastern black nightshade, common lambsquarters, and Russian thistle superior to clopyralid alone and to desmedipham or desmedipham plus phenmedipham alone.

4. Layby Herbicides: Trifluralin at 0.75 lb/acre (1.5 pt/acre) is cleared for use on sugarbeets when the sugarbeets are 2 to 6 in. tall and well rooted. Exposed beet roots should be covered with soil before application. Emerged weeds are not controlled. Trifluralin may be applied over the tops of the sugarbeets and incorporated with a harrow, rotary hoe, or cultivator adjusted to mix the herbicide in the soil without excessive sugarbeet stand reduction. Use of trifluralin can reduce the emergence of late season weeds which often cause problems in sugarbeets. EPITC (Eptam) at 3 lb/acre (3.4 pt/acre) is cleared as a layby herbicide for sugarbeets and should be applied similarly to trifluralin. However, the greater volatility of EPTC and the greater need for thorough incorporation make EPTC less likely to be effective as a layby herbicide than trifluralin. EPTC also can be applied by metering the herbicide into irrigation water. EPTC should be applied in the first irrigation after the last cultivation of the season.

Table 2. Effectiveness of herbicides on major weeds in sugarbeets.

	Grasses			Broadl					
	Barnyard-grass	Foxtails (pigion-grass)	Wild oats	Canada thistle	Cocklebur	Common lambquarters	Eastern blacknight-shade	Kochia	Pigwe redro
Preemergence or preplant incorporated									
coycloate (Ro-Neet.)	G	G	F/G	N	P	F/G	F/G	P	F/(
diethatyl (Astor)	F/G	F/G	F/G	p	P	P	F/G	P	G
EPTC (Eptam)	G	G	F/G	N	P	F	F/G	F	F/(
ethofumesate (Noftron)	P	F/G	F/G	N	P	P/F	F/G	F/G	G
pyrazon (pyramift)	P	p	P	P	P/F	G	a	P/F	G
Postemergence									
clopyralid (Stinger)	P	N	N	G	G	P/F	F/G	N	P
desmedipham (Betanex)	P	P	N	N	PIF	G	G	P/G	G
desmedipham + phenmedipham (Betamix)	P	F	N	N	F	G	G	F	F/(
endothall (Herbicide 273)	N	N	N	N	P/F	P		P	P/I
ethofamesate +	F	F/0	P	N	F/G	G	G	F/G	0

desmedipham (Nortfou + Betanex)									
ethofumesate + desmedipham + phenmedipham, (Nortron + Betamix)	F	F	P	N	F	G	G	F	G
sethoxydim (Proast)	G	G	G	N	N	N	N	N	N
trifluralin (Layby)	G	G	F	N	N	G	N	G	a

G = Good; F = Fair, P = Poor, N = None; O = Often; S = Seldom; - = No data.

I. Diseases and Their Control:

Sugarbeet yield losses are caused by seedling blights, root rots and foliar diseases. Using appropriate control methods will eliminate or reduce losses from diseases.

The most common seedling pathogens are soilborne fungi. These include *Aphanomyces cochlioides, Rhizoctonia solani* and several *Pythium* species. *Phoma betae* is a seedborne pathogen that affects sugarbeets but has not been a common problem in the region. These diseases attack the seed and/or germinating or recently emerged seedlings. Seedling diseases caused by these fungi produce similar symptoms often called damping off. Two or more pathogens may simultaneously or successively attack seedlings. Disease severity and prevalence varies among regions, between fields and within a field. Seedling disease severity is determined by the availability of disease inoculum, environmental factors and varietal susceptibility.

Aphanomyces cochlioides and *Rhizoctonia solani* are the primary fungi that cause root rots of economic concern. *Phoma betae,* several *Fusarium* species, *Pythium aphanidermatum* and *Erwinia caratovora* are of minor importance. Many of these fungi survive for long periods of time in the soil. Symptoms vary from minor lesions to complete destruction of the root by dry or wet rots. Control methods for severe root rot and seedling disease problems include varietal resistance, fumigation crop rotations, seed treatments and fungicide application. Control of root rots is often expensive and temporary in nature. Commercial sugarbeet seed is usually pretreated with one or more protectant fungicides.

Cercospora leafspot caused by the fungus *Cercospora beticola* is the most serious foliar disease of sugarbeets in the north central United States. Losses of 30 % or greater recoverable sucrose per acre are fairly common under moderate to severe disease conditions. Also, roots of affected plants do not keep well in storage piles either. Many of the currently grown high yielding varieties are susceptible or moderately susceptible to *Cercospora.* Warm days and nights with high humidity or free water on the crop canopy are most conducive to serious disease outbreaks.

A *Cercospora* leafspot disease prediction model is available to monitor disease development and plan a fungicide control program. Crop rotation is an important control measure since the disease overwinters on infected beet leaves. A three year rotation is minimal for reducing disease inoculum. Burying beet refuse by tillage helps reduce inoculum survival and dispersal. Varieties vary greatly in *Cercospora* resistance. The disease develops slowly and is a minor problem on some varieties but can cause total defoliation of others. Triphenyl tin hydroxide fungicides give best *Cercospora* leaf spot control. Mancozeb and copper fungicides give acceptable *Cercospora* control especially with less severe disease outbreaks.

Powdery mildew, caused by the fungus *Erysiphe betae*, is the only other serious foliar disease of sugarbeets in the region. The disease is favored by long periods of drought, warm days cool nights and a wide fluctuation in day-night temperatures. Control of powdery mildew with sulfur fungicides is relatively inexpensive and usually very successful. Bayleton also is registered for powdery mildew control, but at rates that make control much more expensive than with sulfur. Crop rotation is not an effective control measure. Little data is available on varietal resistance or tolerance to the disease.

Other foliar diseases that occur in the region are of little if any economic importance. They include *Ramularia, Alternaria* and *Phoma* leaf spots. Virus diseases like Western Yellows, Curly Top and others are absent or of no economic importance.

J. Insects and Their Control

The sugarbeet root maggot, *Tetanops myopaeformis is* the most serious insect of sugarbeets in the region. It is present in all areas of the Red River Valley of Minnesota and North Dakota. Infestations are particularly severe on lighter textured soils. Damage is caused by the larval stage of the life cycle of the insect. Crop damage is caused by feeding on the plant root system. Stand loss may be severe if heavy infestations occur in the seedling stage. Plants surviving feeding damage may yield up to 50% less than undamaged fields. Sugarbeet root maggot control generally is good to excellent when granular soil insecticides are applied at planting time. Crop rotation and resistant varieties are not acceptable control alternatives.

Several species of cutworms are the second most important insect problem. Severe stand loss can occur when heavy infestation of cutworms go undetected in fields. Grasshoppers have caused serious stand loss in droughty years in particular. Several species hatch from late May through June. Heavy infestations of later instar stage grasshoppers can rapidly cause sugarbeet stand loss in a field.

Flea beetles, wireworms, root aphids, white grubs and beet webworms are less common sugarbeet pests. However, severe localized infestations of these pests occur. White grubs and wireworm may cause serious stand loss to germinating and emerging beet seedlings. Flea beetles occasionally cause some stand loss if insect populations are high. Root aphids may cause severe yield loss in dry years, especially when cracks form in the soil providing ready access to secondary plant roots the insects feed on. Sugarbeet webworm outbreaks are very infrequent in the region. Leaf feeding may occasionally justify insecticide treatment.

Wireworms, cutworms and white grubs may be controlled by certain soil applied sugarbeet root maggot insecticides. Check product labels for specific recommendations. Severe cutworm outbreaks usually require a postemergence insecticide application for successful control. Flea beetles and webworms can be successfully controlled with foliar insecticide. No acceptable control measures are available for the root aphid. Crop rotation does not give effective control for any of these insects. The key to a successful insect control program in sugarbeets is timely monitoring of insect populations, followed by recommended insecticide applications when insect populations and crop damage justify pesticide use.

K. Harvesting and Storage:

Sugarbeets are harvested in late September and October. A mechanical defoliator is used to remove all the foliage from the beet root prior to lifting. Removal of all foliage is essential to prevent leaf regrowth in storage piles. Heavy frosts prior to defoliation make proper foliage removal from the beets more difficult. Immediately following defoliation, sugarbeet lifter-loader harvesters pull beets from the soil and load them on trucks. The harvesters remove most of the soil from the beets prior to loading them on trucks. Wet soil conditions greatly slow the harvesting operations and result in higher amounts of dirt clinging to the beets. After the trucks are loaded, the sugarbeets are delivered to piling stations or the factory for storage and processing. Sugarbeet harvesting requires at least two specialized expensive pieces of equipment, the defoliator and the harvester, plus trucks that may be used very little except at sugarbeet harvest.

Storage is primarily on flat unpaved piling grounds provided by the processing company in the factory yard or at outside piling stations. Some storage also may be over forced air ventilation/aeration systems or in climate controlled storage buildings. These specialized piling grounds or buildings minimize the loss of sugar caused by storage rots and root respiration.

VI. Yield Potential:

Sugarbeet yields in Minnesota and North Dakota usually average from 13 to 25 tons/acre under dryland conditions depending on the climate. Less than 1% of the present acreage in Minnesota and North Dakota is irrigated. Yields under irrigation may be 15 to 30% greater. Other crops in rotation often yield less following sugarbeets because of soil water depletion by the sugarbeet crop.

Sugarbeet production requires much more management attention than small grain, soybean, or corn production. Specialized equipment is required for sugarbeets that can not be used for other crops in rotation.

VII. Economics of Production and Markets:

Market access may be the greatest obstacle facing farmers who want to begin sugarbeet production in North Dakota, Minnesota or Wisconsin. All present processing facilities are operating at full capacity as farmer- owned cooperatives. If increased acreage becomes available at these factories, the present grower owners have first opportunity to grow these sugarbeets. A new grower must purchase an existing contract or shares owned in the cooperative by a present sugarbeet grower in order to market sugarbeets.

No new processing facilities have been built in the United States since 1975. Estimated cost to build an average size processing facility today is $100 million.

Average economic returns from sugarbeets in the region have been greater than for small grains, corn, dry edible beans and soybeans. Prices paid for sugarbeets also have been more stable than for most other crops. While return per acre from sugarbeets may be good, risk of economic loss is also greater than with most other crops. Average total cost of production in Minnesota and North Dakota in 1989 was from $492 to $557 per acre. Cost of production for a new grower starting sugarbeet production would probably exceed $600 per acre.

No one should attempt to initiate sugarbeet production on their farm without securing a market for his crop and completing an economic feasibility study.

VIII. Information Sources:

- Sugarbeet Research and Extension Reports. Volume I to 20. North Dakota State University and University of Minnesota Extension Services.
- Sugarbeet Production Guide. 1990 and 1991. North Dakota State University and University of Minnesota Extension Services.
- Sugarbeet Insects. Nov. 1988. North Dakota State University Extension Service, Fargo, ND.
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- Compendium of Beet Diseases and Insects. American Phytopathological Society Series. St. Paul, MN.
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Sunflower

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I. History:

Sunflower (*Helianthus annuus* L.) is one of the few crop species that originated in North America (most originated in the fertile crescent, Asia or South or Central America). It was probably a "camp follower" of several of the western native American tribes who domesticated the crop (possibly 1000 BC) and then carried it eastward and southward of North America. The first Europeans observed sunflower cultivated in many places from southern Canada to Mexico.

Sunflower was probably first introduced to Europe through Spain, and spread through Europe as a curiosity until it reached Russia where it was readily adapted. Selection for high oil in Russia began in 1860 and was largely responsible for increasing oil content from 28% to almost 50%. The high-oil lines from Russia were reintroduced into the U.S. after World War II, which rekindled interest in the crop. However, it was the discovery of the male-sterile and restorer gene system that made hybrids feasible and increased commercial interest in the crop. Production of sunflowers subsequently rose dramatically in the Great Plains states as marketers found new niches for the seeds as an oil crop, a birdseed crop, and as a human snack food. Production in these regions in the 1980s has declined mostly because of low prices, but also due to disease, insect and bird problems. Sunflower acreage is now moving westward into dryer regions; however, 85% of the North American sunflower seed is still produced in North and South Dakota and Minnesota.

II. Uses:

A. Edible oil:

Commercially available sunflower varieties contain from 39 to 49% oil in the seed. In 1985-86, sunflower seed was the third largest source of vegetable oil worldwide, following soybean and palm. The growth of sunflower as an oilseed crop has rivaled that of soybean, with both increasing production over 6-fold since the 1930s. Sunflower accounts for about 14% of the world production of seed oils (6.9 million metric tons in 1985-86) and about 7% of the oilcake and meal produced from oilseeds. Europe and the USSR produce over 60% of the world's sunflowers.

The oil accounts for 80% of the value of the sunflower crop, as contrasted with soybean which derives most of its value from the meal. Sunflower oil is generally considered a premium oil because of its light color, high level of unsaturated fatty acids and lack of linolenic acid, bland flavor and high smoke points. The primary fatty acids in the oil are oleic and linoleic (typically 90% unsaturated fatty acids), with the remainder consisting of palmitic and stearic saturated fatty acids. The primary use is as a salad and cooking oil or in margarine. In the USA, sunflower oils account for 8% or less of these markets, but in many sunflower-producing countries, sunflower is the preferred and the most commonly used oil.

High oleic sunflower oil (over 80% oleic acid) was developed commercially in 1985 and has higher oxidated stability than conventional oil. It has expanded the application of sunflower oils for frying purposes, tends to enhance shelf life of snacks, and could be used as an ingredient of infant formulas requiring stability.

B. Meal:

Non-dehulled or partly dehulled sunflower meal has been substituted successfully for soybean meal in isonitrogenous (equal protein) diets for ruminant animals, as well as for swine and poultry feeding. Sunflower meal is higher in fiber, has a lower energy value and is lower in lysine but higher in methionine than soybean meal. Protein percentage of sunflower meal ranges from 28% for non-dehulled seeds to 42% for completely dehulled seeds. The color of the meal ranges from grey to black, depending upon extraction processes and degree of dehulling.

C. Industrial Applications:

The price of sunflower oil usually prohibits its widespread use in industry, but there are several applications that have been explored. It has been used in certain paints, varnishes and plastics because of good semidrying properties without color modification associated with oils high in linolenic acid. In Eastern Europe and the USSR where sunflower oil is plentiful, sunflower oil is used commonly in the manufacture of soaps and detergents. The use of sunflower oil (and other vegetable oils) as a pesticide carrier, and in the production of agrichemicals, surfactants, adhesives, plastics, fabric softeners, lubricants and coatings has been explored. The utility of these applications is usually contingent upon petrochemical feedstock prices.

Sunflower oil contains 93% of the energy of US Number 2 diesel fuel (octane rating of 37), and considerable work has been done to explore the potential of sunflower as an alternate fuel source in diesel engines. Blends of sunflower oil and diesel fuel are expected to have greater potential than the burning of pure vegetable oil.

D. Non-Oilseed:

The use of sunflower seed for birdfeed or in human diets as a snack, has grown consistently over the past 15 years. Varieties used for non-oilseed purposes are characterized by a larger seed size and require slightly different management practices. During processing, seed is divided into 1) larger seed for in-shell roasting, 2) medium for dehulling, and 3) small for birdseed. Standards for different uses vary.

E. Forage:

Sunflower can also be used as a silage crop. It can be used as a double crop after early harvested small grains or vegetables, an emergency crop, or in areas with a season too short to produce mature corn for silage.

Forage yields of sunflower are generally less than corn when a full growing season is available. In one study, sunflower dry matter yields ranged from 2.0 to 3.0 ton/acre compared with 3.1 to 3.8 ton/acre for corn. Moisture content of sunflower at maturity is usually high (80 to 90%) and would require wilting before ensiling.

Nutritional quality of sunflower silage is often higher than corn but lower than alfalfa hay (Table 1). Crude protein level of sunflower silage is similar to grass hay and higher than corn silage. Generally, crude protein of sunflower decreases and lignin percentage increases after the flowering stage. High plant populations increases fiber and lignin percentage. Seed size does not seem to affect yield or quality.

Table 1: Nutritional quality of sunflower, immature corn, and mature corn silage, alfalfa hay (harvested in early bloom) and timothy bay (harvested in late vegetative stage).[1]

	Silage			Hay	
	Sunflower	Immature corn	Mature corn	Alfalfa	Ti
	% of dry matter				
Total digestible nutrients	67.0	60.0	69.0	58.0	
Crude protein	11-12	8.2	7.8	18.0	
Ether extract	10-12	2.6	2.9	2.2	
Crude fiber	31.0	31.0	23.0	31.0	
Acid detergent fiber	32.0	---	31.0	38.0	
Lignin	10-16	---	---	9.0	
IVDDM 2	63-70	---	---	66.0	

[1]Data from Miller, Oplinger and Collins, 1986.
[2]In vitro dry matter disappearance.

Sunflower silage contains considerably more fat than many other forages, (Table 1). Some producers and researchers in Oregon have experimented with sunflower/corn intercrops to increase energy content of a silage, but results of this work are not yet complete. In South Dakota trials, milk yields were reduced by 9% when straight sunflower silage was compared with corn. The nutritional quality of sunflower silage is generally recognized as adequate for dry cows, steers, and low milk producers.

III. Growth Habit:

Sunflower is an annual, erect, broadleaf plant with a strong taproot and prolific lateral spread of surface roots. Stems are usually round early in the season, angular and woody later in the season, and normally unbranched.

Sunflower leaves are phototropic and will follow the sun's rays with a lag of 120 behind the sun's azimuth. This property has been shown to increase light interception and possibly photosynthesis.

The sunflower head is not a single flower (as the name implies) but is made up of 1,000 to 2,000 individual flowers joined at a common receptacle. The flowers around the circumference are ligulate ray flowers without stamens or pistils; the remaining flowers are perfect flowers (with stamens and pistils). Anthesis (pollen shedding) begins at the periphery and proceeds to the center of the head. Since many sunflower varieties have a degree of self-incompatibility, pollen movement between plants by insects is important, and bee colonies have generally increased yields.

In temperate regions, sunflower requires approximately 11 days from planting to emergence, 33 days from emergence to head visible, 27 days from head visible to first anther, 8 days from first to last anther, and 30 days from last anther to maturity. Cultivar differences in maturity are usually associated with changes in vegetative period before the head is visible.

IV. Environment requirements:

A. Climate:

Sunflower is grown in many semi-arid regions of the world from Argentina to Canada and from central Africa into the Soviet Union. It is tolerant of both low and high temperatures but more tolerant to low temperatures. Sunflower seeds will germinate at 39°F, but temperatures of at least 46 to 50°F are required for satisfactory germination. Seeds are not affected by vernalization (cold) in the early germination stages. Seedlings in the cotyledon stage have survived temperatures down to 23°F. At later stages freezing temperatures may injure the crop. Temperatures less than 28°F are required to kill maturing sunflower plants.

Optimum temperatures for growth are 70 to 78°F, but a wider range of temperatures (64 to 91°F) show little effect on productivity. Extremely high temperatures have been shown to lower oil percentage, seed fill and germination.

Sunflower is often classified as insensitive to daylength, and photoperiod seems to be unimportant in choosing a planting date or production area in the temperate regions of North America. Oil from northern regions tends to be higher in linoleic acid and has a higher ratio of polyunsaturated to saturated fatty acids than oil produced in southern latitudes.

Sunflower is an inefficient user of water, as measured by the amount of water transpired per gram of plant above-ground dry matter. Levels were 577 (g H_2O/g DM) for sunflower, 349 for corn, 304 for sorghum in an Akron, Colorado study. It is similar to wheat, soybean, fieldbean, oat, and rape in that respect. Efficiency is measured at an optimum moisture level and is not a measure of drought resistance.

Sunflower is not considered highly drought tolerant, but often produces satisfactory results when other crops are damaged during drought. Its extensively branched taproot, penetrating to 6.5 ft, aids the plant during water stress. A critical time for water stress is the period 20 days before and 20 days after flowering. If stress is likely during this period, irrigation will increase yield, oil percentage and test weight, but decrease protein percentage.

B. Soil:

Sunflower will grow in a wide range of soil types from sands to clays. The demands of a sunflower crop on soil macronutrients are not as great as corn, wheat or potato. As with other non-leguminous grain crops, nitrogen is usually the first limiting factor for yield. Medium to high levels of macronutrients are usually required for good plant growth. Sunflower stover contains a large proportion of these elements, which means sunflower is relatively inefficient in the use of these elements. However, most of these nutrients are returned to the soil with the stover.

Sunflower is low in salt tolerance but is somewhat better than fieldbean or soybean in this respect. Corn, wheat, rye and sorghum are rated medium, and sugarbeet and barley are high in salt tolerance.

Good soil drainage is required for sunflower production, but this crop does not differ substantially from other field crops in flooding tolerance.

V. Cultural Practices:

A. Seedbed Preparation:

Many different tillage systems can be used effectively for sunflower production. Conventional systems of seedbed preparation consist of moldboard plowing or chisel plowing to invert residue and several secondary field operations. Conventional systems have been shown to increase the availability and improve the distribution of potassium and nitrogen and to increase the seed zone temperatures. However, the risk of erosion and expense of the several tillage operations has led to greater interest in minimum or ridge tillage systems.

Both germination percentage and lodging have been shown to increase in ridge-till systems vs. level plantings. Several tillage systems have been used with some success in specific environments. Major considerations are: 1) firm placement of seed near moist soil, 2) absence of green vegetation during emergence, 3) maintaining an option to cultivate and 4) reduce the risk of soil erosion.

B. Seeding Date:

Sunflower can be planted at a wide range of dates, as most cultivars are earlier in maturity than the length of growing season in most areas. In areas of the world with no winters, sunflower has been planted at any month of the year to obtain satisfactory yields. In northern regions, highest yields and oil percentages are obtained by planting early - as soon after the spring-sown small grain crops as possible. In the northern midwest and Canada this is often May 1 through 20 and mid-March through early April in the southern USA. Resistance to frost damage decreases as the seedlings develop into the 6leaf stage, so too-early sowings in the northern USA or Canada can be risky.

A later planting date tends to increase the proportion of linoleic acid in sunflower, especially at southern locations. Damage of sunflower heads by insect larvae may be increased by early planting. Test weight tends to decrease with late plantings. A planting date of early to mid May is recommended in Minnesota and Wisconsin.

C. Method and Rate of Seeding:

A planting depth of 1 to 3.5 in. allows sunflower seeds to reach available moisture and gives satisfactory stands. Deeper plantings have resulted in reduced stands and yields. If crusting or packing of the soil is expected, with silt loam or clay soils, a shallower planting depth is recommended.

Sunflower row spacing is most often determined by machinery available, which might be 30 or 36 in. for corn, soybean or sorghum growers, or narrower rows for sugarbeet growers. In Minnesota trials, sunflower yield, oil percentage, seed weight, test weight, height, and flowering date did not differ at narrow vs. wide rows over five plant populations. Hence, row spacings can be chosen to fit available equipment. Row spacings of 30 in. are most common. There is evidence that earlier, semidwarf varieties may perform better in narrower rows at high populations.

Sunflower stands have the capacity to produce the same yield over a wide range of plant densities (Table 2). The plants adjust head diameter, seed number per plant, seed size, to lower or higher populations, so that yield is relatively constant over a wide range of plant populations. Trials in eastern North Dakota show increases in yields with densities up to 29,000 plants/acre, but most studies have shown less effect of seeding rate. Higher densities are often recommended for irrigated or high rainfall areas.

Table 2: Effect of plant population on yield and yield components - average of 12 trials in Minnesota

Plant density heads/acre	Seed yield lbs/acre	Seed number seeds/head	Seed weight mg/seed	Large seed[1] %	Oil content %	Lo s
14,970	2,004	831	73	52	42.1	
19,830	2,131	727	67	44	43.2	
25,090	2,169	632	62	33	43.2	
29,940	2,173	548	60	31	43.4	
34,800	2,231	501	58	16	43.8	

[1]Non-oilseed cultivars held on an 0.8 cm round-hole screen
[2]1 = erect, 9 = prostrate.

Plant population has a strong effect on seed size, head size, and percent oil. A medium to high population produces higher oil percentage than does low populations, and the smaller heads dry down faster at higher plant populations.

A lower plant population is critical for maximizing seed size for non-oilseed use. Current recommendations in Minnesota and Wisconsin are 17,000 plants/acre (4 lb seed/acre) for non-oilseed and 23,000 plants/acre (3 lb seed/acre) for oilseed.

Some have suggested that north-south orientation of rows produce higher yields than east-west rows, but studies to examine this effect have found no differences in yield.

D. Fertility and Lime Requirements:

Research has shown that sunflower responds to N, P and K. Nitrogen is usually the most common limiting factor for yield. Nitrogen fertilizer tends to reduce oil percentage of the seed, change the amino acid balance, and increase leaf area of the plant. Yield increases from N fertilizer rates up to 175 lb/acre have been observed, but rates considerably lower than this are usually recommended. Nitrogen recommendations in dryer regions can be made from estimates of nitrate nitrogen in the soil, but in wetter regions, this is not feasible. In the wetter regions of eastern and southern Minnesota and Wisconsin, recommendations are based upon soil organic matter and previous crop history. Recommendations of approximately 18 lb N/acre after fallow or legume sod, 60 lb N/acre after small grain or soybean and 80 to 100 lb N/acre after corn or sugarbeet are common. On higher organic matter soils, amounts should be lowered. Nitrogen can be supplied from mineral or non-mineral sources (manures, legumes, compost). Row placement of P and K may be important in sunflower for maximizing efficiency of fertilizer use, as it is with many species.

More yield increases are reported as a result of applications of P than from K in Europe and North America. Recommendations for applications of P and K should be made from soil tests and the yield goal for each field. Recommendations range from 40 to 70 lbs P_2O_5 and -60 to 140 lbs K_2O /acre for soils testing very low in P or K, depending on soil yield potential. These recommendations decrease as soil test P and/or K increase. Response to P is not expected if soil P exceeds 30 lb/acre nor to K if the K test is greater than 300 lb/acre.

Sunflower is not highly sensitive to soil pH. The crop is grown commercially on soils ranging in pH from 5.7 to over 8. The optimum depends upon other properties of the soil; no pH is considered optimum for all soil conditions. The 6.0 to 7.2 range may be optimal for many soils.

E. Variety Selection:

The development of a cytoplasmic male-sterile and restorer system for sunflower has enabled seed companies to produce high-quality hybrid seed. Most of these outyield open-pollinated varieties and are higher in percent oil. Performance of varieties tested over several environments is the best basis for selecting sunflower hybrids. The choice should consider yield, oil percentage, maturity, seed size (for non-oilseed markets), and lodging and disease resistance. Performance results from the Upper Midwest are usually available annually from North Dakota State University, University of Minnesota, and South Dakota State University.

F. Weed Control:

As a crop, sunflower yields are reduced, but rarely eliminated by weeds which compete with sunflower for moisture and nutrients and occasionally for light. Sunflower is a strong competitor with weeds, especially for light, but does not cover the ground early enough to prevent weed establishment. Therefore, early season weed control is essential for good yields. Annual weeds have been the primary focus of weed control research. Perennial weeds can also present problems but are usually not specific to sunflower.

Successful weed control should include a combination of cultural and chemical methods. Almost all North American sunflower plantings are cultivated and/or harrowed for weed control, and over 2/3 are treated with herbicides. Postemergence cultivation with a coilspring harrow, spike tooth harrow or rotary hoe is possible with as little as 5 to 7% stand loss when sunflowers are at the four to six leaf stage (beyond cotyledon), preferably in dry afternoons when the plants are less turgid. One or two between row cultivations are common after the plants are at least 6 in. tall.

Several herbicides are currently approved for weed control in sunflowers. Information on chemical weed control in sunflowers is available at most county extension offices.

G. Diseases:

The most serious diseases of sunflower are caused by fungi. The major diseases include rust, downy mildew, verticillium wilt, sclerotinia stalk and head rot, phoma black stem and leaf spot. The symptoms of these diseases are given in Table 3. The severity of these disease effects on total crop yield might be ranked: 1) sclerotinia, 2) verticillium, 3) rust (recently more severe), 4) phoma, and 5) downy mildew. Resistance to rust, downy mildew, and verticillium wilt has been incorporated into improved sunflower germplasm.

Table 3: Major sunflower diseases and symptoms.

Downy mildew *Plasmopara halstedi*	Cottony fungus on underside of leaves. Dwarfing, contrasting discoloration of yellow-green and green. Blackening and sometimes swelling at base of stem. Disease most severe when rain occurs before and after emergence.
Powdery mildew *Erysiphe cichoracearum*	Cottony fungus on green leaves late in summer - not largely damaging.
Leaf spot *Septoria helianthi*	Dead blotches on flower leaves before heading. Has not caused appreciable loss.
Verticillium wilt *Sclerotinia sclerotiorum*	Before heading, dead areas along leaf veins, bordered by light yellow-green margins. Decayed vascular tissue in cross-section of stem.
Rust *Puccini helianthi*	Rust colored pustules on leaves, latter black specks on stems.
Sclerotinia head and stem rot *Verticillium dahliae*	Wilt soon after flowering. Light tan band around the stem at soil level. Grey-black sclerotia (size of seed) in rotted heads and stems. Seed and meats discolored.
Phoma black stem *Phoma macdonaldii*	Large chocolate colored blotches on stems at maturity.

H. Insects, Pollinators, and Birds:

Bees are beneficial to sunflower yield because they carry pollen from plant to plant which results in cross pollination. Some sunflower varieties will not produce highest yields unless pollinators are present. All varieties will produce some sterile seed (without meats), but varieties differ in their degree of dependence on insect pollinators. Autogamous sunflower hybrids do not require bees for maximum yield and will yield the same when covered by bags as uncovered. In non-autogamous sunflower varieties, pericarp (bull) development is normal but no ovules or meat develop. Wind is relatively unimportant in cross-pollination of sunflower. Some of the older open-pollinated varieties such as Peredovick set only 15 to 20% of seed without pollinators, whereas many hybrids set 85 to 100% seeds without pollinators.

Insect pests have become major potential yield-reducing factors in sunflower production in the northern Midwest (Table 4). Insects specific to sunflower that feed on the heads include the larvae of three moths; sunflower moth, banded sunflower moth and sunflower bud moth. Sunflower midge has caused widespread damage in some years. Sunflower headclipping weevil, sunflower beetle, sunflower maggot, wireworm, grasshopper, cutworm, sugarbeet webworm, ragweed plant bug, woolybear and painted.lady caterpillar have caused occasional damage to sunflower. Adults of insect pests of other crops (such as corn rootworm beetle and blister beetle) can be found as pollen feeders on sunflower heads, but usually cause little injury.

Table 4: Common Insects in Sunflower

Sunflower moth *Homoeosoma electellum*	Eggs are laid at flowering and hatch in 1 week. Larva have dark bands running length of body. Feeds on floral parts, tunnels in Seed.
Banded sunflower moth *Cochylis hospes*	Moth has brown area mid-wing (.5 in.). Larvae are not dark striped, smaller than head moth. Makes a small hole in top of seed, feeds on meat.
Sunflower bud moth *Suleima helianthana*	Dark grey moth. Larvae .5 to 1 in. in length. Feeds on young stem and head. Headless or damaged heads or large hole on stem near a leaf petiole is symptom.
Sunflower midge *Contarinia schulzi*	Small (.1 in.) gnat with tiny (.1 in.) cream-colored larvae laid when head is 1" in diameter. Brown spots at base of individual florets or absence of ray flowers, cupping of heads is symptom.
Sunflower headclipping weevil *Haplorynchites aeneus*	Black weevil, about .25 in. long, causes head drop.
Sunflower beetle *Zygogramma exclamationis*	Adult is .25 in. long with yellow strips length of wing covers. Humpback yellow larvae causes large areas of defoliation.
Sunflower maggot *Strauzia longipennis*	Adult a yellow fly with dark wing markings, smaller than housefly. Maggots burrow in stem.
Red sunflower seed weevil *Smicronyx fulvus*	Adult about 1/8 in. long, rusty colored, and found in head. Adult female drills egg hole in developing seed and lays egg in hole. Larvae internal to seed; white legless with dark head capsule.
Gray sunflower seed weevil *Smicronyx sordidus*	Adult about 1/8 in. long, gray colored; has behavior similar to red sunflower seed weevil.
Sunflower stem weevil *Cylindrocopturus adspersus*	A robust brown and white spotted snout beetle found on the stem and in leaf axils. It is about 1/4 in. long. Drills egg hole in stem in which it lays its egg. The larva, a white legless larva, burrows in the stem pith. Much more abundant in drouthy sites and years.

Resistance to seed insects can be improved by the presence of a dark colored "armor" layer in the seed coat. Resistance to midge has been suggested but is not currently effective. Only currently approved insecticides should be used for control of insects.

Birds can be major pests in sunflowers. Especially important are blackbird, goldfinch, dove, grosbeak and sparrow. Many approaches to disruption of feeding have been tried, including scarecrows, fright owls, aluminum strips that flutter in the wind, and carbide exploders. No techniques are 100% effective, as birds will adapt to many of these techniques. However, in many environments, some attempt is wan-anted. Currently, no chemicals are approved for bird control in sunflower.

I. Harvesting:

Sunflowers are generally mature long before they are dry enough for combining. Seed maturity occurs when the backs of the heads are yellow, but the fleshy sunflower head takes a long time to dry. Often, there are only a few good combining days in October when the seed is dry enough for storage. Seeds should be below 12% moisture for temporary storage and below 10% for long term storage. Seed up to 15% moisture is satisfactory for temporary storage in freezing weather, but spoilage is likely after a few days of warm weather.

Commercially available sunflower headers are useful in decreasing loss of seed as the crop is direct combined. This equipment usually includes 9 to 36 in. width metal pans for catching matured seed and a three-armed or similar reel. A narrower (9 in.) pan width enables harvesting diagonal to the row, which produces fewer harvest losses in some situations.

Windrowing has been demonstrated to be effective, but probably would not be economical, given the added cost of windrower and pickup-modifications.

VII. Economics of Production and Markets:

The cost of production and return over variable costs for sunflower is similar to that for small grains. The culture of sunflower and growing season requirements makes them a good niche in cropping systems where small grains are the predominant crops. Markets are generally available in most areas where sunflower has been traditionally grown. However, if a grower considers sunflower as an alternative crop, marketing opportunities should be pursued prior to making the decision to grow sunflower, particularly for non-oilseed varieties.

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Triticale

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I. History:

Triticale (trit-ih-KAY-lee) is a crop species resulting from a plant breeder's cross between wheat (*Triticum*) and rye (*Secale*). The name triticale (*Triticale hexaploide* Lart.) combines the scientific names of the two genera involved. It is produced by doubling the chromosomes of the sterile hybrid that results when crossing wheat and rye. This doubling produces what is called a polyploid.

Hybrids between wheat and rye date back to 1875, but until recently there was little effort to develop highyielding triticales as a field crop. Plant breeders originally wanted to include the combination of grain quality, productivity, and disease resistance of wheat with the vigor and hardiness of rye. The University of Manitoba began the first intensive program in North America about 30 years ago working mostly with durum wheat-rye crosses. Both winter and spring types were developed, with emphasis on spring types. Since Canada's program, other public and private programs have initiated both durum wheat-rye and common wheat-rye crosses. The major triticale development program in North America is now at the International Maize and Wheat Improvement Center in Mexico, with some private companies continuing triticale programs; however, the University of Manitoba has discontinued its program.

Even though triticale is a cross between wheat and rye, it is self-pollinating (similar to wheat) and not cross pollinating (like rye). Most triticales that are agronomically desirable and breed true have resulted from several cycles of improvement, but are primarily from the durum-rye crosses with some common wheat parentage occasionally involved.

In the 1960's, approximately 250,000 acres were grown annually in the United States, however markets did not develop as expected, particularly as a food. Today, there are only a few thousand acres grown and much of it is sold as a feed grain. Most of the production is in the western states. The southern states grow winter types which are grazed in the fall. In the Midwest there is some interest in using triticale as a forage crop.

II. Uses:

Plant breeders working with triticale hoped it would have higher yield than other cereal grains, especially under less than ideal growing conditions, and be used both as human and animal food.

A. Milling and Baking:

Quality evaluations of triticale grain for milling and baking show that it is inferior to bread-making wheat and to durum wheat for macaroni, but it is often considered superior to rye. Scientists are testing triticale for possible use in breakfast cereals and for distilling or brewing, but so far no exclusive commercial use has resulted. Table 1 describes the chemical composition of a typical triticale variety.

Table 1. Composition of triticale grain.

Component	Percent of dry matter
Protein	19.71
Fiber	3.10
Fat	1.61
Calcium	.12
Phosphorus	.44
Total sugars (as invert)	5.74
Starch	67.78
Amino acids	
Threonine	.39
Valine	.93
Methionine	.40
Isoleucine	.76
Leucine	1.23
Phenylalanine	.85
Lysine	.57
Histidine	.45
Arginine	.80

Source: Waibel et A., 1992, University of Minnesota.

B. Feed Grain:

Feeding trials in North Dakota, Canada, and Minnesota indicate that triticale has potential as a feed grain. The protein content of triticale lines has ranged from 10 to 20 percent on a dry weight basis, which is higher than wheat. The amino acid composition of the protein is similar to wheat, but may be slightly higher in lysine. As triticale varieties are improved, they may compete with oats and feed barley as a home-grown feed crop, particularly if ergot, a fungus disease, can be eliminated or reduced to less than 0.1 percent in the grain. Higher levels of ergot have ruined the crop for feeding in some years. Ergot is more severe in older than in newer varieties.

Swine: Early North Dakota trials with swine found triticale unsatisfactory for feed and weight gain when fed as the only grain in a complete, balanced ration for growing-finishing swine. Fed a barley ration, for comparison, swine gained up to 27 percent faster than those on the triticale rations. Feed efficiencies on both the triticale and barley rations were similar: the problem was less intake due to unpalatability. The study indicated when equal parts triticale and barley represented half the grain fed, weight gain and efficiency were much improved over a straight triticale ration.

Cattle: Feeding trials with cattle in North Dakota showed that when triticale was the only grain used in fattening rations, both gains and feed efficiency were reduced compared to barley rations. Usually, triticale was fed in smaller amounts and this partly explains the lower weight gains. Recent feeding trials at the University of Minnesota, conducted by Wright and others with calves, indicated that starter rations containing up to 27 percent triticale as dry matter equaled weight gains and starter intakes in calves fed rations containing soybean meal.

Poultry: Triticale (relatively free of ergot) feeding trials with turkeys and laying hens at North Dakota State University showed that triticale was approximately equal to durum wheat for gain in body weight, feed use efficiency, and energy content.

A University of Minnesota study with turkeys by Wright and others showed that triticale substituted for corn in the diet improved growth significantly at 3 weeks of age. Feed efficiency with the entire triticale substitution was unchanged when compared to corn diet. When 25 percent triticale was included in a com-soybean meal diet, both growth and feed efficiency were equal to a corn-soybean meal diet.

C. Forage:

Forage yield and quality investigations of triticale at the University of Minnesota (1978-79) by Cherney and Marten and at the University of Wisconsin by Brinkman and Albrecht (1986-88) found that barley, oat, and triticale had similar dry matter yields. However, oat yielded significantly less dry matter than triticale in 1979 at the University of Minnesota, St. Paul. Wheat often had the lowest dry matter yields. Mean in-vitro digestible dry matter (IVDDK yields were 1.61, 1.43, 1.36, and 1.25 tons/acre for barley, triticale, oat, and wheat, respectively. These means were over six maturity stages from flag leaf to dough stage. Triticale, cut slightly before boot stage, makes the best silage similar to other small grains, but dry matter yields are higher at later maturity stages.

Table 2 gives the crude protein and IVDDM comparison at the milk maturity stage for the four species. Recently, farmers have grown peas with spring triticale for silage.

Table 2. Crude protein concentration and yield and percent digestible dry matter IVDDM and yield of four small grain species harvested at the milk stage of maturity.[1]

Species	Crude protein		IVDDM	
	%	T/A	%	T/A
Spring wheat	15.7	0.43	63.3	1.72
Triticale	15.2	0.45	66.4	1.95
Oat	14.6	0.44	61.5	1.86
Barley	15.7	0.50	68.5	2.20

[1]Source: Cherney and Marten, 1982, University of Minnesota and USDA; means of two varieties, years and locations.

In the Wisconsin studies, four varieties each of winter triticale, winter wheat and winter rye were compared for forage yield and quality (Table 3). When plants were harvested at three-fourths heading, triticale and wheat produced higher forage and crude protein yields than rye.

Table 3: Forage performance of winter cereals harvested at three-fourths heading. Arlington, WI 1986-88.[1]

Crop	Harvest date	Plant height in	Forage yield t/a	Crude %	Protein T/A	ADF %	NDF %
Triticale	6/6	37	3.6	12.4	0.44	36.1	64.2
Wheat	6/2	33	3.7	11.8	0.44	35.9	63.8
Rye	5/22	37	3.0	13.8	0.42	37.6	65.1

[1]Source: Brinkman, Mostafa and Albrecht. 1988. University of Wisconsin; means of four varieties and three years.
Values are expressed on a dry matter basis.

A feeding study conducted in 1987 at the University of Minnesota's Agricultural Experiment Station-Rosemount by Paulson and others compared the use of alfalfa, triticale, or oat as the only forage sources in diets for cows for the first 116 days of lactation. Alfalfa (a composite of three cuttings and harvested at mid-bud stage), triticale (harvested at late boot with approximately 25 percent of the heads emerged) and oat (harvested at early heading) were ensiled in plastic silo bags. Forty-two cows were randomly assigned by parity to one of these diets. Diets were composed of a 50:50 ratio of forage:concentrate (dry matter basis) and balanced for calcium, phosphorus, and crude protein by changing the composition of the grain portion. Diets were fed as a total mixed ration using a Calan door feeding system in a loose housing facility.

Dry matter and nutrient composition of alfalfa, triticale, and oat forages used are listed in Table 4. The researchers indicated that recommended dry matter content of small grains at ensiling is approximately 40 percent. Triticale was near the recommended dry matter content, but oat was harvested under poor conditions and ensiled at a lower dry matter than desired. Crude protein content was highest in the alfalfa forage, intermediate in triticale, and lowest in the oat forage. The researchers indicated that a partial explanation for the higher crude protein content in the triticale than the oat forage was that 92 pounds of supplemental nitrogen were applied per acre to the triticale but not to oat. Acid detergent fiber values were similar for all three forages, but neutral detergent fiber values were higher in triticale and oat forage than in alfalfa. The bottom of Table 4 shows the composition of the total mixed diet (forage and grain mixture) used in the study.

Table 4: Forage and diet composition (dry matter basis).[1]

Item	Alfalfa	Triticale	Oat
	%		
Forage			
Dry matter	43.5	37.8	28.0
Crude protein	22.6	17.5	142.0
Neutral detergent fiber	43.8	54.8	52.4
Acid detergent fiber	32.9	32.1	31.1
Calcium	1.69	.56	.42
Phosphorus	.43	.56	.39
Diet			
Dry matter	58.1	52.4	43.7
Crude protein	16.4	17.2	17.3
Neutral detergent fiber	30.3	36.9	36.0
Acid detergent fiber	18.0	19.8	19.3

[1]Source: Paulson, Ehle, Otterby, and Linn, 1987, University of Minnesota.

Cows fed the diets containing triticale produced significantly more 3.5 percent fat-corrected milk (FCM) than cows fed the diet containing oat forage (Table 5). Milk production of cows fed the diet containing alfalfa was intermediate. Milk fat, protein, and total solids percentages were not affected by forage source. Dry matter intake of cows fed the triticale and alfalfa forage diets were similar and higher than the dry matter intake of cows fed the oat forage diet. According to the researchers, the lower dry matter content of the oat forage diet may have affected intakes and influenced milk production.

From this study these researchers concluded that small grain silages can be used as the sole forage for lactating cows if silages are cut at early maturities and harvested at proper moisture levels. Cows fed triticale were sim- i ilar to cows fed alfalfa in milk production, milk composition, and dry matter intake.

Table 5: Effect of forage on milk yield and milk composition[1].

Item	Forage source		
	Alfalfa	Triticale	Oat
No. of cows	15	15	12
Milk yield and composition			
3.5% FCM 2 (lb/cow/day)	64.7[ab]	71.9[a]	60.7[b]
fat, %	3.7	3.7	3.9
protein, %	3.4	3.4	3.4
total solids, %	13.3	13.3	13.4

[1]Source: Paulson, Ehle, Otterby and Linn, 1987, University of Minnesota.
[2]Fat-corrected milk.
[ab]Means differ (P .05).

III. Growth Habits:

Triticale growth habit is similar to wheat and rye.

IV. Environment Requirements:

Environmental requirements for winter triticale in the upper Midwest are similar to other fall planted small grain crops such as wheat or rye and for spring triticale the requirements are similar to spring planted oats, barley or wheat.

V. Cultural Practices:

A. Seedbed Preparation:

Preparation of the seedbed should be similar to that for oat, barley or wheat.

B. Planting Date:

Spring triticale varieties, as other small grains, should be planted as early as practical. Winter varieties should be planted in the fall on dates similar to winter wheat but even more care should be taken to leave surface residue to catch snow.

C. Rate:

Triticale should be seeded using a standard grain drill. The planting rate should be 28-36 viable seeds per square foot in a seedbed prepared as for wheat.

D. Fertilizer:

Phosphorus must be adequate for good yields and triticale uses more nitrogen than wheat.

E. Variety Selection:

Both winter and spring triticale varieties are available.

Spring Triticale Varieties: Table 6 compares the agronomic characteristics of Karl and Kramer with hard red spring and durum wheat. The triticale varieties are 4-6 days earlier and are more susceptible to leaf rust than hard red spring and durum wheat. Both varieties are susceptible to ergot, but are less so than many of the earlier triticale varieties. Comparable data for Nutricale, a spring variety available from Nutriseeds, Perham, MN, are not available. However, at Staples in 1986 Nutricale yielded 1810 lb/A compared to Rymin winter rye which yielded 2912 INA. The yield range for Nutricale in Minnesota has been from 1250 to 4000 lb/A.

Table 6: Agronomic Data for spring triticale and wheat varieties in North Dakota, 1981-83.[1]

Variety	Crop	Days to heading	Plant height in	Test weight[2] lb/bu	Leaf rust[3]	Grain protein %
Karl	Triticale	58	31	47.1	MR-MS	13.1
Kramer	Triticale	58	36	45.5	MR	13.3
Era	HR spring wheat	64	30	56.7	MR-MS	14.3
Len	HR spring wheat	62	32	57.5	MS	14.8
Cando	Durum wheat	64,	30	57.0	R	13.8
Vic	Durum wheat	62	37	60.0	R	14.0

[1]Source: North Dakota Extension Agronomy Circular No. 1.
[2]Official test wt of triticale = 50, Wheat = 60 lb/bu.
[3]R=resistant, MR=moderately resistant, MS= Moderately susceptible.

In Wisconsin studies conducted at Arlington from 1987-89, six spring triticale varieties were compared (Table 7). Florico, Karl, and Kramer produced the highest grain yields, while Springfest was highest in straw yield. Test weight ranged from 43.2 to 49.8 lb/bu but averaged below the official test weight of 50. Grain protein percentage was inversely related to grain yield.

Table 7: Yield and plant characteristics of six spring triticales harvested at maturity at Arlington, WI in 1987-89.[1]

Variety	Grain yield lb/a	Straw yield lb/a	Test weight lb/bu	Grain protein %	Protein yield lb/a	Head date June	Height in	Leaf rust %	Stem rust 0-9
Florico	3201	4449	49.8	12.7	407	19	37	20	0
Grace	2155	4351	45.3	13.4	289	20	37	8	0
Karl	2970	4141	47.7	12.5	371	14	32	10	3
Kramer	2684	3796	48.0	12.4	333	13	29	15	0
Marval	2065	4037	43.2	13.0	268	18	38	12	0
Springfest	2378	4854	45.3	11.8	281	26	37	0	3
Mean	2576	4271	46.6	12.6	325	18	35	11	1
LSD (0.05)	686	453	3.9	1.0	88	3	4	-	-

[1]Source: Brinkman, Chapco and Albrecht, 1988, University of Wisconsin.

At the present time, the varieties Florico, Karl and Kramer represent the best choices of high yielding spring triticales available for the upper Midwest.

Winter Triticale Varieties: Performance of released and experimental winter triticale lines have been compared to commonly grown soft red winter wheats in 1987-89 at Arlington and Madison, WI, Table 8. Triticale was generally higher in grain yield, lower in winter survival ratings, and higher in protein concentration than were the wheat varieties. Grain yield and test weight were restricted by unusually dry conditions in these tests.

Table 8: Performance of four winter triticales and three soft red winter wheats at Arlington and Madison, Wisconsin, 1987-89.

Variety or	Yield	Test	Winter	Head	Height	Lodging	Protein	Leaf

Selection	Grain lb/a	Straw t/a	weight lb/bu	Survival %	date	in	%	%	rust %
Loc-years	4	2	4	3	4	3	2	2	1
Winter triticale									
Nutriseed 2-2-4	3600	3.6	49.6	48	5/29	47	14	9.8	10
Nutriseed 6-6-2	3640	3.1	45.3	46	6/2	42	13	10.6	10
Tritigold-22	3230	3.6	46.7	64	6/5	45	4	10.5	45
WB-UW26	3930	3.5	46.8	74	6/5	46	2	10.4	35
Winter wheat									
Argee	3250	3.6	52.4	90	6/5	36	3	10.1	30
Caldwell	3170	2.8	53.8	65	5/30	31	3	9.8	65
Charmany	2780	3.8	51.7	73	6/6	36	11	10.3	80

Limited North Dakota winter survival data indicate that cultivars Nutriseed 239 and Double Crop are more winter hardy than cultivar 1-18. Generally, winter triticale will not survive Minnesota winters unless special care is taken to leave field residue (as for winter wheat) to catch snow and provide cover. In addition, also winter triticales are more susceptible to injury from early spring freezing temperatures than winter rye.

F. Weed Control:

Cultural and Mechanical: Select fields with low weed seed density if possible. Plant early in a well prepared seed bed for rapid germination.

Chemical: Bromoxynil (Buctril) is registered for broadleaf weed control in triticale. No herbicides are registered for grass weed control, so the crop needs to be planted on relatively weed-free fields. Triticale grows slower than wheat in the spring and grassy weeds could be a problem.

G. Diseases:

Ergot is the most serious disease of spring triticale and can cause grain palatability problems as well as health problems in animals. Scab is frequently more serious in the winter types. Avoid planting triticale two years in succession or following rye. Leaf rust is more severe on triticale than on the more resistant hard red spring wheat varieties. No fungicides are cleared for use on triticale.

H. Insects:

Insect problems in triticale are generally not serious but are similar to that of the other small grain crops.

I. Harvesting:

Harvest is about one week later than wheat, and it threshes easily when dry. The cylinder and forward speed of the combine should be slower than for wheat. The concaves should be more open and the air less open than when combining wheat. Post harvest dormancy is less than hard red spring wheat and similar to durum, so harvesting needs to be timely to avoid sprouting.

J. Drying and Storage:

Drying and storage of triticale is similar to wheat or rye. For long term storage grain should be 13% moisture or lower.

VI. Yield Potential and Performance Results:

A. Spring Triticale:

There are a number of spring triticale varieties, but yield comparisons are available on only a few of the recent varieties. Grain yield comparisons during 1981-86 from North Dakota indicated that the North Dakota varieties Karl and Kramer were similar in yield to the hard red spring wheats Era and Len and the durum wheats Cando and Vic, at Langdon, North Dakota (Table 9). However, the hard red spring wheat variety, Wheaton, yielded more than either triticale in 1986. During 1982-83, Karl and Kramer yielded more than Era, Len, and Cando, but less than Vic at Casselton, located just west of Fargo.

In Wisconsin studies, spring triticale yields have ranged from 2000 to 4100 lb/a and have equaled or exceeded the yield of spring wheat, barley, and oat when compared on a lb/a basis (Table 10). The performance of six spring triticale varieties at Arlington, WI is summarized in Table 7.

Table 9: Grain yields of spring triticales and wheat in North Dakota, 1981-86.[1]

Variety	Origin	Crop	Langdon		Casselton 82-83
			81,83	86	
			lb/A		
Karl	ND	Triticale	3315	2148	3152
Kramer	ND	Triticale	3355	2677	3175
Era	MN	HR spring wheat	3200	--	2695
Len	ND	HR spring wheat	2805[2]	--	2765

Wheaton	MN	HR spring wheat	--	2889	--
Cando	ND	Durum wheat	2550	--	2722
Vic	ND	Durum wheat	3156[2]	--	3485

[1]Source: North Dakota Extension Agronomy Circular No. 1.
[2]1983 only; yields adjusted for comparison.

Table 10: Average grain yields of spring triticale, hard red spring wheat, barley and oats at Arlington, WI. 1987-89.

Crop	Year			Avg.
	1987	1988	1989	
	lb/a			
Triticale	3531	2428	1768	2576
Wheat	3300	1740	2600	2547
Barley	3168	2064	4650	3294
Oat	2720	2244	3550	2838

B. Winter Triticale:

Yield and survival data for winter triticale in North Dakota and Minnesota are limited because of its poor winter survival. Table 11 shows winter triticale yield data when early snow cover occurred in 1985-86. Two varieties of winter triticale, 1-18 and Double Crop, yielded about the same as the winter wheats, Northstar and Rose, but less than Rymin rye at Staples, Minnesota on irrigated sandy soil. The yield of 1-18 was comparable to Rymin rye, but the other two varieties, 239 and Double Crop, yielded much less than Rymin rye.

As noted earlier in Table 8, the average yield of winter triticale was 3800 lb/a compared to 3070 lb/a for three commonly grown winter wheat varieties in trials conducted at two southern Wisconsin locations under dry growing conditions.

Table 11: Yield of winter triticale, rye and wheat, 1986.

Variety	Origin	Crop	Location	
			Williston, ND[1]	Staples, MN[2]
			lb/A	
1-18	Nutriseed	Triticale	1963	2965
239	Nutriseed	Triticale	--	1960

Double Crop	Nutriseed	Triticale	1937	1505
Rymin	MN	Rye	--	3013
Puma	Canada	Rye	2244	--
Northstar	Canada	Wheat	1876	--
Rose	SD	Wheat	1951	--

[1]Source: North Dakota Extension Agronomy Circular No. 1.
[2]Source: Meredith and Weins, 1987, University of Minnesota.

VII. Economics of Production and Markets:

In 1987 there were about 10,000 acres of triticale planted in North Dakota, Minnesota, and Wisconsin. Some elevators such as the Farm Service Elevator in Wilmar, MN have been paying a slight premium above No. 2 yellow corn on a weight basis at 14 percent moisture. The official test weight of triticale is 50 lbs/bu. Markets are limited and should be obtained before triticale is planted as a cash crop.

VIII. Information Sources:

- Triticale in Minnesota. 1988. E. A. Oelke and R.H. Busch. University of Minnesota Extension Service Pub. AG-FO-3337.
- Triticale Performance in Wisconsin. 1974. E. S. Oplinger and V. L. Youngs. University of Wisconsin Field Crops 26.4-T.

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Wild Rice

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I. History:

Wild rice (*Zizania palustris* L.) is native to North America and grows predominantly in the Great Lakes region. This large-seeded species, one of four species of wild rice, is in the grass family (Poaceae) and has been eaten by people since prehistoric times. Early North American inhabitants, especially the Ojibway, Menomini, and Cree tribes in the North Central region of the continent, used the grain as a staple food and introduced European fur traders to wild rice. Manomio, the name they gave wild rice, means good berry. Early English explorers called this aquatic plant wild rice or Indian rice, while the French saw a resemblance to oats and called it folle avoine. Other names given to wild rice include Canadian rice, squaw rice, water oats, blackbird oats, and marsh oats. However, the name "wild rice" persisted and today it is the common name for the genus *Zizania*, even though the wild type of rice (*Oryza*) is also called wild rice.

Prior to 1965 most wild rice in the United States was produced in natural stands in lakes, rivers, and streams. In Canada most wild rice is still produced in lakes and streams that are leased from the government. Growing wild rice as a field crop was first suggested in 1852 by Joseph Bowron from Wisconsin, and in 1853 by Oliver H. Kelley of Minnesota. Efforts to grow wild rice as a field crop did not begin until 1950. James and Gerald Godward grew wild rice in a one-acre diked, flooded field (paddy) near Merrifield, Minnesota. By 1958 they had 120 acres of paddies for growing wild rice. Additional growers started paddy production during the mid-1950s and early 1960s, and in 196S, Uncle Ben, Inc. started contracting acreages. These initial efforts to commercialize wild rice production resulted in an organized effort to domesticate this crop using plant breeding.

Development of more shatter-resistant varieties was largely responsible for the rapid expansion of field production in the late 1960s and early 1970s. Production in Minnesota increased from 900 acres in 1968 to 18,000 acres in 1973. Most wild rice from natural stands was harvested by hand prior to this time using the traditional canoe-and-flail method. Mechanical harvesting of wild rice on private lands began during 1917 in Canada. Harvesting with more efficient grain combines was possible with the discovery of shattering resistance. Wild rice is currently produced commercially as a field crop in

Minnesota and California, which account for most of the acreage (20,000 and 8,000 acres, respectively, in 1991). Additional amounts are grown as a field crop in Idaho, Wisconsin and Oregon. In Canada, there has been much recent effort to increase total production from lakes by seeding lakes that were without wild rice. The lakes are then mechanically harvested by airboats equipped with collecting troughs. Researchers in Europe are currently investigating the possibility of wild rice production there.

II. Uses:

Wild rice is a nutritional grain that serves as a substitute for potatoes or rice, and is used in a wide variety of foods such as dressings, casseroles, soups, salads, and desserts. In recent years, wild rice has been used in breakfast cereals, and mixes for pancakes, muffins, and cookies. Blends of wild rice and long-grain regular rice (Oryza) that were introduced in the early 1960s increased the popularity of wild rice among consumers. Wild rice from natural stands is popular among health-food enthusiasts.

This grain has a high protein and carbohydrate content, and is very low in fat (Table 1). The nutritional quality of wild rice appears to equal or surpass that of other cereals. Lysine and methionine comprise a higher percentage of the amino acids in the protein than in most other cereals. The SLTM value (sum of lysine, threonine, and methionine contents) often serve as a measure of the nutritional quality of cereals, and is a little higher for wild rice than for oat groats, which is one of the better cereals for humans. Amino acid composition of processed and unprocessed wild rice is similar, which indicates little reduction in nutritional quality during processing. Wild rice contains less than one percent fat, of w which linolenic and linoleic acids together comprise a larger proportion of the fatty acids (68%) than in wheat, rice, or oats. Although these two fatty acids are easily oxidized and make wild rice prone to develop rancid odors, the high levels of linolenic acid make the fat in wild rice highly nutritious.

Mineral content of wild rice, which is high in potassium and phosphorus, compares favorably with wheat (Table 1), oats, and corn. Processed wild rice contains no vitamin A, but serves as an excellent source of the B vitamins: thiamine, riboflavin, and niacin.

Table 1. Nutritional composition of wild rice, cultivated brown rice, and wheat.

Nutritional Component	Wild Rice	Cultivated Brown Rice	Wheat
Protein	13.8 (12.8–14.8)[1]	8.1	14.3
Ash (%)	1.7 (1.4–1.9)	1.4	2.0
Fat (%)	0.6 (0.5–0.8)	1.9	1.8
Fiber (%)	1.2 (1.0–1.7)	1.0	2.9
Carbohydrate (%)	(72.5–75.3)	77.4	71.7
Ether Extract (%)	0.5 (0.3–1.0)	2.1	1.9
Phosphorus (%)	0.28	0.22	0.41

Potassium (%)	0.30	0.22	0.58
Magnesium (%)	0.11	0.12	0.18
Calcium (ppm)	20	32	46
Iron (ppm)	17	10–17	60
Manganese (ppm)	14	30–39	55
Zinc (ppm)	5	24	--
Copper (ppm)	13	4–7	8
Nitrogen (free % extract)	82.4	87.4	78.9

[1]Numbers in parentheses indicate ranges in values.
Source: Handbook of Cereal Science and Technology, Chp. 10, Oelke and Boedicker, 1991; and Wild Rice: Nutritional Review, R.A. Anderson, 1976.

III. Growth Habit:

Wild rice is an annual, cross-pollinated species. In Minnesota, it matures in about 110 days, and requires about 2,600 growing degree days (40° F base). Plants are five to six ft tall and can have up to 50 tillers per plant. In cultivated fields that have four plants/sq ft, plants usually have three to six tillers. Stems are hollow except at nodes where leaves, tillers, roots, and flowers appear. Internodes are separated by thin parchment-like partitions. The shallow root system has a spread of 8 to 12 in. Mature roots are straight and spongy. Ribbon-like leaf blades vary in width from 1/4 to 1 1/2 in. Mature plants have five or six leaves per stem or tiller above the water.

Flowers are in a branching panicle with female (pistillate) flowers at the top and male (staminate) flowers on the lower portion. Cross pollination usually occurs since female flowers emerge first and become receptive and are pollinated before male flowers shed pollen on the same panicle. Sometimes the transition florets, which are located between the pistillate and staminate florets on the panicle, have both stigmas and anthers (pollen), and can therefore be self-pollinated. Two weeks after fertilization the wild rice seeds are visible, and after four weeks, it is ready for harvest. This seed is a caryopsis that is similar to the grain of cereals. The caryopsis has an impermeable pericarp, large endosperm, and small embryo. The grains with the palea and lemma (hulls) removed, range from 0.3 to 0.6 in. in length, and from 0.06 to 0.18 in. in diameter. Immature seeds are green, but turn a purple-black color as they reach maturity. Seeds on any tiller will mature at different times, and on secondary tillers they mature later than on main tillers. There is little shattering resistance in natural stands.

Seeds will not germinate for at least three months after reaching maturity, even if environmental conditions are satisfactory for growth. An after-ripening period is required in water at freezing or near-freezing temperatures (35°F) before the embryo breaks dormancy and develops into a new seedling. This seed dormancy is caused by the impermeable pericarp that is covered by a layer of wax, and by an imbalance of endogenous chemical growth promotors and inhibitors. In the spring, seeds will start to germinate when the water temperature reaches about 45°F. Freshly harvested seeds can be made to germinate by carefully scraping off the pericarp directly above the embryo. These seeds cannot be planted directly, but must first be germinated in water, and then the seedlings transplanted later.

IV. Environment Requirements:

A. Climate:

Wild rice is well adapted to northern latitudes. It is not very productive in the southern United States since warm temperatures accelerate plant growth, and as a result, plant heights are shorter with an accompanying lower number of florets. The number of florets per panicle also decreases when the daylength is shorter than 14 hours. However, moderate yields have been produced in southern climates when planted in late February or early March. Northern California, Idaho and Oregon have recently been other areas where wild rice has produced good yields.

B. Soil:

Wild rice in Minnesota and Wisconsin is usually produced on low, wet land that has never or seldom been farmed. The paddy site should be net enough to avoid expensive or excessive grading that would expose the subsoil. This crop grows well on shallow peat soils, and clay or sandy loams. The site should have an impervious subsoil, such as clay, which prevents seepage during most of the growing season and is a solid footing for heavy field equipment. The majority of wild rice fields have been developed on organic soils with a peat depth ranging from several inches to more than 5 ft. Peat areas in Minnesota, except for acid bogs which are low in fertility, are ideal for growing wild rice since they are generally flat and slightly above the flood plain. Peats with pH 5.5 as well as sphagnum bogs should be avoided. Ideally, the soil should contain 20% mineral matter and have a carbon to nitrogen ratio less than 16.

C. Land Preparation and Dike Construction:

Brush and small trees on a new paddy site are usually removed during winter by shearing with a bulldozer, and then burned the following summer, if weather conditions permit. Large disks or rotovators are used to till the soil rather than moldboard plows. When sod peats are turned over with a moldboard plow the rotting vegetation can produce enough carbon dioxide and methane to cause the soil to float when flooded. A detailed topographic survey is needed to help determine the dike height, location of culverts, and portions of the paddy that should be leveled.

Small fields will have a perimeter dike and water outlet at the lower side. Fields that are 30 or more acres in size will have cross dikes with water gates, as well as the larger perimeter dike. A slight slope of less than one-half percent (six in. per 100 ft) within the paddy promotes preharvest drainage. Tiling of larger fields is common now to promote drainage and fall tillage.

Dikes must be impervious to water. Clay soil is ideal for dike construction. The dikes must be wider if peat soil is used. The top width of the main dike should be eight ft, while the inner dike should have a minimum top width of four ft, but never less than the height of the dike. The steepest side slopes should be 1.5:1 (1.5 ft of horizontal distance for every one ft drop) and the height should be one-half to one ft above the water level. On highly erodible soils, the slope should be 3:1, and the height of the dike should be one to two ft higher than the water level. Use of organic soil for dikes may cause problems since peat erodes easily and may not hold back water. The sides of the dike may need to be flatter than the minimum recommended height to provide wave protection and fill stability. A mixture of mineral soil with peat soil may reduce erosion problems, especially on the sides of dikes. Place dikes so that a maximum water depth of 8 in. can be maintained in the shallow end and 16 in. in the deep end of the field.

Access roads should be located so they can serve as part of the dike system to divert or collect water and to divide the drainage areas. Culverts or other permanent structures should be positioned where roads cross the drainage channels to provide access to every field for easy observation and movement of equipment. The location and size of culverts, water gates, and pumps should be determined prior to construction so the desired water control can be achieved.

D. Water:

Wild rice in natural stands grows in water with a concentration of less than 10 parts per million (ppm) of sulfate. Research has found that wild rice can grow satisfactorily in water with sulfate concentrations of up to 250 ppm. The growth of wild rice is also tolerant to a wide variation in the hardness (22 to 300 ppm calcium carbonate) and pH (5.0 to 8.0) of the water.

This crop will thrive only in flooded soils. Flood the fields as early as possible in the spring. If seeds germinate in unflooded soils, the seedlings are stunted and yellow in color probably due to lack of iron. Soils should be saturated from germination until 2 or 3 weeks before harvest to ensure vigorous plant growth. A constant water depth of at least 6 in. is important to help control weeds during the first 8 to 10 weeks after seeds germinate. Variable water depths during this period can damage wild rice plants. Water deeper than 14 in. causes weak stems and lodging during water drawdown. A 3-year study conducted in northern Minnesota indicated that a 13-in. water depth resulted in adequate plant populations, no delay in maturity, good yields, and the best weed control during the early portion of the season. To maintain the proper depth, water should be added as needed to compensate for soil percolation, evaporation, and plant transpiration. The water level can be permitted to decrease slowly during flowering so that little water needs to be drained 2 or 3 weeks prior to harvest.

An acceptable water source must be available from a stream or lake. Permits are required in Minnesota from the Department of Natural Resources to use surface or ground water for irrigation, and from the Pollution Control Agency for the drainage of water from paddies. These permits are available only to landowners whose fields are next to the water source. Wells can also be used if the recharge rate is sufficient. Applications for these permits should begin early in the planning stage to assure they are granted prior to construction.

One possible plan for an irrigation system has a central water supply ditch from which numerous fields can be flooded. A second system allows water to flow from one field to another. However, this system does not allow crop rotation or fallowing of individual fields. The amount of water needed to grow this crop varies from 24 to 30 acre-in. Research conducted by the University of Minnesota found that wild rice with a plant density of two plants/sq ft required 25 acre-in. during the growing season. Most growers have water-use permits that allow them to pump this amount of water, but nearly half is often supplied by rainfall. The water system should flood a field in 7 to 10 days. A 30-acre field requires about 15 million gallons of water for the initial flooding. A 12-in. pump that delivers 4,000 gallons per minute, and operates for 24 hours a day, will deliver S,760,000 gallons per day. This pump would take 2 1/2 days to flood a 30-acre paddy to a depth of 11 in. Less water would need to be pumped in subsequent years when the winter snow and spring rains are retained after the water gates of paddies are closed following the harvest in the fall.

E. Seed Preparation and Germination:

Plant new fields with the most shatter-resistant varieties. New producers should make arrangements to buy seed from seed growers before harvest in the fall. Some certified seed of new varieties is available. Growers can save their own seed, but it should be from weed-free fields. Seed should be cleaned immediately after harvest with an air or gravity cleaner before fall planting or winter storage that precedes spring planting. If the seed will be stored, even if for a short time, it must be placed in water to assure germination. Seed used for fall planting is usually placed in tanks filled with water. Seed for spring planting can be stored in 50-gallon drums that are perforated with many small holes or plastic-mesh bags to permit water circulation. The drums or bags are placed below the ice in lakes or streams, or in water-filled pits that are 10 ft deep. Do not let mud cover the seed or allow water surrounding the seed to freeze. Seed can also be stored in tanks where the water is kept at 33 to 35° F and it should be changed every three to four weeks.

Seed dormancy will prevent germination until after three months of cold (33 to 35°F) storage in water. The percent germination is determined by placing seeds in a pan of water at room temperature (68°F). The water should be changed every two days, and after 21 days, high quality seed should have a 70% or higher germination rate. Seed germinates at 42°F, but the optimum temperature is between 64 to 70°F. Viability of dormant seed can be checked by removing the pericarp above the embryo and then placing the seed in a pan of water, or by performing the tetrazolium test.

V. Cultural Practices:

A. Seedbed Preparation:

A new wild rice field that has a large amount of vegetation should be tilled one or more years before planting. Small grains such as oats or winter rye can also be grown for one or two years prior to planting wild rice. This initial cropping, prior to flooding the fields, allows vegetation to decompose and reduces problems with floating peat when fields are flooded. Frequently, a rotovator is used to till the soil to a six-in. depth. A roller or row of tires is often attached to the rear of the rotovator for better floatation on peat soils. A disk can be used to prepare the seedbed, but it is not as effective as a rotovator in destroying and incorporating the existing vegetation. Moldboard plows are not satisfactory for primary tillage of peat soils with vegetation since the turned-over soil may float when the field is flooded. Land-breaking plows will cause less soil flotation, but should not be used in shallow peat where the underlying mineral soil is brought to the surface. Wild rice is difficult to establish on clay subsoil. The final seedbed should be free of ridges and depressions to ensure good water drainage.

Fall tillage is recommended for seedbed preparation, weed control, fertilizer incorporation, and covering plant residue to decrease the severity of leaf diseases in the following year. Growers often fallow fields during the third year. Soil is removed from ditches in the perimeter of fallow fields to maintain good drainage and ease of tillage and harvesting. Other crops can be grown in rotation with wild rice, such as buckwheat, rye, wheat, mustard, canola, or forage grasses for seed production. Barley should not be in the rotation because it is an alternate host of brown spot which is a severe disease in wild rice.

Changing a field to a new variety is not easy since wild rice seeds survive in the soil for several years. The eradication of seeds from the old variety begins by not doing the fall tillage. Seeds that remain on the soil surface during the winter will die. The field should be flooded in the spring to permit germination, and after four to six weeks, the field should be drained and tilled to eliminate any plants. A short-season crop like buckwheat could be planted following the summer tillage. After two years this system should eliminate most of the seed from the old variety. Another method for changing varieties has been successful in areas with a peat layer that is more than 24 in. thick. The field is plowed 20 to 24 in. deep in the fall to bury the seed so seedlings are unable to emerge. This system has allowed some growers to change a field to a new variety in one year.

B. Seeding Date:

Wild rice can be seeded in the fall or spring. Fall planting is preferred since it is the natural seeding time, and eliminates the need to store seed over winter. Other advantages of fall seeding are that the weather is mild, and fields are usually dry so heavy field equipment can be used. However, if the soil is too dry, the fields may need to be flooded immediately after planting to prevent the seeds from drying out. Spring seeding should occur as early as possible before the seeds begin to sprout. A seeding trial at Grand

Rapids, Minnesota found that planting the variety K2 after June 1 was too late in the growing season to allow the crop to mature.

C. Method and Rate of Seeding:

Do not allow the wild rice seed to dry during planting. Drain the water from the seed just before planting and then mix it with oats in a ratio of 2 or 3 lb of oats per lb of wild rice. This combination allows the wild rice seed to flow uniformly through the seeding equipment. Successful planting requires that the seed is covered promptly with soil or water to maintain viability and minimize feeding losses from birds.

Wild rice should be planted at a depth of one to three in. Seedlings will not emerge when planted deeper than 3 in. Mineral soils require a shallower planting depth than peat soils. Wild rice may be planted by using a bulk-fertilizer spreader to broadcast the seed, which is followed by using a disk or harrow to incorporate it to a depth of 1 to 2 in. A grain drill may also be used. These seeding methods cannot be used in the spring due to wet field conditions. Seed is usually sown directly into the water from an airplane or broadcasting equipment in the spring. Seeding rates that are 15 to 20% higher should be used when planting directly into water.

A plant density of 4 plants/sq ft is recommended. Higher plant populations have lodging and leaf-disease problems. Planting rate with good quality seed should be 30 to 45 lb/acre. The amount of seed needed to obtain the optimum plant density varies with the seed quality, which is reflected by the germination rate. Germination rates of commercial seed can vary from 15 to 95%.

In second-year and older fields, varieties will reseed themselves. A very high plant population will result since up to 1,000 lbs of seed per acre can shatter before harvest. Reducing the plant population is necessary to produce higher yields. Plants are thinned at the floating-leaf stage. The thinning is done by an airboat with a series of V-shaped knives set six to eight in. apart on a toolbar attached to the rear of the boat. The boat travels at a speed of 35 m.p.h. with the knives riding on the soil surface, and removes approximately 70% of the plants. The plant density should then be 4 plants/sq ft. Sometimes it is necessary to thin fields with a second series of passes that are perpendicular to the first series.

D. Fertility and Lime Requirements:

Flooding a field to grow wild rice causes changes in several chemical systems of the soil that affect plant nutrition. The only form of nitrogen that is stable in flooded soils is ammonium. Nitrate nitrogen is rapidly lost due to the formation of dinitrogen gas. Consequently, only ammonium based fertilizers, including urea, should be used on wild rice. Also, fall testing for nitrate nitrogen, as is done in small grains, is not useful in making fertilizer recommendations in wild rice. Ammonium nitrogen near the surface of a flooded soil can be oxidized to nitrate then lost by being transformed to dinitrogen gas.

To minimize this type of loss nitrogen should be plowed under with a moldboard plow or injected to a depth of 6 to 8 in.

Phosphorus and potassium are both more highly available in peat soils than in mineral soils and tend to be more highly available in flooded mineral soils than non-flooded mineral soils. Leaching losses are possible but in well managed wild rice paddies leaching is not much of a problem. Phosphorus in the flood water enhances algae growth which can be a problem especially in the early stages of wild rice growth. Phosphorus fertilizers should be injected or plowed in.

The availability of iron and manganese increase greatly upon flooding. Wild rice does not have the ability to obtain sufficient iron in non-flooded soils and iron availability is one of the major reasons wild rice must be grown in flooded soils.

The wild rice plant has a relatively high requirement for plant nutrients for each pound of dry matter produced. This crop grows rather slowly during the vegetative phase, so that by jointing, less than 12% of total dry weight is produced. Most plant growth and dry matter accumulation occurs during flowering and grain maturation. Consequently, the nitrogen requirement for wild rice is greatest during the reproductive phase when 70% of the total nitrogen is assimilated by the plant. Growers often apply 30 to 50 lb/acre of urea nitrogen by air at the late boot stage to supply sufficient nitrogen for grain fill. Assimilation of phosphorus and potassium follow a similar pattern during crop development.

Plants that are nitrogen-deficient are shorter and have a lighter green color than plants with a sufficient amount. Lower leaves of nitrogen-deficient plants have yellow tips and margins. A slight deficiency of nitrogen results in less lodging, vegetative growth, and damage from brown spot disease. In addition, yields are higher and harvesting with a combine is easier. Sulfur deficiency can also result in a yellowing that looks similar to nitrogen deficiency. Experiments with sulfur application have not yielded consistent results but the data are suggestive of a response to fertilization for some acid peats with pH less than 6.

Soil testing and plant analysis are the best methods to determine how much fertilizer may be needed by a wild rice crop. The amounts of nitrogen, phosphate, and potassium fertilizer that are recommended for wild rice by the University of Minnesota Soil Testing Laboratory are summarized in Table 2. Tissue nitrogen concentrations of less than 3.5% in the boot stage suggest that fly-on nitrogen, in addition to that normally applied, is needed. Liming has not been effective and liming of acid peats can result in gas production and floating of the soil. If lime is applied the soil should be fallowed or used for an upland crop for one more season. Fertilization with sulfur may be helpful in some acid peats but there is no documented evidence of response to other micronutrients.

Much of the nitrogen can be applied in the fall if it is incorporated to a depth of 6 to 8 in. All ammonium sources, anhydrous ammonia, aqua ammonia, ammonium phosphate, and urea, work equally well. Urea ammonium nitrate, UAN, has 29% of the nitrogen in the nitrate form which will be lost to the atmosphere. This source can be used for wild rice but only 71% of the nitrogen that is applied will be available for wild rice. The phosphorus fertilizer should also be incorporated into the soil to help control algae. Application of phosphorus in the spring should be avoided. If conditions do not permit fall application of fertilizer it is better not to apply phosphorus in the spring. In fields that have been cropped for several years, the buildup of phosphorus from previous fertilization will probably supply the crop with sufficient P.

Under some conditions, losses of fall applied nitrogen can be high. In drained soils ammonium is convened by soil microbes into nitrate which will be lost after flooding in the spring. The rate of the process is slower at lower temperatures and fall fertilization is not recommended until the temperature at 6 to 8 in. depth is less than 50°F. Even at this temperature much of the ammonium can be converted to nitrate within 2 to 3 weeks if the soil is well drained. Fall flooding, within 5 days after nitrogen application, will stop nitrification and result in a better efficiency for fall nitrogen fertilization. Top-dress applications of urea should be made at the boot stage or very early flowering.

Table 2. Fertilizer recommendations for wild rice[1].

Nitrogen	Criteria	Amount to Apply (lb/acre)	
		Mineral Soils	Organic Soils
Nitrogen	Status of Paddy:	Incorporated	Incorporated
	First year only	70	25
	Second year and older	70	50
Phosphorus	Soil Test Results (ppm)	Amount to Apply (lb/acre)	
(P_2O_5)	0–7	40	
	8–15	20	
	16+	0	
Potassium	0-50	60	
(K_2O)	51–100	40	
	101–150	20	
	151+	0	

[1]Source: Fertilizer Recommendations for Agronomic Crops in Minnesota 1990. George Rehm and Michael Schmitt, University of Minnesota, Minnesota Extension Service, AG-MI-3901, 1990.

E. Variety Selection:

Most of the paddy-grown wild rice in Minnesota and Wisconsin is produced using varieties that have a nonshattering tendency. All the following varieties shatter somewhat and are susceptible to lodging and diseases. The most popular variety is K2.

K2- has a medium height, early to medium maturity, and medium to high yield. Developed by Kosbau Brothers in 1972.

M3- has a medium height, medium to late maturity, high yield, and variable plant and panicle type. Developed by Manomin Development Co. in 1974.

Meter- has a shorter height, very early maturity, low to medium yield, and large seed size. Reduced foliage in the canopy compared to other varieties. Released by the Minnesota Agricultural Experiment Station in 1985.

Netum- has a medium height, early maturity, and low to medium yield. Released by the Minnesota Agricultural Experiment Station in 1978.

Voyager- has a short to medium height, early maturity, and medium to high yield. Should equal or exceed K2 in yield and mature a few days earlier. Released by the Minnesota Agricultural Experiment Station in 1983.

Yield and other agronomic characteristics are shown in Table 3.

Certified seed is not available of the above varieties except during the first year of release. Growers maintain and sometimes select their own seed and new growers need to make arrangements for seed with current growers during harvest. Because of cross-pollination variety integrity is difficult to maintain in a field, thus most seed is not the same as the original variety unless reselection has been done. The breeding program at the University of Minnesota is continuing to develop varieties for future release.

Table 3. Yield and other characteristics of wild rice varieties evaluated in Minnesota.

	Yield			Shattering		Harvest Date	Height	
Variety	1981–1986	1989[1]	1990[1]	1989[1]	1990[1]	1981–1986	1981–1988	Seeds
	lb/acre[2]			%[3]			(in.)	(no/lb[4])
K2	1,578	1,083	796	37	59	Aug. 23	72	7,300
M3	1,613	649	720	55	59	Aug. 27	74	9,460
Meter	1,078	1,070	--	21	--	Aug. 2	53	6,880
Netum	1,497	728	--	27	--	Aug. 17	68	8,300
Voyager	1,500	1,082	--	31	--	Aug. 18	66	8,600

[1]Data for 1990 was from Grand Rapids, Minnesota, and for 1989 it was from on-farm site and Grand Rapids combined.
[2]Green weight of harvested grain adjusted to a 40% moisture content.
[3]Shattering expressed as percent of total possible yield (sum of the harvested and shattered grain).
[4]Number of seeds per pound based on wet, stored seed. Seed size will vary among years

and seed lots.
Source: 1991 Varietal Trials of Selected Farm Crops, Minnesota Agricultural Experiment Station, Minnesota Report 221-1991.

F. Weed Control:

The common broadleaf water weeds of the Upper Midwest are a more serious problem than aquatic grassy weeds. Common waterplantain (*Alisma plantago-aquatica* L.), an aquatic perennial weed, is the most troublesome weed in wild rice fields. Research conducted by the University of Minnesota found that waterplantain which developed from corms caused yield losses of 43% when one weed/sq ft was present. Early control of waterplantain is critical since competition with wild rice is greatest after 8 weeks of growth. First-year seedlings of waterplantain are usually too small and late in appearance to compete with wild rice. Weed seedlings should be controlled since they will cause problems in succeeding years. Consult the Minnesota Extension bulletin on wild rice production for a discussion of other weeds that are present in paddies, yet are usually not economically significant.

Control of weeds should consist of a combination of cultural and chemical methods. Fall tillage after harvest will control cattails (*Typha latifolia* L.) and reduce plant numbers of common waterplantain. Other effective methods to control aquatic weeds include the use of weed-free seed, maintenance of the water depth at six to ten in. especially during the first 6 weeks, and to fallow weedy fields for a year. The fallow fields should be flooded in the spring for 6 weeks to ensure the growth of weeds, and then drained, so they can be tilled to destroy weeds.

Presently, the only herbicide that can be used in Minnesota for controlling weeds in wild rice is 2,4-D (amine) at one-quarter pound of active ingredient per acre. No herbicides are cleared for use in Wisconsin. 2,4-D should be applied when wild rice is in the tillering stage since considerable injury can occur with later applications. Avoid spray overlaps in the field because one-half pound of active ingredient per acre can injure the crop. This herbicide does not give complete control of waterplantain, but will reduce the infestation in the following year. Algae can form a mat on the water surface before wild rice emerges, which will reduce the stand in some areas of the field. Copper sulfate applied at 15 lb/acre into the flood water may help to control algae. Retreatment is often necessary for complete control. Consult your Extension agent or specialist for current herbicide recommendations.

G. Diseases and Control:

Diseases in natural stands of wild rice are not usually destructive, but in field-grown wild rice they can cause serious losses. In the early years of commercial production, severe epidemics of brown spot destroyed entire crops in some locations. Almost every disease pathogen of wild rice has been observed previously on rice (*Oryza*).

Brown spot (formerly called *Helminthosporium* brown spot) is the most serious disease affecting wild rice that is grown in fields. This disease is caused by *Bipolaris oryzae* Luttrell (*Helminthosporium oryzae* B. de Haan) and *B. sorokiniana* Luttrell (*H. sativum* P.K. and B.). These fungi are considered to cause brown spot since both are found on infected plants and cause similar symptoms in wild rice plants. Every variety of wild rice, at each stage of development, is susceptible to brown spot. This disease is most severe when day temperatures range from 77 to 95° F and nights are 68° F or warmer. High relative humidity (greater than 89%), and the continuous presence of free water on leaf surfaces for 11 to 16 hours, can also favor infection. All parts of the plant are susceptible to infection. The brown, oval leaf spots usually have yellow margins and are about the size of sesame seeds. These spots are uniform and evenly distributed over the leaf surface. Severe infections cause weakened and broken stems, damaged florets, and a reduced quantity and quality of grain. Yield reductions can vary from insignificant to 100%.

Sanitation and appropriate cultural methods are important parts of a program to control disease. Disease problems are reduced by the incorporation of crop residue into the soil after harvest, planting disease-free seed in new fields, using rotation crops resistant to brown spot or fallowing fields, and planting grass or other plants on dikes that are not alternate hosts. Barley and reed canarygrass are alternate hosts. Application of a balanced fertilizer can also reduce the severity of disease problems by avoiding nutrient deficiencies which can predispose plants. Higher plant densities than 4 plants/sq ft can also lead to more disease. Use of propiconazole (Tilt), a fungicide, may be necessary. Apply 6 oz/acre at the boot stage followed by an additional 6 oz 14 to 17 days later at early flowering. This fungicide is approved for use on wild rice in Minnesota.

Stem rot is the second most common disease in field-grown wild rice. Two fungi, a *Sclerotium* sp. and *Helminthosporium sigmoidium* Cav., may cause this disease. These fungi produce dark structures called sclerotia in culms, leaf sheaths, and stems. Sclerotia survive in infected plant debris or float in the water until deposited on the soil surface when paddies are drained. In the spring, sclerotia germinate and produce conidia (infective spores) that are spread by the wind or by sclerotia themselves, which can float to new plants and infect at the water level. Small, oval, purple lesions develop initially on stems or leaves at the water surface. Extensive lodging may result after the fields are drained prior to harvest, since the infected stems become necrotic, dry, and brittle. Control of stem rot is achieved most effectively by appropriate sanitation and cultural practices such as burning the residue. Plant residue must be removed or tilled into the soil, only clean seed should be used, and resistant crops or fallow should be in the rotation. There is no fungicide available for effective control.

Stem smut is caused by the fungus *Entyloma lineatum* (Cke.) Davis. Economic losses from this disease have not been a problem in cultivated fields.

Ergot is rarely found in cultivated fields of Minnesota, but can be a serious problem in natural stands. This disease is caused by the fungus *Claviceps zizaniae* Fyles, which is a different species than the one causing ergot in cereal grains. Wind-borne ascospores infect flowers and hard, dark sclerotia eventually develop in place of the grain. No specific control is recommended, but poisonous ergot bodies should be removed from harvested grain by flotation, or by screening.

Bacterial leaf streak caused by (*Pseudomonas syringae* pv. *zizaniae*) and *Xanthomonas oryzae*, as well as bacterial leaf spot (*P. syringae* pv. *syringae*) have been found in cultivated wild rice in Minnesota. The wheat streak mosaic virus-wild rice (WSMV-WR) is the only one known to infect wild rice. The eriophyid mite vector, *Aceria tulipae* Keif., which is commonly found on wild rice, retains WSMV-WR for several days and can be transported long distances by wind. Economic losses for grain yield, if any by these diseases, have not been determined. No control measures are known.

H. Insects and Other Pests:

The rice worm (*Apamea apamiformis* Guenee), which is the larval stage of the noctuid moth, is the most serious insect pest of wild rice in the Upper Midwest. Significant yield losses have been caused by this insect. Its life cycle is coordinated closely with the growth and development of wild rice. Adult moths begin to emerge at about the same time as flowering begins in wild rice during late June or early July. Nectar from milkweed flowers serves as the primary food source for adult moths through August. Eggs are deposited in wild rice flowers over a period of 4 to 6 weeks. Larvae hatch and develop through several instars or stages, and feed as they grow. Yield potential is reduced by the initial feeding activity on the glumes of the spikelet and subsequent feeding on kernels. Rice worms bore into stems of wild rice or migrate to plants that border the production area as their growth and development nears completion. Rice worms over-winter inside the stems in the seventh instar. After a final molt and some additional feeding in the spring, the larvae usually pupate in early June, and develop into the adult moth. Research in Minnesota found that one larva per plant reduces yield by 10%. Control of the rice worm has been effective with several insecticides; yet only malathion at one pound of active ingredient per acre is approved for use in Minnesota. Malathion should be applied 14 to 21 days after eggs become visible in the bracts at the base of florets. Control is only economical if there are 10 or more larvae per 100 panicles.

A number of midges use the flooded paddies for larval development. Eggs are laid in the moist soil and hatch when the fields are flooded. One of the midges, *Cricotopus* spp., has caused severe damage to first-year fields. The mosquito-like adults are so small that most growers will not see them. Algal growth is associated with paddies showing high midge numbers. A slow emergence of seedlings results in greater damage by midges since it allows more time for feeding activity. The larvae feed on leaf edges and cause frayed leaf edges with subsequent curling of leaves. The leaf curling and webbing that midges produce will interfere with seedling emergence above the water. As a result, the damaged seedlings fail to reach the floating-leaf stage and the stand is thinned severely. Midge control with malathion is often necessary in first-year fields. In the following years control is not usually necessary since there is no economic loss. This is not the result of a lack of midges, which actually increase in number, but due to higher plant numbers so the damage goes unnoticed.

Rice stalk borers (*Chilo plejadellus* Zincken), rice water weevils (*Lissorhoptrus* spp.), rice leafminer (*Hydrellia* spp.), rice stem maggot (*Eribolus longulus* Loew), and other insects will feed on wild rice plants. Research in Minnesota did not reveal any economic injury from these insects.

Crayfish (*Orconectes virilis* Hagen) are carried into paddies by flood waters where they forage and may cut back the seedlings. Once crayfish are established in a field, they persist and can increase in number. They survive in production fields by burrowing into moist soil between periods of paddy flooding. Severe stand reductions have occurred in some fields in Minnesota. No chemicals are cleared for their control.

Blackbirds are a major pest. These birds use the paddy dikes as nesting sites and are present in large numbers in the growing areas. Birds begin feeding on wild rice when the kernels are in the milk stage. Control measures should start when blackbirds are first observed in the area. Numerous methods of bird management have been used by commercial growers. Shooting, carbon-dioxide guns or bangers, Av-Alarm records, and continuous overflights by aircraft have been tried or are now used by producers. Oats have been planted around the perimeter of fields to draw the birds away from the wild rice. Methiocarb (Mesurol) has been investigated as a chemical bird repellent, since it causes illness and conditions an aversion to wild rice. This repellent must be applied uniformly on hulls of wild rice grains to be effective. It is difficult to apply methiocarb uniformly to the grain under field conditions, which results in an inconsistent effectiveness in repelling birds. However, methiocarb has not yet been approved for this use. There is no method that has been completely effective in keeping blackbirds away from production fields.

Wild rice fields are also ideal sites for resting, foraging, nesting, and raising broods of migratory and resident water birds. Four species of ducks (mallard, pintail, bluewing teal, and green-wing teal) and more than 35 species of shorebirds and wading birds inhabit wild rice paddies. Economic damage from waterfowl is rarely observed. Paddies are excellent areas for duck production.

Raccoon, mink, and skunk search for food on the dikes and in ditches. Deer and moose occasionally cause some damage in the fields, but it usually has no economic importance. Muskrats can cause problems by feeding on plants and by burrowing holes in the sides of dikes. However, since muskrats are not permanent inhabitants due to the annual drainage of the paddies for the harvest, they do not pose a threat to the dikes.

I. Harvesting:

Paddies should be drained gradually in late July and early August during grain fill. It usually takes about two to three weeks for paddies to drain and become dry, but will vary with soil type and if drain tiles have been installed. Drainage allows the soil to dry so it can support harvest machinery. Peat soils must be drained completely, although harvesting is possible on mineral soils with some standing water.

Maximum yields of processed wild rice are obtained when about one-third of the grain at harvest time is greenish brown or black, rather than green in color. The grain at this time has the consistency of firm dough and contains 35 to 40% moisture. This moisture content usually occurs when some of the seeds have fallen from the main stem, but very few have dropped from tillers on the same plant. Growers may not always be able to wait until this time to harvest due to imminent climatic conditions such as frost, high winds, and hail. Some paddies may need to be harvested early if enough combines are not available to do all the fields in a short time. The harvest of nonshattering varieties usually begins in early to mid-August.

Direct harvest with a combine is possible since shatter resistance and uniformity of maturation have been improved compared to the original lake types. Field conditions result in severe limitations of machinery that are not found usually in the harvest of other crops. High capacity combines are required to harvest wild rice because the plants are still green. Ground conditions are extremely wet even though fields are drained 2 to 3 weeks before harvest. The crop stubble provides little support for combines since wild rice is a poor sod former and the organic soils on which this crop is usually grown lose most of the fiber strength from tillage.

Growers have made innovative changes to various components of combines such as reels, grain divide points, draper systems, and track-type support systems. Reels seven feet or more in diameter are needed to allow the reel bats to enter the crop without pushing it forward. Extended bats on the reel and crop-divide points prevent the straw from wrapping around rotating pans of the combine. The pickup-type reel is considered necessary to reduce shattering since the bats remain parallel to the original position as they rotate. Reel tines should be adjusted to point downward or somewhat rearward to provide lifting action. This adjustment, which gives a positive pitch to the pick-up teeth, also prevents a pressing action on the crop.

A header equipped with a draper extension between the sickle and crossauger is used due to the height of wild rice plants. This extension provides a space in which plants fall before entering the crossauger and a "live" surface to assist in moving plant material to the crossauger. The divide point of combine grain header is usually modified to handle this crop. Larger and different divide points are used to avoid the hairpining of stems and accumulation of straw on the end of the header. Spike-tooth cylinders are effective for threshing heavy clumps of crop material. Rasp-bar cylinders effectively separate a large portion of the grain through the concave concave rather than passing it to the walkers. Rasp-bar cylinders leave straw in larger pieces, which results in easier separation of straw and grain on the walkers and sieves.

The very soft soil of paddies requires an effective support system. Extensive support systems for combines range from conventional half-tracks with dual guide wheels to full-track systems with 45-in. pads bolted to each track shoe. Half-track systems are standard attachments for most combines. The addition of planking to reduce ground support pressure is fairly quick and easy to accomplish. This modification places the ground support pressure of paddy soils in the range of an individual's foot. A full-track system must be used in more difficult situations. Conversion to a full-track system is a major project that is usually done by the grower. Guide wheels are removed and the rear of the combine is mounted on a "walking beam" that is supported on the channel frames of the two tracks. The original steering and brake systems must also be changed since there are no guide wheels. A steering clutch is installed in the right and left drive shafts so the original steering and brake systems can continue to control these operations. The steering clutches require widening the track tread, but allow the use of wider pads on the tracks. Growers find it advantageous to have access to both half- and full-track combines. Half-track combines are used to open fields and harvest on firmer areas. Full-track machines are useful on soft ground where half-tracks cannot operate.

The height of the cut should be adjusted low enough to harvest most of the grain, yet high enough to reduce the amount of straw entering the combine. The peripheral speed of the reel should be 1 1/4 to 1 3/4 times the travel speed of the combine. Rethreshing wild rice with the tailings return in the combine is not needed. Any material that was not threshed in the first pass is still attached to the straw and passes out the discharge over the walkers. The sieves and air flow should be adjusted to allow only a small amount of material in the tailings-return.

Adjustment of the air setting is critical for the separation of grain and straw on the sieves. Excessive air flow will blow the lighter kernels out the rear of the machine, whereas a low air flow permits too much light, chaffy material to accumulate with the clean grain. Check the air passages often for plugging by plant material. The distribution of material on the walkers and sieves is examined by quickly stopping a combine that is operating normally by turning off the engine with the machine engaged and applying the brakes. Clumps of dense plant material on the walkers indicate an inadequate air flow. A problem may occur in unloading the grain from the combine due to the high moisture content. Kernels may interlock and cause a bridge in the grain tank. Growers remove obstructions in the grain tank to reduce bridging.

J. Postharvest Handling and Processing:

Freshly harvested grain has a moisture content of 35 to 45% and proper handling of the grain is necessary prior to drying to maintain grain quality by preventing heating and mold growth. Freshly harvested grain should be delivered to the processing plant as soon as possible. If the grain cannot be transported immediately, it should be kept cool by refrigeration or adding water and stirring. The expanded commercial production of wild rice has led to great changes in the processing sector of this industry. Before commercial production of wild rice began, there were many small processing plants located in the Great Lakes area that used a variety of homemade devices. Today, most of the larger processing plants are in Minnesota with additional ones located in California and southern Canada. Some of the newer plants are capable of processing more than 6 million pounds of wild rice during the several weeks of the harvest season.

Most wild rice is processed on a custom basis. Processing fees and the method of charging for this procedure vary. Some processors charge on a freshly harvested (green) basis and others on a finished (processed) basis. Charging for processing on a green basis is potentially disadvantageous to the grain owner since it gives processors little incentive to maximize the yield of finished grain. Alternatively, charging on a finished basis can penalize processors if grain yield is lower than expected. Processing charges range from 18.5 to 85 cents/lb of finished grain, with the average price being between 40 to 50 cents/lb. The wide range in processing fees is due to the variation in processing efficiency. Large operations can handle greater volumes than small plants, which will still process quantities as small as 100 lb.

The steps in processing involve the separation of immature kernels, fermentation or curing, drying or parching, hulling, scarification, cleaning, grading, and packaging. Fermentation is necessary to partially degrade the hulls to permit easier hulling, impart some of the characteristic flavor of wild rice, and change the immature kernels from a green to a brown color. Scarification removes pan of the outer impermeable layer, which reduces the cooking time, so it is similar to that of rice. Uniformity of cooking times is important for wild rice and rice marketed as blends. These processing steps are common to all major plants with the exception of the separation of immature kernels and the packaging. Most plants store processed wild rice in 100 lb sacks in clean, dry warehouses. Several processors put wild rice in small packages and some make blends of wild rice and rice according to customer specifications.

VI. Yield Potential and Performance Results:

One hundred pounds of unprocessed wild rice will usually yield 40 lb of processed grain. Yields of unprocessed grain from shattering types grown in paddies have ranged from 150 to 200 lb/acre. With shattering-resistant varieties, yields as high as 1,500 lb/acre of unprocessed grain have been reported in Minnesota. Average yields of varieties from experimental trials in Minnesota during 1981 to 1986 ranged from 1,078 to 1,613 lb of unprocessed grain per see (Table 3).

VII. Economics of Production and Markets:

The cost of preparing a site for wild rice production will vary considerably depending on the amount of trees and brush that needs to be removed before ditching and diking. In addition, the amount of land leveling will vary. Preparation costs, which include the water pumping and control system can range from \$500 to \$1,500 an acre.

The cash production costs will vary for each field depending on the year of production. The cash costs for a new field are higher because of the initial seed cost which is about \$80 an acre (40 lb/acre seed). However, there are added costs such as airboat thinning and more nitrogen fertilizer for second and third year fields. First year fields will often yield more, thus compensating for the increased seed cost. The cash costs for the first year are approximately \$360 with a return of \$508 (290 lb/acre of processed grain x \$1.75). Some growers sell their grain before processing for about \$0.60/lb giving a return of \$435 (725 lb/acre x \$0.60), thereby eliminating the processing cost.

The marketing system for wild rice consists of five major groups: harvesters and growers, buyers, processors, wholesalers, and retailers. Wild rice from natural stands is often purchased by buyers at the harvest site on a commission basis for a processor or wholesaler. Some buyers are brokers, while other buyers purchase the grain and process it themselves. Over 80% of the cultivated wild rice produced in Minnesota is marketed by three cooperatives: United Wild Rice, Minnesota Wild Rice Growers (MRG), and New Frontier Foods, Inc. They either sell unprocessed or processed grain directly to processors, wholesalers or food companies. Two major buyers are Busch Agricultural Resources, Inc. and Uncle Bens, Inc.

Wild rice was an expensive gourmet food when the only source was from natural stands. The growth of wild rice as a field crop coincided with the market expansion, which resulted in lower prices and a more consistent supply. Since 1968 the wholesale price of processed wild rice per pound has ranged from a low of $2.10 in 1987 to a high of $5.15 in 1978. Price variations between 1968 and 1977 were due to limited and erratic supplies from lake harvests and the initial years of paddy production. The high prices during 1978 to 1980 were due to attempts by marketers to withhold supply, and were short-lived since high prices encouraged increased production. Production expansion in Minnesota was moderate during 1978 to 1980, while in California, production doubled annually through 1981. High costs of grain storage forced the sale of stocks by 1981, and consequently, prices returned to market-determined levels. Production increased 26% each year between 1982 to 1984, yet markets were able to absorb this increase with only a slight drop in price. In 1985, California production more than doubled over the 1984 level, and prices have since declined sharply. In 1991 the price to growers for processed grain averaged $1.75/lb.

Markets for wild rice have expanded at a vigorous rate since 1978, especially during 1982 to 1984 when the demand increased 52%. Market expansion has been due in large pan to the introduction of wild rice blends. Although the blends usually contain only 15% wild rice, they make up over two-thirds of the total sales of wild rice. If blends had not been introduced, perhaps the industry for field-grown wild rice would not have developed. Sales in the blend market have increased an average of 15% each year since 1961 when the first blend of wild rice, long-grain rice, and herbs was sold. Pure wild rice and blends have seasonal and geographic sales trends. Consumers purchase more pure wild rice in Minnesota than elsewhere due to a greater familiarity with this food, lower prices, and shipment out of the state as gifts. The demand for wild rice is expected to increase substantially in the future as prices stabilize and production expands.

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Castorbeans

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I. History:

The castorbean plant (*Ricinus communis*) has been cultivated for centuries for the oil produced by its seeds. The Egyptians burned castor oil in their lamps more than 4,000 years ago.

Thought to be native to tropical Africa, the plant is a member of the spurge family. The seeds with hulls removed contain 35 to 55% oil. The seeds, leaves, and stems of the plant contain ricin and ricinine, which are poisonous to humans and animals. Eating a castorbean causes nausea, and eating several may cause death. These toxic compounds are not present in the oil.

Castorbeans are grown on a limited scale in the United States. Demand for the crop peaked in the early 1950s, when the federal government wished to increase supplies of castor oil for military applications in the event of a national emergency. The government guaranteed farmers, particularly in the Southwest, ten cents per pound for the seeds, which were grown under contract with castor oil processors.

The castorbean plant grows well in soil of medium texture. It is best adapted to southeastern Kansas, Missouri, southern Illinois, southern Indiana, Tennessee, Kentucky, and parts of Oklahoma and Texas. With irrigation, it also grows well in the Southwest.

II. Uses

In the United States, castor oil has been used by the military in aircraft lubricants, hydraulic fluids, and in the manufacture of explosives. It has also been used in the synthesis of soaps, linoleum, printer's ink, nylon, varnishes, enamels, paints, and electrical insulations. Textile scientists have used sulphonated castor oil in the dyeing and finishing of fabrics and leather. The most infamous application of castor oil may have been as a purgative popular for the treatment or prevention of many ailments in the first half of the twentieth century.

Castorbean meal is included as a protein source in feed for swine. Castorbean pomace, or meal, the residue left after the oil has been extracted from the seeds, has been included in mixed fertilizer. This product contains the ricin and ricinine from the seeds. Certain varieties of castorbean plants are grown as ornamentals.

III. Growth Habits:

In the tropics, the castorbean plant is a perennial. It is grown as an annual in temperate regions, however, requiring a growing season of 140 to 180 days.

Germination is slow. Seedlings will emerge 10 to 21 days after planting. Commercial varieties grow to a height of 3 to 10 ft.

The plant consists of several stems or branches, each terminated by a spike. The mature spike is six to 12 in. long. In some varieties, female flowers are on the upper part of the spike and male flowers on the lower part. Other varieties have male and female flowers interspersed on the spike. Varieties with spikes of only female flowers have made possible the production of hybrid seed. Male flowers drop off the spike after pollination.

The lower spikes on the plant mature first, followed by the upper spikes. Each spike bears 15 to 80 capsules, which may be prickly or smooth on the outer surface. The capsules, which develop from the female flowers, contain three seeds each and explode when ripe.

The seeds may be egg-shaped, oblong, or round, usually with an enlargement on one end, called the caruncle. Seeds vary in size, but most commercial varieties average 1,000 to 1,500 seeds/lb.

The plant is not a legume, as its name would imply. It has no soil-improving value other than that of any rotation crop.

IV. Environment Requirements:

A. Climate:

Castorbeans grow best where temperatures remain fairly high throughout the growing season of 140 to 180 days. The soil must be able to warm up early in the spring. The seed may fail to set, however, if the temperature stays above 100°F for an extended period.

B. Soil:

The crop requires a loamy soil of medium texture. Castorbeans do well on either alkaline or acid soils, as long as the subsoil is permeable and there is good drainage. Seed will not set if soil moisture is inadequate. Castorbeans should not be planted in an area that is subject to erosion.

C. Seed Preparation and Germination:

Seeds should be cleaned to remove foreign material, seeds with attached hulls, and damaged seeds. They should also be treated with a fungicide before planting. This is particularly important where there is a risk of low spring temperatures and high soil moisture immediately after planting. Thiram is the only registered seed treatment fungicide for use on castorbeans.

Castorbeans are poisonous for animals and humans. In addition, inhaling dust from the seeds may cause allergic reactions in some individuals. Seed treatment should be performed carefully to minimize dust and to avoid contamination of food and livestock feed. Children should be kept away from castorbean storage areas, and adults working with the seeds and plants should be warned of their poisonous properties.

V. Cultural Practices:

A. Seedbed Preparation:

To prepare the seedbed, plow or disk the land. Be sure the soil is moist at the planting depth of one to three in.

B. Seeding Date:

Castorbeans should be planted in early May, about the same time as corn. Seedlings will emerge in 10 to 21 days.

C. Method and Rate of Seeding:

Good stands of castorbeans require fairly heavy planting rates, because germination of the seed is usually rather low. Seeding at 10 to 14 lb/acre will give a good stand, depending on the seed size and the height of the variety. Row width should be 38 to 40 in. with 8 to 12 in. between plants. Because of differences in germination rates and plant size, growers should calculate rates based on the seed lot. Seeds should be planted at a depth of 1 1/2 to 3 in.

Because castorbeans are oily and easily broken, they can clog machinery and cause irregular spacing. Most corn planters with an air metering system should perform well. Planters using metering plates will require plates with proper cell size. Always check the planting unit to ensure that excessive bean cracking or crushing is not occurring during planting.

D. Fertility and Lime Requirements:

Castorbeans grow well on slightly alkaline or acid soils. The most important factor in fertility level is the supply of nitrogen in the soil. Insufficient nitrogen results in reduced castorbean yields. Excessive nitrogen produces heavy vegetative growth with little or no increase in seed yield.

The amount of nitrogen required by castorbeans depends on the soil organic matter content, as shown in Table 1. Preplant and sidedress applications of nitrogen may be beneficial at the higher application rates or on lighter-textured soils.

In general, castorbeans require the same amount of nutrients as other low-demand field crops. For typical silt loam soils testing in the optimum range (6 to 10 ppm P; 81 to 100 ppm K), approximately 20 lb P_2O_5 and 40 lb K_2O should be applied per acre. If soil tests are below optimum, approximately 5 lbs P_2O_5 and 20 to 30 lb K_2O should be applied in addition to the previous amounts. Castorbeans do not generally respond to phosphorus, and excess soil phosphorus levels can actually decrease yields. Therefore, do not apply P_2O_5 except where soils test in the optimum or below optimum level for extractable P.

Table 1: Nitrogen recommendations for castorbeans.

Soil Organic Matter	Nitrogen Application Rate
%	lb/acre
< 2	100
2–4.9	80
5–10	60
> 10	40

E. Variety Selection:

Castorbean varieties have been developed to produce large yields of seed with a single harvest. The tall varieties may reach a height of 10 ft or more. The dwarf types seldom exceed four or five ft.

No information is available about the adaptability of varieties to the Upper Midwest.

F. Weed Control:

The slow emergence and early growth of castorbeans means the plants are not strong competitors against weeds. Rotary hoeing during the first few weeks after planting, followed by row cultivation should provide acceptable control. Because the main lateral roots of the castorbean plant are near the soil surface, cultivation should be shallow. At the present time, herbicides are not registered for controlling weeds in castorbeans in Wisconsin or Minnesota.

G. Diseases and Their Control:

Resistance to various diseases varies among castorbean varieties. During periods of heavy rains or dews, capsule molds, Alternaria leaf spot and bacterial leaf spot may occur. Alternaria leaf spot is more severe in nitrogen-starved plants. Other diseases may occur, particularly in wet seasons. To help prevent disease problems, a good rotation program and treatment of seed with a fungicide prior to planting are recommended. Thiram is the only registered seed treatment fungicide.

H. Insects and Other Predators and Their Control:

Though leaf- and stem-feeding insects usually do not cause serious damage to castorbean plants, cutworms and wire worms may reduce stands. Stink bugs, corn earworms, webworms, caterpillars, grasshoppers, thrips, spider mites, leaf miners, Lygus bugs, the yellow-striped army worm, and the European corn borer also may attack the plants.

I. Harvesting:

The castorbean crop is ready for harvesting when all the capsules are dry and the leaves have fallen from the plants. Ideally, harvesting should begin 10 to 14 days after the first killing frost. If killing frosts will not permit completion of harvesting before winter, a chemical defoliant may be applied 10 to 15 days ahead of the desired harvest date. Defoliants tend to reduce yields, however. Delay in harvesting after the crop is ready may result in losses from "shattering," in which the seeds pop out of the capsules.

Since castorbeans are very susceptible to cracking and splitting during harvest, adjustment of the combine cylinder speed and cylinder-concave clearance is very important. Usually, a low cylinder speed and wide cylinder concave clearance are recommended. Combine operators should frequently inspect harvested beans for breakage.

Weeds cause problems in the castorbean harvest. They may clog machinery or push in front of the harvester and cause shattering of the castorbeans. Volunteer corn plants present no special problem in the harvesting operations, but do add foreign material to the yield.

After harvest, break up the stalks mechanically and work them into the soil. The stalks deteriorate rapidly and furnish organic matter. Castorbean hulls, which are scattered over the field during harvest, are about equal to barnyard manure in fertilizer value.

Seeds left in the field after harvest may cause a volunteer problem in the next year's crop. Waiting until seeds germinate and then disking the young plants down will prevent this to some extent. Follow castorbeans with a row crop or a grain crop, for which the volunteer castorbean plants will not present a problem.

J. Drying and Storage:

Moisture content, foreign material, and cracked or broken beans are considered in grading the seed. Ideally, castorbeans should be stored at less than 6% moisture.

VI. Yield Potential and Performance Results:

Yields vary depending on variety, the season, cultural conditions, and the care exercised in harvesting. No information is available concerning castorbean yields in Wisconsin and Minnesota. However, yields of about 2,200 lb/acre have been produced in Nebraska tests.

VII. Economics of Production and Markets:

Castorbean markets are limited. The crop should be grown only after identifying a market, and preferably after arranging a contract with a buyer.

VIII. Information Sources:

Castorbean Production. 1960. U.S.D.A. Farmers' Bulletin No. 2041

Cool-Season Grass Seed Production

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I. History:

When the United States was settled, the Europeans brought with them seed from the pastures and hay fields of their homeland. As settlers moved west, the grass prairies appeared inexhaustible to the farmers and ranchers who grazed their livestock on the native stands. This was followed by extensive farming operations with little respect for soil and water conservation of the grasslands leading to the destruction of the native prairies and huge losses of valuable topsoil. The production of grass seed did not become an important agricultural crop until after the destructive 1930's Dust Bowl days when the importance of grasslands for conservation was realized. Since that time, grass seed production has become an important agricultural crop primarily in the Pacific Northwest followed by Minnesota and other north central states.

II. Uses:

Cool-season grasses have played an important role in agricultural and horticultural settings. The forage grasses provide pasture and hay for the livestock industry , help prevent soil erosion on land which is unsuited for row crops, provide wildlife habitat and contribute to land reclamation. Turf grasses have long been a major landscape surface in the urban and suburban environment. Home lawns, golf courses, school grounds, cemeteries, athletic fields and parks are some of the major uses of turf grass seed.

III. Growth Habit:

The growth habits of cool-season perennial grasses are similar to annual cereals. There are two types of growth habits associated with cool-season grasses; bunch or rhizomatous. The bunch grasses tend to produce erect tillers which develop and grow upwards within the leaf sheath. The rhizomatous or sod-forming grasses tend to produce procumbent shoots or tillers which break through the leaf sheath and form either rhizomes, stolons or shoots. Most cool-season grasses require vernalization to flower the following year. In most species, this is a combined requirement of cool temperatures and short daylengths. In the fall, perennial grasses produce buds and tillers that overwinter. In the early spring, basal buds at the crown develop into new shoots consisting of unelongated internodes and leaves.

The young shoot, if it has been properly vernalized, will begin to differentiate into an inflorescence. The shoot then elongates to elevate and expose the newly formed inflorescence. The shoot will then flower and be fertilized by wind dispersed pollen, and produce seed.

IV. Environment Requirements:

A. Climate:

Cool-season grass seed production can be a viable alternative to the production of other agricultural crops throughout the north central and midwestern states. However, certain species and varieties have narrow regions of adaption. Climatic conditions such as moisture availability, winter conditions and day length requirements should be considered when selecting the grass species and varieties. Consult your county extension agent about species and varieties adapted to your location.

B. Soil:

For high seed production potential, select an easily worked, well drained soil such as a sandy loam, loam or silt loam soil. Production of Kentucky bluegrass seed has been successful on organic soils.

V. Cultural Practices:

A. Seedbed Preparation:

The factors to consider when selecting a field for producing grass seed include: cropping history; isolation distance from other grass fields, ditches, waterways, and native stands; soil erosion potential; time constraints for land usage; and weed infestations. Soil erosion can be a serious problem when establishing grass seed production fields or when producing grass seed in wide row spacings. Initial seedling growth is often slow which leaves soil bare in the early spring. Land that is subject to surface runoff water during spring snow melts or heavy rains may have serious weed and cross species contamination due to seed being carried into the field by runoff water.

All perennial weeds and annual grass weeds are difficult to control in grass seed fields. Perennial weeds such as quackgrass and Canada thistle should be controlled prior to seeding the grass seed production field. It is also important to control grass weeds, since perennial grass and weed seed are often impossible to be cleaned out of seed lots of other grass species which makes the seed less valuable or even unsalable. Fields with a history of grassy weeds should also be avoided because they provide heavy competition for the newly seeded grass plants.

A firm, well packed seedbed on a level, moderately well-drained soil is desirable. The seedbed should be firm enough that a footprint goes no deeper than 1/4 in. It is often necessary to use a cultipacker or harrow after the seed is planted to ensure good stand establishment of the small seeded grasses.

B. Seeding Date:

It is important to have adequate soil moisture and soil temperatures for germination and establishment. Coolseason grasses may be planted either in the spring or late summer. If planting cool-season grasses in the spring, seed when the soil temperatures are 40 to 45°F and the fields can be worked resulting in a firm seedbed. If weed competition is anticipated, seed in late summer and control weeds by tillage and/or chemical methods prior to seeding. Problems with late summer and fall seedings may be a lack of sufficient soil moisture and time for adequate growth before frost to properly establish a stand. Seeding in late summer may also reduce or prevent harvesting a seed crop the year after establishment for some grass species.

C. Method and Rate of Seeding:

Cool-season grasses can be established with a companion crop or direct seeded with herbicides. The use of a companion crop is species and grower dependent, and has both advantages and disadvantages. Companion crops will provide soil cover faster than grass crops to protect against soil erosion. Companion crops will compete with the grass seedlings for light, moisture and nutrients, however some grass species are more sensitive to competition from the companion crops while other species may require the extra protection from the companion crop stubble to successfully overwinter (Table 1).

The choice of a companion crop species also depends upon the grass species seeded and the marketability of the harvested companion crop. Small grains are more competitive than flax with grass seedlings, but the market or farm value of the small grain may make it the better choice. Companion crops allow producers to harvest a crop during the establishment year. However, companion crop competition can reduce potential seed yield of the grass during the first production year. If using a companion crop, the seeding rate should be reduced to minimize competition.

Herbicide and/or cultural control of weeds prior to seeding without a companion crop usually produces a larger seed crop the first production year. Consult your county agricultural agent or chemical representative for herbicide recommendations.

Most grass species are small-seeded requiring a shallow seeding depth, from 1/4 to 3/4 in. deep. Planting equipment with double disc openers, depth bands and packer wheels usually provides excellent results. Seeding rate is dependent upon the species being seeded and the method of seeding. Grass seed fields may be seeded broadcast or in rows dependent upon available equipment, moisture availability and species. If moisture is limiting in your environment, seeding some species into wide rows should produce a better yield response. The highest seeding rates are required for broadcast seedings and the lowest seeding rates for wide row spacings (Table 1).

Table 1: Cool-season grass species, seeding rate, seeding method, and special problems or processing techniques related to seed production potential.

Species	Seeding rate[1] lb/acre	Suggested seeding method[2]	Special problems or processing techniques
Kentucky bluegrass	0.5-2.0	CC/DS	seed must be debearded
Smooth bromegrass	4.5-6.0	CC/DS	no problems
Reed canarygrass	2.0-4.0	CC/DS	seed shatters at maturity
Timothy	1.0-3.0	CC/DS	no problems
Orchardgrass	3.0-5.0	CC/DS	winterhardiness problems
Perennial ryegrass	4.5-6.0	CC	winterhardiness problems
Tall fescue	4.5-6.0	DS	winterhardiness problems
Fine-leaved fescues	2.5-5.0	CC/DS	natural tolerance to sethoxydim (Poast)

[1]Use higher rates within seeding rate range for broadcast seedings, lower rates within rate range for wide row spacings.
[2]CC=establish with companion crop; DS=direct seeding.

D. Fertility and Lime Requirements:

Prior to establishing the grass seed production field, soil test the field to determine fertility levels. It is necessary to maintain adequate levels of P and K according to soil test. Soils should be limed to a minimum soil pH of 5.5. If soil tests or past cropping history indicate a low level of N, apply 10 to 15 lb/acre N prior to planting or in a band when planting. At the 2 to 3 leaf stage, application of an additional 20 to 30 lb/acre N may be necessary. High rates of nitrogen are not recommended because the new grass seedlings are less able to utilize the nitrogen than the competing weed species. On organic soils, no additional N is necessary at establishment.

Cool-season grasses require fertilization to maximize seed yields. Nitrogen fertilization is critical to performance and seed yield of cool-season grasses. On established fields, fall application of nitrogen is recommended in most areas for a number of reasons. Cool-season grasses initiate seed heads in the fall of the year. Proper nutrition will promote seed head development producing higher yields in the succeeding production year. In addition, cool-season grasses often initiate growth early in the spring before fertilizer applications can be made. Fall fertilization also helps distribute the work load on the farm. Fertilizer requirements will vary with the grass species and variety under production. On mineral soils, 75 to 125 lb/acre N are required for optimum seed production. On organic soils, lower rates of N are generally required for seed production, usually 20 to 40 lb/acre N. Previous experience with organic soils is invaluable when deciding on nitrogen fertility rates. Limited research and experience in Minnesota on sandy soils receiving irrigation suggests that split applications of nitrogen may be necessary to obtain optimum growth and seed production. On established seed production stands, there is no experimental evidence showing that seed yields can be increased profitably in northern Minnesota by fertilizing with sulfur or other micronutrients. Boron levels should be monitored carefully however, as B is particularly important for seed production.

E. Variety Selection:

The seed producer should set a goal of optimizing production. The important first step is to select a grass species which is well adapted to the environment, especially the soil type, winterhardiness requirements and moisture conditions. In addition, be sure to consider establishment and production costs; potential yields; seed harvesting, cleaning and conditioning needs; market potential and contract availability. Many different cool-season grasses are adapted to Minnesota and Wisconsin, but potential seed yields and marketability of the seed crops differ significantly. Variety selection is critical if the producer is to profit as a seed grower.

F. Weed Control:

1. Mechanical: Weed control while establishing seed production fields is critical to obtain a high yielding stand. There are three mechanical options available for controlling weeds in newly seeded fields. Cultivation is applicable only when the seed production field was established in rows. Cultivate when the weed seedlings are small. Shallow cultivation is recommended to prevent damage to the newly seeded grass roots. Be careful to avoid soil ridging when cultivating because it will make harvesting difficult. It may be necessary to cultivate three to five times to control annual grasses and broadleaf weeds. Cultivation in an established stand can help control seedling volunteer grasses and help prevent the stand from becoming sod-bound. Cultivation should be shallow, 1.0 to 1.5 in. to prevent damage to the feeder roots in the established stand.

The second mechanical weed control option is mowing to control annual weeds. Mowing is an excellent option and provides good weed control when done in a timely manner. Mowing also promotes newly seeded grass plants to tiller and produce sturdier plants. Both mowing and cultivation are economical and environmentally sound options for many producers concerned about minimizing chemical inputs.

The last mechanical option open to the producer is hand roguing the field. This option is viable if the seed production field has small areas of high perennial weed infestations. The grower would be advised to rogue out those areas of the field with herbicides or hand labor to prevent weed seed contamination in the seed harvested in succeeding years.

2. Chemical: There are a few herbicide options for controlling grassy weed species in new and established grass seed production fields. The choice of herbicides is limited and depends upon the grass species seeded, the weed species and the presence of a companion crop.

In established stands, herbicides such as 2,4-D or dicamba (Banvel) can be used to control broadleaf weeds. Apply herbicides according to label recommendations. Generally herbicides should be applied in the fall to prevent potential seed yield losses. Check with your county agricultural extension agent or crop consultant for labeled herbicides to control the weed species in the field.

G. Diseases and Their Control:

Few economically important diseases limit seed production in the north central states. Powdery mildew is the most important disease on Kentucky bluegrass which can cause severe seed yield depression in the north central states. Kentucky bluegrass varieties differ in their level of resistance to powdery mildew. Kentucky bluegrass stand age also influences the incidence and severity of the disease with first year seed production fields suffering the most severe infections. Other foliar diseases of grasses generally do not limit seed production because the symptoms of the diseases such as leaf rust do not appear until later in the growing season on the vegetative regrowth after the seed has been harvested. Smut and ergot diseases have limited production of some cultivars in the west and could do the same in the Upper Midwest.

H. Insects and Other Predators and Their Control:

Insects are usually not a problem in the production of grass seed. However, the capsus bug causes silvertop on all varieties of Kentucky bluegrass and is the major insect pest in grass seed fields in Minnesota. The insect emerges and matures at the same time as the panicles of Kentucky bluegrass. The capsus bug punctures the culm to lay its eggs causing the upper portion of the culm and panicle to die resulting in the silvery appearance of the panicle. The eggs overwinter in the culm and hatch the following year to produce the next generation. Control of the capsus bug is most effectively and economically achieved by burning the field in July. If open field burning is not permitted or the field burned poorly, labeled insecticides can be applied when symptoms of silvertop first appear. Under extreme infestations and favorable conditions, a second application of insecticide may be necessary.

The bromegrass seed midge has been identified in areas of smooth bromegrass seed production, primarily in Nebraska and other midwestern states. To date, the only known host of the midge is smooth bromegrass, and the damage can be devastating to smooth bromegrass seed production. If insects such as the bromegrass seed midge, thrips or grasshoppers are found in economically significant numbers in the grass seed production field, the field should be treated with an appropriate insecticide. Consult your local county extension office for appropriate recommendations to control specific insect problems.

I. Harvesting:

1. Time of Harvest: Grasses generally do not mature uniformly. Seed ripening begins at the panicle tip and moves downward. The recommended stage of harvest is at the medium to hard dough stage. This is the stage where moderate to hard pressure with a thumbnail will make a mark on the seed. There often needs to be a compromise between maturity and shattering losses when making the decision to harvest to maximize yield.

2. Method of Harvesting: There are three methods of harvesting grass seed: direct combining, swathing and combining, and seed stripping. The advantages of direct combining are the seed is more mature when harvested and less time and labor are required for harvest. However, the disadvantages of direct combining a crop are the seed moisture content is high requiring the seed to be dried down prior to storage; the crop is more vulnerable to weather because it stands longer in the field; the combining is slower because more green material is run through the combine; and the quality and germination of the seed may be reduced. Swathing and combining the field is the most common method of harvesting grass seed. Swathing and combining has the advantages of faster combining of the field-cured foliage; earlier harvesting because seed cures in the windrow; less seed loss through shattering; and the harvested seed is usually dry and safe to store directly. The disadvantages to swathing and combining are swaths may be scattered or lost by high winds; rains may delay combining causing substantial shattering and potentially lowering seed quality; and more weed seed contamination will be in the grass seed. Seed stripping methods are generally not used with cool-season grasses. The best use of seed strippers is with native prairie grasses. Seed strippers generally produce higher yields and seed quality with less chaff in the seed. Only mature seed is harvested leaving immature seed for a second harvest. The disadvantages are increased harvest and machinery costs, often more soil compaction from the machinery on the field, and high seed moisture content at harvest requiring drying before storage.

For direct combining or swathing and combining harvest methods, a standard grain combine properly adjusted will do an excellent job of harvesting grass seed. The air intake should be adjusted based on seed weight. For light, chaffy seeds, shut down the air allowing only a small amount through the combine. For heavier seeds, slightly increase the air through the combine. The cylinder speed should run about 5000 ft per minute [ft per minute = rpm × cylinder diameter (ft) × 3.14]. The cylinder spacing should be based on seed size. For most grasses, use a 1/4 in. conclave clearance but for small-seeded grasses such as Kentucky bluegrass, a 1/8 in. conclave clearance is recommended. Make sure the sieves are properly adjusted. If direct combining, adjust the sickle position to cut at least 90% of the panicles while avoiding most of the green foliage. Check the tailings and material from the grain spout often for cleanliness and damage during combining.

3. Residue Management: Crop residue should be removed following seed harvest to maintain high seed yields. Residue management is critical for maintaining high seed production because sunlight penetration to the crown is critical to grass plants recovering from harvest. For cool-season grasses, three methods are available for removing the residue. The residue can be clipped, raked and baled. Forage quality and feeding value of the residue is low, however it may be satisfactory feed for dry dairy or beef cows. The residue may be burned if burning is allowed by local regulations. If you do bum the residue, be careful to burn on a day when the winds are light so the smoke will rise from the field and not drift into neighboring communities or across highways causing a safety hazard. The residue may also be removed by grazing the seed production field. This practice is risky because grazing does not provide a uniform removal of the residue and livestock may graze the higher quality new growth selectively damaging the stand.

J. Drying and Storage:

Condition the grass seed at a properly equipped processing plant to remove damaged seed, contaminants, and other field trash. Because of the seed size of many grasses, specialized equipment is necessary to clean seed properly. Major marketing decisions should have been made prior to field establishment. It is desirable to have contract arrangements for your seed guaranteeing the marketability of the variety produced.

VI. Yield Potential and Performance Result:

The yield potential of cool-season grasses is dependent upon a number of different factors. The producer should make an informed decision about the species and variety to produce. After choosing a well adapted and high yielding variety, climatic conditions can greatly influence seed yield with moisture being the limiting factor in most north central states. Table 2 contains some performance data on selected cool-season grass species and varieties tested in Roseau, MN between 1980 and 1989. In Wisconsin trials conducted in 1986 and 1987, yields of named smooth bromegrass cultivars ranged from 122 to 575 lb/acre in tests at three locations.

VII. Economics of Production and Markets:

The decision to produce forage and turf grass seed requires a commitment of time and a dedication to quality production. It offers an opportunity for producers to develop a profitable alternative cropping system. Many factors should be considered by the producer before entering into grass seed production. Grass seed production is a long term cropping system and may require more than two years before a seed crop is harvested and profits are realized by the producer. Unlike many annual crops, the value of the seed is dependent upon the market value of the variety produced and usually requires the grower to have a production contract with a seed processor or distributor to insure profit potential.

There are many advantages to producing perennial grasses for seed production. There are no yearly planting costs as with annual crops. No yearly tillage operations are required reducing soil erosion potential after the grasses are established. Chemical and fertilizer inputs are often less than with other commodity crops. Perennial grasses improve the soil texture leading to better moisture penetration. Cool-season grass seed production spreads the work load out more evenly on the farm. Cool-season grass seed production can be an excellent alternative for producers interested in diversification on their farm.

Table 2: Yield performance of selected cool-season grasses evaluated in Roseau, MN from 1980 to 1989.

	Seed yield		No. of years[1]
	Mean (lbs/acre)	Range (lbs/acre)	
Kentucky bluegrass:			
Aquila	240	24-538	12
Park	366	104-647	17
Rugby	271	98-671	17
Timothy:			
Climax	397	127-579	21
Goliath	387	123-760	18
Heidemij	304	30-529	21
Fine Fescues:			
Jamestown	412	128-707	8
Permlawn	417	98-998	10
Reed canarygrass:			
Palaton	502	202-820	13
Rise	332	98-570	13
Smooth bromegrass:			
Barton	491	149-858	8
Baylor	610	199-1096	5
Perennial ryegrass:[2]			
NK-200	819	555-1212	6
Delray	499	343-629	5
Orchardgrass[3]:			
Crown	183	0-722	7
Hawk	289	0-858	7

[1]Number of years used to determine the mean and range in seed yield values from seed production variety trials established in Roseau, MN.

[2]Perennial ryegrass behaves as a biennial in northern Minnesota producing only one seed crop.
[3]Crown was not harvested 3 of the 7 years and Hawk was not harvested 2 of the 7 years because of severe winter injury.

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Crambe

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[3]Center for Alternative Plant and Animal Products, University of Minnesota, St. Paul, MN 55108. July, 1991.

I. History:

Crambe (*Crambe abyssinica* Hochst.) is believed to be a native of the Mediterranean area. The oilseed crop contains an inedible oil used for industrial products. It has been grown in tropical and subtropical Africa, the Near East, Central and West Asia, Europe, United States, and South America. It was first used as a crop in 1933 at the Boronez Botanical Station, U.S.S.R., and has been a part of a Swedish breeding program since 1949.

Crambe was introduced to the U.S.A. by the Connecticut Agricultural Experiment Station in the 1940s. Evaluations for strains of the crop began in Texas in 1958. Crambe has since been successfully grown in several areas of the United States.

II. Uses:

The oil extracted from crambe seed is used as an industrial lubricant, a corrosion inhibitor, and as an ingredient in the manufacture of synthetic rubber. The oil contains 50 to 60% erucic acid, a long chain fatty acid, which is used in the manufacture of plastic films, plasticizers, nylon, adhesives, and electrical insulation.

Crambe is being promoted as a new domestic source of erucic acid, which has primarily come from imported rapeseed oil. Supplies of industrial rapeseed are less-plentiful since the development of varieties (Canola) that have no erucic acid content. The United States uses up to 40 million pounds of high-erucic acid oil annually mostly imported from Poland and Canada. Although rapeseed is grown domestically, crambe oil contains 8 to 9% more erucic acid than industrial rapeseed oil, and the crop is better suited to the higher rainfall areas of the U.S.

Defatted crambe seed meal can be used as a protein supplement in livestock feeds. The meal contains 25 to 35% protein when the pod is included and 46 to 58% protein when the pod is removed. It has a well balanced amino acid content and has been approved by the FDA for use in beef cattle rations for up to 5% of the daily intake.

The meal has not been approved for nonruminant rations because it may contain glucosinolates, which may be broken down in digestive systems to form harmful products that can cause liver and kidney damage, and appetite depression. Untreated, oil-free crambe meal may contain up to 10% thioglucosides, which are toxic to nonruminant animals, such as hogs and chickens. However, subjecting whole seed to moist heat before processing can deactivate the enzyme, and the glucosinolates remain intact through the oil extraction process.

III. Growth Habits:

Crambe, which is closely related to rapeseed and mustard, is an erect annual herb with numerous branches that grows to a height of 24 to 40 in. Under stress conditions plants may develop long tap roots, which later become conical. The leaves are oval shaped, but asymmetric. The leaf blade is approximately 4 in. long and 3 in. wide, with a smooth surface; the petiole is channeled, about 8 in. long, and pubescent (hairy). Crambe initially produces numerous small, white flowers in a compact group, which are later distributed on 1 to 2 ft stalks or spikes. The spherical fruits bear one seed each. The seed remains in the pod or hull at harvest. Mature fruits are dry, persistent and indehiscent. They vary in color from light green to light brown. Crambe seeds weigh approximately 0.25 oz/1,000 seeds and have a hull content of 25 to 30%.

IV. Environment Requirements:

A. Climate:

Crambe is widely adapted and can be grown as a spring crop in the Midwest, Pacific Northwest, and Southwest of the U.S.A. This oilseed crop is a cool season one and can tolerate temperatures as low as 24°F. The crop requires 90 to 100 days from planting to maturity. Although it is relatively drought-tolerant, the best yields have been obtained in moist areas. While crambe requires adequate soil moisture during pod set and filling, a subsequent dry period as the plant matures promotes high yields.

B. Soil:

Well-drained, fertile soils of moderately coarse to fine texture with a pH of 6.0 to 7.0 or slightly higher, are best suited for crambe production. The crop will not tolerate heavy clay, wet or waterlogged soils.

C. Seed Preparation and Germination:

For highest yields, certified seed should be used that is free of viruses. Seed can be treated with a fungicide or soaked in water at 140°F for 20 minutes or at 130°F for 30 minutes to reduce problems with *Alternaria brassicicola*.

V. Cultural Practices:

Machinery used for tillage, planting, spraying, and harvesting crambe is similar to that used for small grains. Farmers producing small grains would not have to purchase additional machinery to produce crambe.

A. Seedbed Preparation:

The soil should be plowed or disked and then worked with a cultipacker and heavy drag. Smoothing and packing are usually essential to provide a smooth, firm seedbed and to ensure seed placement at a uniform depth. Soybean-stubble fields have been disked and smoothed for planting with satisfactory results. When growing crambe following wheat or barley, the straw should be removed or a chopper used on the combine at harvest. A seedbed can then be prepared by disking the wheat stubble. This method will help conserve soil moisture after wheat.

B. Seeding Date:

Crambe can be planted as soon as the threat of temperatures below 24°F has passed—mid to late April in Wisconsin and Southern Minnesota and late April to early May in northern areas of these states.

C. Method and Rate of Seeding:

Crambe can be solid-seeded or planted in rows, depending on the equipment available. For solid seeding, a small grain drill or cultipacker seeder may be used. Since solid-seeded crambe cannot be cultivated, it should be grown in fields where weeds are not a problem.

When crambe is planted in 20 to 30 in. rows, a corn planter fitted with corn or soybean plates can be used. Planting in rows will result in more uniform emergence, less loss due to soil crusting, and lower seed cost. In addition, narrow rows promote reduced branching and more uniform maturity. Acceptable yields have been recorded for row widths ranging from 6 to 36 in. However, where weeds are not a serious problem, row widths of 6 to 12 in. give highest yields. Crambe planted in rows wider than 30 in. will tend to lodge, making harvest difficult.

Planting depth is a critical factor in obtaining good crambe yields. Seed should be planted 1/4 in. deep in humid regions and up to 1 in. deep in drier areas. A cultipacker seeder does an excellent job of placing the seed at the appropriate depth. A seeding rate of 10 to 20 lb/acre is recommended.

D. Fertility and Lime Requirements:

Phosphorus and potassium recommendations for small grains are usually adequate for crambe also. For soils showing an option test in phosphorus and potassium, approximately 45 lb/acre of P_2O_5 and 80 lb/acre of K_2O are recommended. Crambe also responds to nitrogen fertilizer with approximately 80 to 100 lb/acre of actual N recommended. Credits for legume or manure N should be taken when appropriate. Like rapeseed, crambe may respond to sulfur (20 to 25 lb/acre) on low sulfur soils.

E. Variety Selection:

The number of crambe varieties available for commercial production is limited. Meyer is the only variety available in sufficient quantity for field production. Belann, Belenzian, Indy, and Prophet are other registered varieties; however, commercial seed supplies of these varieties do not exist. Three varieties of crambe were tested at four locations in North Dakota in 1990 (Table 1). Seed yields, as well as other agronomic characters for crambe were evaluated in Minnesota during 1960 to 1974 (Table 2).

Table 1. Relative yield performance of crambe varieties at Carrington, North Dakota, 1988-90.

Variety	1988-90 lb/acre	1990 lb/acre
Belann	2175.3	1487.3
Belenzian	2008.0	1429.6
Meyer	1726.2	1353.

Source: Crop Production Guide 1991. North Dakota State University Extension Service, Fargo, ND 58105.

Table 2. Summary of crambe performance data from Rosemount, MN, 1960-1974[1].

Variety	Year(s)	Maturity date	Height (in.)	Lodging[2]	Seed weight (g/1000 seeds)	Bushel weight (lb/bu)	Oil content %	Yield (lb/acre)
unknown	1960-62	8-8	46	5.1	5.9	24.0	35.3	1,499
MN24427	1963	8-2	44	4.7	5.8	23.6	28.7	950
Indy	1967	7-27	39	2.0	6.4	25.5	27.8	1,334
MN24427	1967	8-7	41	5.7	7.9	23.3	32.0	1,214
Crookston 65	1973	7-28	37	3.0	6.7	21.0	31.5	1,632
Prophet	1973	7-25	38	2.4	7.0	22.4	32.0	1,960

Indy	1973	7-20	33	1.7	5.7	24.1	29.7	936
Meyer	1973	7-20	34	3.0	7.0	22.7	30.8	1,825
Meyer	1974	7-25	41	1.3	---	23.8	30.8	1,446

[1]Source: R. G. Robinson and D. H. Putnam, Dept. of Agronomy and Plant Genetics, University of Minnesota, St. Paul, MN.
[2]1 = erect, 9 = flat.

F. Weed Control:

Weed competition can reduce crambe yields significantly. Some of the weeds that may cause difficulties are pigweed, foxtail, smartweed, lambsquarter, ragweed, and kochia.

A uniform, thick stand of crambe is an effective means of weed control. Early planting also increases crambe's ability to compete with weeds, which require a higher soil temperature for germination. However, as crambe approaches maturity, weeds may emerge through the crop canopy, posing problems with harvest and increasing the moisture of harvested crambe seed. Crambe planted in 20 to 30 in. rows can be cultivated to control weeds.

No herbicides have been registered for use on crambe in the U.S. Crambe is very susceptible to injury from 2,4-D drift and the residual effects of atrazine.

G. Diseases and Their Control:

The most serious disease in crambe is caused by *Alternaria brassicicola*. This fungus causes darkening of the seed and stems, and reduces seed germination. Crambe is also susceptible to turnip mosaic virus. Use of high-quality seed is the best defense against disease problems. The seed can also be treated with a fungicide or hot water (as described in the section on seed preparation) prior to planting.

H. Insects and Other Predators and Their Control:

Crambe seedlings may be attacked by flea beetles and aphids. At the present time there are no insecticides labeled for insect control. If insecticides were available, insect control should be avoided during bloom because of the beneficial value of pollinators.

I. Harvesting:

As crambe approaches maturity, the leaves turn yellow and drop from the plant. A few days after the last leaves have fallen, the seed pods and small branches turn a straw color. When this color has progressed down the stems below the last seed-bearing branches—generally 90 to 100 days after planting—the seed should be ready to harvest. Crambe is susceptible to seed shatter and a higher risk of *Alternaria brassicicola* infection if harvest is delayed until all the seeds change color.

Crambe can be harvested with a standard combine with adjustable sieves. If the plants are standing, they should be cut 12 to 18 in. above the soil surface. The seed should be harvested with the hulls intact. A cylinder speed of 400 to 500 RPM and concave clearance of 3/8 in. are recommended. The air should be set as low as possible with fan speed at less than 500 RPM, but never disconnect the fan to completely shut off the air flow. Set the reel to move only slightly faster than the ground speed of the combine to minimize shattering. Crambe seed is small, round, and very lightweight. To prevent losses, a transport vehicle with no cracks or holes should be used, and the load should be completely covered with a tarp.

J. Drying and Storage:

Crambe should be dried to no more than 10% moisture before storage. Before storing the seed, it should be passed over a scalper to remove trash. Store crambe in clean, insect-free bins with perforated floors and a fan. A corn storage bin is suitable for crambe.

Even if the crambe seed is dry at harvest, it may contain green plant parts from weeds and grass, as well as insect parts. This wet trash can cause the seed to heat in a short time. To prevent heating, aerate the seed as soon as the bin floor is covered with 2 to 3 ft of seed. Use a minimum air flow of 0.1 cfm per bushel. Continue aeration until the moisture and temperature of the seed have reached equilibrium throughout the bin.

The fan may also be used to continue drying the seed in the bin. Bin- drying with unheated air requires a minimum air flow of 1 cfm per bushel and should not be attempted if the moisture level in the seed exceeds 20%. Seed depth in the bin should be limited to 16 ft. Heat-sensing equipment can help detect hot spots within the grain mass.

VI. Yield Potential and Performance Results:

Crambe has yielded up to 2,500 lb/acre on small commercial fields and demonstration plots. A yield of 1,200 to 1,800 lb/acre is more typical in commercial production fields with good management practices.

VII. Economics of Production and Markets:

Production costs for crambe in the Midwest are approximately the same as those for wheat, except for the higher cost of crambe seed, since the same equipment and methods are used. In 1990, crambe yielding 1,500 lb/acre in the Midwest cost almost $0.10/lb to produce. Crambe production would not compete directly with domestic seed oils since it would provide a substitute for erucic acid extracted from imported rapeseed. There is no broad commercial outlet for crambe seed, and growers are advised to identify a market before planting. Crambe seed meal has little market value, but can be useful in livestock feed. Finding additional uses for crambe meal will enhance the value of the seed.

VIII. Information Sources

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Ginseng

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I. History:

American ginseng (*Panax quinquefolius*, L.) is a perennial herb native to the deciduous forests of the eastern United States. Wild ginseng once thrived along most of the nation's eastern seaboard, from Maine to Alabama and west to Michigan, Wisconsin and Minnesota. It still grows wild, but it was over-harvested in the mid-1970s and was subsequently defined as an endangered species. Currently, 18 states issue licenses to export it. In Wisconsin and several other states where ginseng is cultivated, a permit is not required to export artificially propagated ginseng.

Ginseng was one of the earliest marketable herbs to be harvested in this country. Wild ginseng was one of Minnesota's first major exports. In 1860, more than 120 tons of dried ginseng roots were shipped from the state to China. American ginseng is similar to Asian ginseng, *Panax ginseng*, L., which grows wild in Northern Manchuria and has been harvested there for thousands of years.

Ginseng is prized in the Orient for its purported curative properties. Based on an ancient Chinese legend, early emperors proclaimed it a panacea to be ingested or used in lotions and soaps. The genus name, *Panax*, is derived from the Greek "panakeia," which means universal remedy. The term "ginseng" is derived from the Chinese term "jen-shen," which means "in the image of a man." Ginseng roots shaped like the human body are considered highly desirable. In particular, old roots (some may be nearly a century old) are prized because their longevity is claimed to be transferred to the person who consumes them.

Ginseng root is reputed to lower blood sugar and cholesterol levels, protect against stress, enhance strength and promote relaxation. Koreans have fed ginseng to race horses to enhance their performance on the track. Although some European and Asian studies appear to support some of these claims, American researchers remain skeptical. Ginseng is not a drug and should not be taken as such. It is classified by the Food and Drug Administration (FDA) as a "generally recognized safe food" (GRAS).

Ginseng became a domesticated crop in the late 1800s. Attempts to produce the crop in Wisconsin in the late 1870s failed due to disease. In 1904, the four Fromm brothers from the Wisconsin township of Hamburg, near Wausau, transplanted 100 wild ginseng plants from nearby forests onto a plot of their land and carefully duplicated the natural growth conditions. The perseverance of these early ginseng growers and the ideal growth conditions in Marathon County have made it the ginseng capital of the United States, producing approximately 10% of the world's supply of ginseng root. More than 90% of the cultivated ginseng grown in the United States is grown in Wisconsin, and 90 to 95% of Wisconsin-grown ginseng is produced in Marathon County.

It is estimated that Wisconsin grew 3,000 to 5,000 acres of ginseng in 1990, and sales of the root earned almost $70 million for farmers in Marathon County. Most of Wisconsin's ginseng growers cultivate no more than one acre of the crop annually. Most of the nation's ginseng crop is exported to Hong Kong, where it enters duty-free. Much is then redistributed to other locations in the Far East.

Ginseng can be a profitable crop, but it requires an enormous commitment of time, money and labor for successful commercial production. Ginseng beds in Wisconsin are usually cultivated for three years before harvest, unless disease problems mandate earlier harvest.

II. Uses:

In the Far East, ginseng root is used in toothpaste, soft drinks, tea, candy, chewing gum and cigarettes. It also appears on the market as crystals, extract, powder capsules and is sold as the whole root. In the United States, ginseng and ginseng products are marketed in Asian food and health food stores. Most of the ginseng used in the United States, however, is imported from Korea. The amount of Asian ginseng that is imported is about equal to the amount of higher-priced American ginseng that is exported.

Ginseng seed is also marketed. Ginseng plants generally begin to produce harvestable seed in the third year of growth. It takes approximately 200 plants to produce 1 lb of seed, which may produce 5,000 seedlings.

III. Growth Habits:

American ginseng plants are generally started from seeds. Seedlings or roots for transplanting are available commercially, but are used infrequently. Seeds are planted in the fall and germinate in the spring. Although researchers have examined ways to break this juvenility requirement and hasten germination, it is still not understood.

First-year seedlings produce one compound leaf with three leaflets. This leaf, 1 to 2 in. in height and spread, is the only above-ground growth in the first year. Underground, the plant develops a thickened root about 1 in. long and up to 1/4 in. wide. At the top of the root, a small rhizome or "neck" develops with a regeneration bud at the apex of the rhizome. In autumn, the leaf drops, and a stem supporting new leaves emerges from the regeneration bud the following spring.

The plant develops more leaves, with more leaflets, each year until the fourth or fifth year. A mature plant is 12 to 24 in. tall and has 3 or more leaves, each consisting of 5 ovate leaflets. Leaflets are approximately 5 in. long and oval-shaped with serrated edges. In midsummer, the plant produces inconspicuous greenish-yellow clustered flowers. The mature fruit is a pea-sized crimson berry, generally containing 2 wrinkled seeds.

After three years of growth, the roots begin to attain a marketable size (3 to 8 in. long by 1/4 to 1 in. thick) and weight (1 oz). In older plants, the root is usually forked. Wild or high-quality cultivated ginseng root has prominent circular ridges. Highest quality mature root breaks with a somewhat soft and waxy fracture. Young or undersized roots dry hard and glassy and are less marketable.

IV. Environment Requirements:

A. Climate:

Ginseng grows best under conditions that simulate its natural habitat. It requires 70% to 90% natural or artificial shade. Ginseng thrives in a climate with 40 to 50 in. of annual precipitation and an average temperature of 50°F. It requires several weeks of cold temperatures for adequate dormancy.

B. Soil:

Ginseng generally prefers a loamy, deep (12 in.), well-drained soil with a high organic content and a pH near 5.5. Extremely sandy soil tends to produce long, slender roots of inferior quality.

C. Seed Preparation and Germination:

Most ginseng crops are started from seed, rather than roots or seedlings. This is the least expensive way to start a plantation and may help prevent the introduction of soil-borne disease to new plantations. Ginseng requires 3 to 5 years to produce a marketable crop from seed.

As there is an 18 month seed dormancy, freshly harvested seed cannot be used for starting a crop. It must be stratified for 18 to 22 months before planting. Seed stratification involves soaking the seed in a formaldehyde solution and in a fungicide, then burying the seed outdoors in moist sand. Most seed is already stratified when it is purchased and needs only to be treated with a fungicide and sown. Seed should not be allowed to dry out before or after seeding. (For detailed instructions on seed stratification, see "American Ginseng Culture in the Arid Climates of British Columbia" by Oliver, Van Lierop and Buonassisi).

V. Cultural Practices:

A. Seedbed Preparation:

For planting seeds or seedlings, till the soil to a depth of 8 to 10 in., and remove rocks. For root planting, work the beds 12 in. deep. For best results, mix soil 1 to 1 with fiber-free woodland soil. Make beds 4 ft wide with alleys between them for walkways and for farm equipment. If the bed is on flat ground, mound the center to facilitate good runoff. Slope the walkways so they will drain water from the beds during heavy rains.

Shade can be provided by wooden lath sheds or polypropylene fabric. Artificial shade should be placed about 7 ft above the ground to ensure good air circulation. Do not use burlap or muslin, which can interfere with air circulation. (For more detailed instructions on how to provide artificial shade, see "American Ginseng Culture in the Arid Climates of British Columbia" by Oliver, Van Lierop and Buonassisi).

B. Seeding Date:

Ginseng seed is generally planted in the fall and covered with mulch until spring. It can also be spring-planted, but if seeding is not completed by May 1, the seed may begin to sprout prematurely.

Roots can be transplanted any time after the tops of the plants have begun to die back but before the ground has frozen.

C. Method and Rate of Seeding:

Plant seedlings 1/8 to 1/2 in. deep and 4 in. apart in the row. Space the rows 6 in. apart across the bed. The recommended seeding rate for a 4 ft wide bed with 2 ft wide paths between beds is 80 to 100 lb/acre. To keep the seed from drying out, the beds should be covered immediately with 2 to 3 in. of straw.

Plant roots at a 30° to 45° angle from the vertical, with the crown of the root 3/4 to 1 in. deep. Cover the bed immediately with 1 to 2 in. of straw. A 4 to 5 in. layer of mulch is necessary on fall transplants to prevent heaving in frost. Some of the mulch can be removed in the spring before the first shoots appear.

Set seedlings 8 in. apart in each direction. Closer spacing tends to increase disease in the plantation.

Light mulching (1 to 2 in. thick) to retain moisture during dry weather is advisable.

D. Fertility and Lime Requirements:

Heavy use of manure or commercial fertilizers lessens the resemblance of cultivated ginseng to the wild root and hence may reduce marketability. Over-manuring may also force growth and lower disease resistance. Although little research in ginseng fertility has been conducted, common practice has been to fertilize as for other root crops. Recommended rates are about 15 lb P_2O_5/acre and 60 lb K_2O/acre for soils testing in the optimum range for vegetables (30 to 45 ppm Bray P1 and 140 to 200 ppm soil test K).

Nitrogen needs range from 20 to 60 lb/acre, depending on soil organic matter level. (However, some growers have been known to use considerably more.) Growers have tended to use lower-salt fertilizers, such as ammonium sulfate, potassium sulfate and potassium-magnesium sulfate. Although secondary and/or micronutrients are often involved in fertilization programs, little research has been conducted to confirm responsiveness.

Some growers fertilize with leaves or old hardwood sawdust or with ground-up rotted hardwood. Others prefer woodland soil or rotted leaves 4 to 6 in. deep, spaded to a depth of about 8 in. with fine raw bonemeal (1 lb/sq. yd.) worked in.

Fertilizers should be applied during the dormant season at least a couple of weeks before plants emerge.

E. Variety Selection:

Although no improved varieties have been developed, American ginseng shows variations in certain characteristics, particularly in the roots. Plants from the northern part of the country, particularly Wisconsin and New York, are considered good breeding stock, because they furnish roots of good size, weight and shape.

F. Weed Control:

Weeds can be controlled mechanically with mulching and hand weeding and chemically with Fusilade 2000. See Table 1 for instructions on herbicide use.

Table 1. Pesticides Labeled for nationwide use on cultivated ginseng as of November 1, 1991.

Use only approved materials...Follow label directions!

Pest	Materials	Treatments(s)	Restrictions/Comments
ALTERNARIA Left and Stem Blight	Tankmix ROVRAL 50W or ROVRAL 4F (Rhone-Poulenc)	2 lbs/acre	Best if applied 8 hours before rain. DO NOT apply ROVRAL within 36 days of harvest.

	CHAMPION WETTABLE POWDER hydroxide (Agtrol Chemical)	2.6 lbs/acre in min. 100 ga/acre	Also available as FLOWABLE CHAMP. Tankmix 3.5 pts/acre 2 lb ROVRAL 50W EPA REG NO: 55146-1
PHYTOPHTHORA Root Rot and/or Foliar Phytophthora	No materials labeled for use on ginseng nationwide		
INSECTS			
(Soil)	DIAZINON 14G (Ciba-Geigy)	14-28 lbs/acre pre-plant and incorporate to 4-8" depth 21 lbs/acre broadcast over beds (Spring or Summer or Fall)	1 pre-plant & 1 broadcast treatment/year in 1st and 2nd seasons only. Recommended broadcast just before rain. DO NOT apply within 1 year of harvest. EPA REG NO: 100-46g
(Above Ground)	PYREZONE CROP SPRAY (Fairfield American)	Up to 12 oz/acre	A broad spectrum contact spray. EPA REG NO: 4816-490
	DIAZINON AG 500 (Ciba-Geigy)	0.75 to 1 pt/acre	No more than 1 application/year. DO NOT apply during flowering on 3 and 4 year old plants. EPA REG NO: 100-461
SLUGS	DEADLINE BULLETS (Pace National)	20-40 lbs/acre Apply at 3-4 week intervals as needed	Follow all label instructions for storage, application, and disposal of this product. EPA REG NO: 8501-34
WEED CONTROL	FUSILADE 2000 (ICI Americas)	1 qt Fusilade 2000/acre plus 1% crop oil (e.g., 1 gal/100 gal), or 0.25% surfactant(e.g., 1 qt/100 gal)	Apply when grasses are 2-8" tall; before tilling or heading. Direct spray away from ginseng foliage. DO NOT apply within 1 year of harvest. EPA REG NO: 10182-104

All recommendations are in terms of product per acre (not a.i. - active ingredient).
Compiled by Jennifer Parke and Brian Hudelson, University of Wisconsin-Madison

G. Diseases and Their Control:

Ginseng is susceptible to a number of fungal diseases, including Alternaria leaf and stem blight, Phytophthora root rot and foliar blight, seedling damping-off caused by *Pythium* and *Rhizoctonia*, rusty root and root knot nematode. Ginseng gardens that are cultivated in the woods may suffer less from diseases than do plantings under artificial shade.

To minimize disease problems, select a growing site with good drainage. Good air circulation is also crucial and can be attained by providing cleared areas (walkways) around the beds, relatively uncrowded spacing and control of weeds. Thin spacing also reduces the likelihood of disease spread through foliar or root contact. Wisconsin growers generally do not reuse a ginseng field for succeeding ginseng crops.

Table 1 shows pesticides labelled for nationwide use on ginseng. The University of Wisconsin has obtained approval from the Environmental Protection Agency (EPA) (Sec. 18 and Sec. 24) for several additional fungicides. Approval is granted for use in Wisconsin only, and use must be reported to the Wisconsin Department of Agriculture. Consult your local County Extension Agent each year to find out which pesticides may be applied to ginseng in your area.

H. Insects and Other Predators and Their Control:

Ginseng is sometimes attacked by white grubs and wireworms. Voles and field mice may feed on the roots. See Table 1 for recommended pesticides.

I. Harvesting:

In Wisconsin, most growers harvest ginseng the third year after planting from seed. The roots are dug in the fall and vigorously washed to remove surface soil. It is important to handle the roots carefully to keep the branching forks intact and maintain the natural color and circular markings.

J. Drying and Storage:

Ginseng roots are dried on wire-netting shelves in a heated, well-ventilated room. Since overheating destroys color and texture, begin drying the roots at a temperature between 60deg and 80°F for the first few days, then gradually increase it to about 90°F for three to six weeks. Turn the drying roots frequently. Store the roots in a dry, airy, rodent-proof container just above freezing.

VI. Yield Potential and Performance Results:

Yields of dried roots from a well-managed planting average about 1 ton/acre, although greater yields are often reported.

A typical seed yield is 150 to 250 lb/acre.

VII. Economics of Production and Markets:

Ginseng growers typically invest $20,000/acre and 600 hrs of labor annually and get no return on their investment until the third or fourth year. Seed and shading materials alone can cost more than $29,000/acre. It may take 10 years to break even. An average crop might net $30,000/acre, depending on the price, which tends to fluctuate widely from year to year. Prices for dried roots range from $20 to $45/lb. Seed sells for $50 to $100/lb.

In Wisconsin, growers are assessed $0.15/lb of dried root for promotion and research, and the funds are administered by the Ginseng Board of Wisconsin, located in Wausau, Wisconsin. There are several seed and root suppliers and ginseng buyers in Wisconsin. For information, contact the Ginseng Board of Wisconsin, or the Wisconsin Ginseng Growers Association both at 500 3rd St., Suite 208-2, Wausau, Wisconsin 54401 (tele 715-845- 7300).

VIII. Information Sources:

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Guar

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I. History:

Guar, or clusterbean, (*Cyamopsis tetragonoloba* (L.) Taub) is a drought-tolerant annual legume that was introduced into the United States from India in 1903. Commercial production of guar in the United States began in the early 1950s and has been concentrated in northern Texas and southwestern Oklahoma. The major world suppliers are India, Pakistan and the United States, with smaller acreages in Australia and Africa. In the early 1980s, Texas growers were planting about 100,000 acres annually. They harvested about half of the planted acreage and plowed the rest under as green manure.

Unlike the seeds of other legumes, the guar bean has a large endosperm. This spherical-shaped endosperm contains significant amounts of galactomannan gum (19 to 43% of the whole seed), which forms a viscous gel in cold water. Guar gum is the primary marketable product of the plant. India and Pakistan export much of their guar crop to the United States and other countries in the form of partially processed endosperm material. World demand for guar has increased in recent years, leading to crop introductions in several countries.

Like other legumes, guar is an excellent soil-building crop with respect to available nitrogen. Root nodules contain nitrogen-fixing bacteria, and crop residues, when plowed under, improve yields of succeeding crops.

II. Uses:

In Asia, guar beans are used as a vegetable for human consumption, and the crop is also grown for cattle feed and as a green manure crop. In the United States, highly refined guar gum is used as a stiffener in soft ice cream, a stabilizer for cheeses, instant puddings and whipped cream substitutes, and as a meat binder. Most of the crop in the United States, however, is grown for a lower grade of guar gum, which is used in cloth and paper manufacture, oil well drilling muds, explosives, ore flotation, and a host of other industrial applications.

Guar gum consists of long branching polymers of mannose and galactose in a 2:1 ratio. After extraction of the gum, guar meal contains approximately 35% protein, which is about 95% digestible. The seed protein is low in methionine, like most legumes. Enough gum remains in the meal to make it an excellent feed pelleting material. Toasting improves its palatability to livestock and helps remove a trypsin inhibitor for non-ruminants.

III. Growth Habits:

Guar is an upright, coarse-growing summer annual legume known for its drought resistance. Its deep tap roots reach moisture deep below the soil surface. Most of the improved varieties of guar have glabrous (smooth, not hairy) leaves, stems and pods. Plants have single stems, fine branching or basal branching (depending on the variety) and grow to be 18 to 40 in. tall. Racemes are distributed on the main stem and lateral branches. Pods are generally 1 1/2 to 4 in. long and contain 5 to 12 seeds each. Seeds vary from dull-white to pink to light gray or black and range from 900 to 1,600 seeds/oz.

IV. Environment Requirements:

A. Climate:

Guar tolerates high temperatures and dry conditions and is adapted to arid and semi-arid climates. Optimum temperature for root development is 77 to 95°F. When moisture is limited, the plant stops growing but doesn't die. While intermittent growth helps the plant survive drought, it also delays maturity. Growing season ranges from 60-90 days (determinate varieties) to 120-150 days (indeterminate varieties). Guar responds to irrigation during dry periods. It is grown without irrigation in areas with 10 to 40 in. of annual rainfall. Excessive rain or humidity after maturity causes the beans to turn black and shrivel, reducing their quality and marketability. While profitable seed production in southern U.S. areas of high rainfall and humidity is likely to be limited, guar can be successfully grown as a green manure crop under these conditions. Guar varieties that require a particular daylength to flower or day-neutral have been described. Considering these high soil temperatures and long growing season, successful guar production in Wisconsin and Minnesota is very unlikely.

B. Soil:

Guar grows well under a wide range of soil conditions. It performs best on fertile, medium-textured and sandy loam soils with good structure and well-drained subsoils. Guar is susceptible to waterlogging. Guar is considered to be tolerant of both soil salinity and alkalinity.

Guar is an excellent soil-improving crop and fits well in a crop-rotation program with grain sorghum, small grains or vegetables. In Australia, guar was found to add 196 lb N/acre to the soil-plant system over three years. Increased yields can be expected from crops following guar because of increased soil nitrogen reserves. When used in rotation with cotton in Texas, researchers measured a 15% yield increase in cotton.

C. Seed Preparation and Germination:

Select seed that is uniform in color and size and is free from other crop and weed seed. New guar varieties have been released that have some resistance to diseases that once devastated fields of the crop. To prevent disease problems, select certified seed that does not contain seed of older varieties with less disease resistance.

Seed should be inoculated just before planting with a special guar inoculant or the cowpea (Group "E") inoculant. Exposure of inoculum to sunlight, heat and drying before planting can impair the effectiveness of the nitrogen-fixing bacteria. Seed should be planted in moist soil within 2 hours after inoculation. Fungicidal seed treatments may inhibit inoculation.

V. Cultural Practices:

A. Seedbed Preparation:

The seedbed should be firm and weed-free. Soil in the row should be ridged slightly to facilitate harvest of low-set beans.

B. Seeding Date:

Guar should be planted when soil temperature is above 70°F; the optimum soil temperature for germination is 86°F. A warm seedbed, adequate soil moisture and warm growing weather are essential for establishment of a stand. In Texas, June plantings of guar produce more reproductive buds than July plantings, resulting in substantially higher yields. Thus, production of this crop in the Upper Midwest is unlikely.

C. Method and Rate of Seeding:

1. Method of Planting: Guar is usually planted in 36 to 40 in. rows with a row crop planter. However, it can be broadcast seeded or planted in narrower rows with a grain drill if moisture is adequate. A planting depth of 1 to 1 1/2 in. is usually recommended. If guar seed is crushed, gumming or clogging of equipment may occur. To prevent clogging, holes on the bottom sides of the plates should be straight, rather than beveled or tapered. Adding graphite or a dry detergent to the seed box and reducing seed weight on the plates by filling the planter box only about one-third full may also help prevent gumming during planting.

2. Rate of Planting: Although some studies have found little effect on yield when seeding rates ranged from 5 to 44 lb seed/acre, other researchers have indicated an optimum seeding rate of 5 to 9 viable seeds/ft of row (30 in. rows). Current Texas recommendations are 5 lb/acre for 30 in. rows and 12 lb/acre for broadcast. Broadcasting should be practiced only where moisture is sufficient to support the higher plant population.

D. Fertility and Lime Requirements:

Nitrogen is not thought to be limiting in guar when the plants are well nodulated. Like most legumes, guar usually requires application of a rather high level of phosphorus (20 to 30 lb of P_2O_5/acre) and medium levels of potash (40 to 50 lb of K_2O/acre). For highest yield, fertilize according to soil test results. Apply fertilizer below the seed before planting or to the side and below the seed at planting. Sulfur fertilizers have been found to affect guar on some soils, and zinc deficiency is a common problem in India.

Moderately alkaline soils are considered desirable for guar crop production (pH 7.0 to 8.0).

E. Variety Selection:

There have been notable improvements in guar varieties developed in the last 30 years. The newer cultivars are much more disease resistant with higher yields. Pod set in improved varieties is higher, and pods are well distributed on the main stem and branches, increasing harvest efficiency. The multiple branching of these newer cultivars also produces more pods.

Only the earliest-maturing varieties are recommended for production in Wisconsin and Minnesota.

Brooks, released in 1964, was the first improved variety, replacing Texsel and Groehler. Brooks has been grown on most of the guar acreage since 1966, but is rapidly being replaced by two newer releases, Kinman and Esser. Brooks is high-yielding and resistant to the major guar diseases, Alternaria leaf spot and bacterial blight. It is medium to late in maturity. Plants have a fine-branching growth habit and small racemes of medium-sized pods. Leaves and stem are glabrous. The seed is of medium size.

Hall is a slightly later-maturing variety than Brooks, and therefore not recommended for production in the Upper Midwest. It is resistant to bacterial blight and Alternaria leaf spot. Plants are relatively tall, coarse, finely branched, and produce small racemes of medium-sized pods. Leaves and stems are glabrous. This variety is best adapted to heavier soil types and higher elevations.

Mills is an early-maturing variety which also is resistant to bacterial blight and Alternaria leaf spot. Plants are short and finely branched and produce small racemes with relatively large pods. Leaves and stems are pubescent (hairy). Seeds are larger than those of Brooks and Hall. In dry seasons, Mills does not grow tall enough for efficient harvest. Yields are generally lower than those of Brooks and Hall.

Kinman, released by the Texas Agricultural Experiment Station, the USDA-ARS and the Oklahoma Agricultural Experiment Station in 1975, is derived from Brooks and Mills. Kinman is about 7 days earlier in maturity than Hall and of the same maturity as Brooks. It is highly resistant to bacterial leaf blight and Alternaria leaf spot. Kinman is slightly taller and coarser-stemmed than Brooks, but less so than Hall. It is fine branched and produces small-to-medium sized racemes. Seed pods are medium in length and generally contain from 7 to 9 seeds each. Seed of Kinman is slightly larger than Brooks. In 41 yield trials at eight locations in Texas and Oklahoma from 1971 to 1976, Kinman produced 17% more seed than Brooks.

Esser, released with Kinman in 1975, is a selection from progeny of the same Brooks × Mills cross. It is medium to late in maturity and therefore is probably not a good cultivar for Wisconsin and Minnesota. It has high resistance to Alternaria leaf spot and bacterial leaf blight. Esser has shown superior disease tolerance to Brooks and Kinman under severe bacterial blight conditions. Esser plants have Brooks' fine branching growth habit, but Esser has stronger main stems and fewer lateral branches. Esser produces small racemes with medium-sized pods.

Lewis, released by the Texas Agricultural Station and the USDA- ARS in 1986, is a selection from a cross of a glabrous parent with a pubescent (hairy) parent. Lewis is a medium-to-late maturing variety that is highly resistant to Alternaria leaf spot and bacterial leaf blight. Leaves, stems and pods are glabrous. Plants have a basal branching growth habit. The main stem and the basal branches possess short internodes with racemes initiated at each node over the entire plant. Plants are of average height, and racemes and pods are of medium length. Pods generally contain 5 to 9 seeds of average size. In 10 yield tests at five Texas locations during 1980-1983, Lewis produced mean seed yields approximately 25% higher than Kinman and 21% higher than Esser (Table 1).

Table 1. Yields of five guar varieties in Texas from 1980 to 1983.

Year/location	Variety				
	Lewis	Kinman	Esser	Brooks	Hall
	lb/a				
1980					
Chillicothe[1]	1,474	1,149	1,135	1,087	876
1981					
Chillicothe	844	781	666	617	458
Iowa Park	1,052	941	1,116	969	932
Stephenville[1]	1,415	1,011	1,168	1,022	922
1982					
Chillicothe	1,631	1,275	1,450	1,319	1,186
Corpus Christi	935	718	653	676	467
Munday	1,022	756	733	689	436

Stephenville[1]	1,197	1,042	875	1,240	1,009
1983					
Chillicothe[2]	454	354	428	239	310
Munday[2]	997	794	900	727	676
Mean	1,102	882	912	858	727

[1]Test received supplemental irrigation.
[2]Disease was present in the test.
Source: Stafford, R.E. 1986. Lewis: A New Guar Variety. Texas Agricultural Experiment Station Bulletin L-2177, February 1986. Texas A&M University System, College Station, Texas.

F. Weed Control:

Young guar plants grow slowly and are particularly susceptible to weed problems. Weeds can reduce yields and create harvesting problems.

1. Mechanical control: Guar should not be seeded in fields heavily infested with Johnsongrass (Sorghum halepense) and other perennial weeds. Early preparation of land and mechanical cultivations during the growing season will help minimize weed problems. Covering the lower branches during cultivation may promote development of disease and increase harvest difficulties.

2. Chemical: Treflan (trifluralin) is registered for use on guar as a preplant incorporated treatment to control most annual grass and several annual broadleaf weeds. Follow label instructions carefully for different soil types.

G. Diseases and Their Control:

Selecting disease-resistant varieties and high-quality certified seed is the best defense against disease problems. There are two major diseases of guar worldwide:

1. Alternaria leaf or target spot (*Alternaria cucumerina* var. *cyamopsidis*): This fungal disease may become severe during periods of heavy dew and high humidity. It causes a brown target-like lesion on the leaf between bloom and pod set. As the disease progresses, lesions enlarge, join and cause leaf drop.

2. Bacterial blight (*Xanthomonas cyamopsidis*): This seed-borne disease can cause loss of plants from the seedling stage until maturity. Symptoms include large angular necrotic lesions at the tips of leaves, which cause defoliation and black streaking of the stems. This is potentially the greatest disease hazard to guar.

H. Insects and Other Predators and Their Control:

The guar midge (*Contarinia texana*) is the primary guar insect pest in the Southwest. Heavy midge infestations have caused up to 30% loss in seed production. Guar midge infestations are generally heavier in fields with sandy or sandy loam soils.

Damage to guar is caused by the larvae, which develop in the guar buds. Infested buds eventually dry up and fall from the plant. The adult female midge deposits her eggs in developing buds. After larvae complete their development, they drop from the buds to the ground to pupate. There are several generations each year.

Rainfall or sprinkler irrigation can reduce midge populations drastically. However, field inspection should continue because midge infestation problems may increase again as a result of improved growing conditions. Control midges while guar is producing buds -- primarily between 45 and 90 days after emergence.

Other guar insect pests include the gall midge (*Asphondylia* sp.), three-cornered alfalfa hoppers, pea aphids, white grubs, thrips, and whiteflies. Storage pests have not been a problem with guar.

I. Harvesting:

Since guar beans generally do not shatter, the crop can be direct-combined as soon after maturity as possible. Harvest does not generally take place until after frost in northern regions. At maturity, the seed pods are brown and dry, and seed moisture content is less than 14%. Gramoxone (paraquat) can be used as a harvest aid to speed up drying and to kill weeds prior to frost. Apply when pods are fully mature. Preharvest interval is 4 days. Do not graze treated areas or use the treated forage for animal feed.

Guar beans can be harvested with an ordinary grain combine. The cylinder should be slowed and the combine speed reduced to a rate that will permit proper threshing of the beans. A high fan speed can be used to clean out foreign material. Reel speed should be slightly greater than combine ground speed. Improper reel speed can shatter seed pods. Reels should be set just deep enough in the guar to control the stalks, and should be about 6 to 12 in. ahead of the cutterbar. Some operators replace the wooden reel bats with 1/2 in. steel rods to reduce shattering. When harvested for hay, guar leaves drop readily unless extreme care is taken during the curing process. For hay, the crop should be cut when the first lower pods turn brown.

Guar can be harvested for seed and then plowed under or used as a mulch. If seed is not harvested, guar used for green manure should be turned under when the lower pods begin to turn brown.

J. Drying, Storage and Seed Quality:

Following harvest, the seed is graded for size and cleaned to remove shrunken seed and crop residue. Little information is available on optimum storage conditions for guar, but this has not been identified as a problem in most production guides. Following cleaning, milling for gum extraction may proceed.

The principal factors that decrease seed quality in guar are seed blackening and the production of small and shrunken seed. White seed is preferred for many food applications, and black seed is often discounted. Darkening tends to follow patterns of increasing rainfall, especially when it occurs during the period of seed maturation.

Small seed contains less endosperm and therefore is less desirable for milling. Late flowering, diseases, insects and low moisture can cause small seed (preferred size is 4 mm).

VI. Yield Potential and Performance Results:

Production practices and rainfall during the growing season cause seed yields to vary from about 300 to 2,000 lb/acre. Yields of several varieties in Texas are shown in Table 1. Experimental plantings of guar at Rosemont, Minnesota, have resulted in plants that bloomed but produced very little seed.

VII. Economics of Production and Markets:

Income and production costs for guar vary from year to year and according to soil types. Production costs often vary by $20 to $40/acre between farms because of different fertilizer usage and other production practices.

Demand for guar is increasing because of the wide use of the gum in more products and efforts of dealers to obtain a larger percentage of the gum from domestic sources. Growth in the early 1980s was estimated at 10% annually. Grade factors considered by the purchaser are the moisture, foreign material and test weight. Identify a market and secure a contract, if possible, before growing guar for bean production.

The value of guar as a soil builder to increase yields of succeeding crops should not be overlooked when considering guar as an alternative crop.

VIII. Information Sources:

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Hairy Vetch

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I. History:

The vetches (plants of the genus *Vicia*) are distributed throughout the temperate zones of both hemispheres. There are about 150 species of vetch, several of which were of agricultural importance centuries ago. Some 25 species are native to the United States. However, the species in commercial use, including hairy vetch (*Vicia villosa* Roth), are all native to Europe or western Asia.

Hairy vetch, also called sand vetch, is a moderately winter-hardy species. It is the only vetch species that can be fall-seeded and reach maturity the following July.

II. Uses:

Hairy vetch is a legume used primarily for soil improvement along roadsides and for bank stabilization. Well-nodulated hairy vetch can enrich the soil with 60 to 120 lb/acre of nitrogen through nitrogen fixation. Later seeded vetch grown as a cover crop for green manure, will supply a smaller amount of N.

Vetches are also grown for pasture. They withstand trampling, provide grazing during May and June and have a feeding value slightly lower than that of clover and alfalfa. The protein content of vetch hay ranges from 12 to 20%, depending on the stage of development of the crop when cut.

Vetch is often grown with a small grain for forage; rye is generally used for this purpose in the Upper Midwest. The grain supports the weak stems of the vetch and reduces lodging. However, when grown together, vetch and rye make a hay that is fair in quality but tangles badly.

Vetch can be difficult to grow for seed. The pods mature unevenly and tend to shatter easily.

III. Growth Habits:

While most of the cultivated vetches are annuals, hairy vetch is grown as an annual or winter annual. When hairy vetch is sown in late July or August, the seed germinates readily and the plants generally form a crown before the first snow. In spring, the plant produces 3 to 10 long, weak, branching stems or vines 3 to 6 ft long. The leaves have 12 to 20 leaflets and terminate with tendrils. Although hairy vetch is typically pubescent, the most extensively used commercial variety is called smooth vetch because it appears to have no pubescence. The purple and white flowers appear in mid-June and are borne in a cluster, or raceme. Seed pods, bearing 4 to 8 seeds each, mature unevenly from July 10 to July 25. Pods tends to shatter soon after maturity. When hairy vetch is spring sown, it will bloom and produce some seed the same season.

IV. Environment Requirements:

A. Climate:

Hairy vetch is the most winter-hardy of the commercial vetches, though it may not survive a winter without a snow cover. Plants on poorly drained soil will kill more easily than those on well-drained land. Late seeding and unusually cold fall weather also result in more winter injury. Protective covering by a companion crop or crop waste reduces the danger of winter kill. Hairy vetch will not successfully overwinter in many northern areas of the Midwest. Check on the adaptability of hairy vetch to your location before planting.

Although the vetches are not drought resistant, this is rarely a problem. The crop is summer-seeded and harvested the following July before the hot, dry conditions of late summer.

B. Soil:

Vetches grow well on a wide range of soil types, but are best adapted to loamy and sandy soils. Because they are legumes, vetches can be grown on nitrogen-depleted soils without the addition of N fertilizer.

C. Seed Preparation and Germination:

The seed should be inoculated with the proper strain of Rhizobium bacteria within 24 hours of planting, unless well-nodulated peas or vetch have been grown on the field recently. Follow instructions carefully to achieve an even coat of fresh inoculum on the seed. Seed should be sown when the soil is moist, because a hot, dry soil will reduce, if not prevent, effective inoculation. Some fungicide seed treatment compounds can also interfere with the nodulation process.

V. Cultural Practices:

A. Seedbed Preparation:

Vetch can be grown following any crop harvested before mid- August. For crops which leave a relatively uniform seedbed, vetch can be planted without plowing. Similarly, vetch seeded into small grain stubble need not be plowed or disked before sowing. The stubble may provide enough winter protection to overwinter a vetch crop by holding snow on the field.

Plowing or heavy disking is essential on heavy soils and firmly packed soils, or where there is heavy weed infestation. Grassy fields should be plowed or thoroughly cultivated during July before planting vetch.

For best results, the seedbed should be firm and have adequate moisture for good seed germination.

B. Seeding Date:

In central Wisconsin or Minnesota, the best time to plant vetch is from July 25 to August 30. Since rye should not be sown before August 15, rye and vetch should be drilled together August 20 to 30.

C. Method and Rate of Seeding:

Inoculated hairy vetch seed can be drilled at a rate of 25 to 35 lb/acre. When seeding a mixture of vetch and rye, the quantity of vetch seed should be reduced by about 25% and the grain should be reduced by about 50% of the monoculture rate. Some separation of seed will occur if the two seeds are mixed together in the same seed box. Good stands are obtained from planting the vetch at a depth of 1/4 to 1/2 in. Shallower plantings will give good stands if there is sufficient moisture.

D. Fertility and Lime Requirements:

Vetch does not require nitrogen fertilization. This legume grows best in soils high in available potassium. Requirements for phosphorus, calcium and other minerals are less pronounced. For most soils, applications of about 40 lb/acre of P_2O_5 and 120 lb/acre of K_2O should be adequate. However, where soil tests are very high (greater than 25 to 30 ppm P and 110 to 130 ppm K) applications can be eliminated. Small amounts of nutrients can be applied with the drill (less than 40 lb of N + K_2O/acre), or topdressed.

Vetches are more tolerant to acid soil conditions than most legumes. Soils should be limed to a pH of about 6.0.

E. Variety Selection:

Hairy vetch is the most winter-hardy of the vetches. It is the only vetch that can be grown in the Upper Midwest.

F. Weed Control:

Weeds are rarely a serious problem in vetch fields, especially when seeded in late summer or early fall. Repeated production of rye and vetch on the same land, however, favors growth of winter annual and perennial weeds.

The crop should be planted in a relatively weed-free seedbed, and the land should be plowed and planted to a row crop every three to five years to control weeds.

G. Diseases and Their Control:

Vetches are susceptible to several fungal diseases, some of which are restricted by temperature and moisture conditions to certain parts of the country. Black stem occurs wherever vetches are grown in the United States and is caused by several closely related fungi. Stem discoloration is the most distinctive symptom, although the fungi also produce large, dark, irregular lesions on the leaves. The disease can cause serious damage to hairy vetch seedlings.

Root rot also occurs wherever vetches are grown. It may be caused by one or several unrelated fungi that can attack plants at all stages of growth. Symptoms are most conspicuous in seedlings, which wilt and die. Older plants become stunted or discolored red or yellow when infected. Roots of diseased plants are badly discolored.

Gray mold, or botrytis leaf spot, sometimes causes considerable defoliation of vetch. The spots are small and dark red when young, later fading to light gray or brown with a maroon border.

A disease that resembles anthracnose, but is caused by a different fungus, is prevalent on hairy vetch in the South. This "false anthracnose" produces a brown discoloration and girdling of stems. Spots on leaves are small and circular but tend to form elongated streaks. When pods are heavily spotted, the fungus penetrates the seed. Seed development may be hindered by this disease.

Downy mildew has caused considerable damage to common vetch in the Pacific Northwest. The underside of infected leaves is covered with fine grayish fungal threads. Infected leaves turn yellow and drop off prematurely.

Stem rot of vetch is caused by a fungus that is destructive during cool, wet weather. This disease sometimes causes considerable damage in the Pacific Northwest.

Root-knot nematode can cause considerable damage in vetch. Nematodes are most active in warm weather, and damage may be reduced by moderately late planting.

Resistant varieties may offer the best means of control of vetch diseases. In addition, it is advisable to avoid growing vetch continuously on the same land, use disease-free seed, and destroy volunteer plants that may harbor or spread diseases to new seedlings.

H. Insects and Other Predators and Their Control:

Vetch is attacked by many of the insect pests of alfalfa, clover and other forage legumes, including the pea aphid, cutworm, corn earworm, fall armyworm, vetch bruchid, grasshopper, lygus bug and leafhopper.

The pea aphid may become abundant on vetch in the spring. It sucks sap from the plant, causing the leaves to turn yellow. A heavy infestation will kill the plants. If the vetch is to be used for hay and is near harvesting, it is advisable to cut the crop promptly. Pea aphid infestation may require chemical control to reduce crop damage.

The vetch bruchid is a small, blackish, chunky seed weevil about 1/8 in. long. The eggs are laid on the green vetch pods in the spring. The larvae enter the pod and feed on the seed, destroying its viability. They do not infest dry seed.

Lygus bugs can cause considerable damage to vetch. Both adults and nymphs suck sap from the plant. These bugs tend to feed on the reproductive parts, often causing the buds and flowers to drop. After the pods are formed, lygus bugs will feed on the immature seeds and cause them to shrivel and turn brown. Control of lygus bugs may be necessary in seed production fields.

I. Harvesting:

1. For soil improvement: When sown in August, a considerable growth of rye and vetch can be plowed down the following spring, prior to June 10, so that a crop of silage corn, late-planted potatoes, or another late-planted crop can be planted on the land. When this is done, the amount of nitrogen credited to the succeeding crop should be about 60 lb/acre. Vetch allowed to grow for a full season can credit 120 lb/acre of N.

2. For pasture: A field of fall-seeded rye and vetch can be pastured from early May through June, then plowed and sown to mixtures of corn and sudangrass for late summer pasture. In this case, the N credit should be determined by the amount of material incorporated and may range from 40 to 80 lb/acre.

Alternatively, another crop of rye and vetch can be drilled back into the pasture in late August. To get the most out of this plan, pasturing should be timed with regard to the weather and other available pasturage.

If the vetch is not grazed too closely and not cut in July, a fair seed crop may be secured later in the summer. Light, early- spring pasturing reduces excessive vine growth, delays bloom and may improve the seed yield.

3. For hay: Rye and vetch produce a tangled hay that is quite difficult to handle. Because rye is well past the stage for best quality hay by the time vetch is ready for mowing, the quality of the hay is low. Earlier cutting will reduce the total yield, but result in better quality hay. Increasing the proportion of vetch also improves the quality, but adds to mowing difficulties. Vetch is generally cut for hay when the first pods are well developed and the grain is in the early soft-dough stage.

When the crop is thin, it can be cut with a mower and windrowed. Heavy, green vetch should be windrowed with a side-delivery rake. The hay can be cured in the windrow or bunched and allowed to cure in shocks.

4. For seed: Harvesting for seed is difficult because the pods do not mature uniformly. Vetch seed can be harvested with a combine when the lower pods are fully ripe. This will provide the maximum ripe seed yield. Harvesting losses due to shattering may be large. Shattered seed can be disked in as soon as possible after harvest to start a new crop.

Vetch, alone or with rye, is threshed with a grain thresher. To reduce losses, it may be necessary to remove a number of the concave and cylinder bars of the combine and to reduce the cylinder speed to 800 rpm or less.

The seed crop must be cleaned at once to remove green pods, immature seeds, insects and other debris. If seed is not cleaned, a white mold will grow on the black vetch seed, lowering the quality. Rye and vetch seed can be separated with a spiral seed separator.

VI. Yield Potential and Performance Results:

Vetch produces a hay yield of 1.5 to 3.5 ton/acre dry weight. Vetch seed remains viable for 5 years or longer.

VII. Economics of Production and Markets:

Growers are advised to identify a seed market before harvesting seed.

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Hop

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I. History:

German beermakers have been using wild hop (*Humulus lupulus* L.) to flavor their brew for hundreds of years. Hop was introduced to the United States from England in 1629. The first commercial hop yard in the United States was established in New York in 1808. Cultivation of the crop rapidly spread south and west. Wisconsin became a major producer of hop for a brief period late in the nineteenth century, but New York remained the leader until the crop was virtually wiped out in both states by downy mildew in the 1920s.

Today, the Yakima Valley in Washington produces about 75% of the hop grown in the United States. The combined total production of Washington, Oregon and Idaho (the major producing states) exceeds 50 million pounds annually. Hop is produced on a limited scale in the Upper Midwest for local markets.

Improved varieties have been selected for resistance to downy mildew, adaptation to mechanical harvesting, and brewing characteristics.

II. Uses:

The manufacture of beer utilizes 98% of the world's production of hop. Before the days of pasteurization, brewers used hop for its antibiotic properties as well as its flavor. In some countries the young shoots are eaten as a boiled vegetable.

The female "cone," which contains the small flowers and later the fruits, has resin glands which produce lupulin. Lupulin contains the essential oils and resins that give the hop its aroma and beer its bitter flavor. The alpha acids in the resin contribute to the bitter components and constitute 4.5 to 7% of the weight of the dried hop in most domestic varieties and 8 to 12% in some English varieties. Eight to 13 oz of hop are used for each barrel of beer.

III. Growth Habits:

The hop plant is a vine that produces annual stems from a perennial crown and rootstock. The shoots, or 'bines', grow rapidly to a length of 18 to 25 ft. As the bines grow, they wind around their support in a clockwise direction, clinging with strong, hooked hairs. The leaves are dark green, hairy, heart- shaped, deeply lobed and serrate. The perennial crown becomes woody with age and produces an extensive root system. The roots may penetrate the soil to a depth of 15 ft or more.

The female flowers are borne in clusters on lateral branches. The hop plant is dioecious (male and female flowers are on separate plants). Female flowers form pale green conelike structures that are 1 to 4 in. long and papery. Seedless hop, which is considered more desirable by brewers, is produced by preventing pollination. Seedless hop weighs about 30% less than seeded hop and is more shatter-resistant at harvest.

IV. Environment Requirements:

A. Climate:

Hop is adapted to a wide range of climatic conditions; ample moisture early followed by warm, dry weather is ideal. In areas where rainfall is lacking and the water table is more than 5 ft deep, irrigation may be required.

B. Soil:

A deep sandy loam is best. Poorly drained, strongly alkaline or saline soils should be avoided.

C. Propagation:

Hop plants are propagated from runners that arise from the crown just below the soil surface. The runners are cut into pieces 6 to 8 in. long, each bearing at least two sets of buds. Cuttings should be planted immediately or if not, stored in a cool, moist, well ventilated place. Cuttings that are poorly developed, misshapen, damaged or diseased should not be planted.

Many hop growers establish a nursery block where cuttings are planted and grown for one season. One-year-old sets are transplanted from the nursery in the spring or fall.

V. Cultural Practices:

A. Seedbed Preparation:

The soil should be tilled to create a weed-free field prior to planting. Cuttings are planted in hills with a spacing of approximately 8 × 8 ft at a planting density of 800 hills/acre. Hop is grown on an overhead trellis system that may be designed to facilitate mechanical harvest.

B. Planting Date:

Plant in early May or as soon as the soil can be worked into a fine, mellow condition. Plant 2 to 4 cuttings/hill with the buds pointed up and covered by 1/4 to 1 in. of loose soil.

C. Pruning:

When the young vines are about 2 ft long, two to six vigorously growing vines are selected for each hill and the rest are removed. One to three vines may be trained up each of two strings staked to the hill and extending up to the stringing wires of the trellis overhead. When the vines reach the stringing wires, the lowest 4 ft of foliage and lateral branches are removed to aid in prevention of disease, especially downy mildew, and insect pests, particularly spider mites. The removal of lower leaves (stripping) must be done carefully to avoid damaging the stem. Shoots arising from the crown are continually removed early in the season in order to promote the growth of the selected vines. Allowing the suckers to remain later in the season seems to promote hardiness of the crown.

D. Fertility and Lime Requirements:

Hop can produce good yields in the Upper Midwest if soil has adequate fertility, although little information specific for Wisconsin or Minnesota soil conditions is available. Approximately 100 lb/acre of nitrogen is removed by the harvested portion of a good yielding hop crop. This amount of nitrogen should be applied on soils with organic matter levels between 2 and 5%. Slightly less N (about 70 lb/acre) is needed if soil organic matter levels are greater than 5%. About 130 lb/acre of N is needed if soil is coarse-textured, organic matter level is less than 2% and the field is irrigated. Split applications are recommended on these coarse-textured soils. Organic matter may be added by returning the spent vines to the field, applying manure or plowing under a winter cover crop such as vetch or small grain.

Levels of phosphorus and potassium adequate for good yields are similar to that required by field corn. If soils have optimum levels of extractable P (11 to 20 ppm for silt loams, 23 to 32 ppm for sands) approximately 30 lb/acre of P_2O_5 should be applied to replace that P removed by the harvested portion of the crop. About 100 lb/acre of K_2O are required for soils testing in the medium K range (81 to 110 ppm for silt loams, 61 to 80 ppm for sands). Lesser amounts can be applied if soil test levels are above medium, but additional applications of about 10 to 30 lb/acre P_2O_5 and/or 20 to 40 lb/acre of K_2O are needed for best growth if soil test levels of phosphorus and/or potassium are less than medium. Fertilizer should be applied and incorporated prior to planting.

E. Variety Selection:

Three types of hop are grown in the United States: the Old World (aroma) varieties; the American varieties; and the new High Alpha (extract) varieties.

Old World (aroma) varieties include the traditional aroma cultivars of Europe and hybrids derived from them that share their aroma and brewing characteristics. These varieties are considered to be of moderate brewing value, with 4 to 8% alpha acid and weak to mild aroma. They are usually early maturing varieties and are adapted to production in a cool climate. Some aroma type hop varieties include Fuggle, Willamette, Columbia, Cascade, and the German cultivars Tettnanger, Hallertauer and Hersbrucker.

Fuggle has been grown commercially in England for more than a century. It became popular in Oregon in the 1930s because of its resistance to downy mildew. Fuggle is also resistant to hop mosaic virus, but susceptible to hop nettlehead disease and to Verticillium wilt diseases. Fuggle has an essential oil content of approximately 1.0 ml/gram of dry matter (1%), an alpha acid content of 4 to 6% and a pronounced aroma.

Fuggle is not trained up the strings the first season and does not produce its first full crop until the third season. Fuggle is an early maturing variety with a low yield potential (1,100 to 1,400 lb/acre). Because Fuggle is not naturally high-yielding, growers generally grow male hop plants with Fuggle to pollinate the female plants, resulting in larger cones.

Willamette was released by the Oregon Agricultural Experimentation Station in 1976. This variety produces seedless hop in the presence of male flowers. Pollinated cones are larger than unpollinated cones, but the seed content is low in this triploid cultivar. The pale green cones are easy to see against the dark green foliage. Willamette matures later than its parent, Fuggle, and is picked in late August or early September in Oregon. This variety has an oil content of 1%, alpha acid content of 6 to 7% and a pleasant aroma. Willamette is resistant to downy mildew, but susceptible to the potato strain of *Verticillium dahliae*. Willamette produces up to 2,000 lb/acre of dried hop.

Cascade, released in 1972, matures later than Fuggle. It is resistant to downy mildew, but very susceptible to *Verticillium* wilt and to Prunus necrotic ringspot virus (PNRSV). Willamette has an oil content of 1 to 2%, alpha acid content of 5 to 7% and a distinct fragrance. The orange-yellow lupulin of this variety is plentiful, and the cone feels buttery when rubbed. Cascade produces up to 2,000 lb/acre.

Columbia was released in 1976 by the USDA and the Oregon Agricultural Experiment Station. This nearly sterile triploid cultivar is well-suited to a mechanical harvest. Oil, alpha acid and aroma are similar to its parent Fuggle.

Columbia is medium to late maturing with a yield potential of 1,900 lb/acre.

Tettnanger and Hallertauer are continental aroma cultivars from Germany. These cultivars are fairly tolerant to crown infection by downy mildew, though susceptible to mite infestations. Because yield potential is only 50 to 70% that of cultivars released in the United States, production is based on brewery demand. These varieties are grown organically in Wisconsin and produce up to 800 lb/acre.

The American varieties include Early Cluster and Late Cluster, which are the most widely grown hop varieties in the United States. Both varieties are vigorous, high yielding, and well adapted to mechanical harvesting. The Clusters have similar brewing characteristics, with 5 to 7% alpha acid at maturity.

Early Cluster matures approximately 10 to 14 days earlier than Late Cluster. Early Cluster is resistant to *Verticillium* wilt, but somewhat susceptible to downy mildew via crown and root infection.

Late Cluster produces up to 2,000 lb/acre. Downy mildew can become a problem late in the season, and the several strains of Late Cluster are also somewhat more susceptible to viruses than Early Cluster.

Talisman, released by the Idaho Agricultural Experiment Station in 1965, is the highest yielding variety in Idaho, with a yield potential of up to 3,200 lb/acre. It matures a week later than the Late Cluster. Talisman has an oil content of 1.5% and alpha acid content of 8 to 10%. Although Talisman is resistant to the crown rot phase of downy mildew, it is vulnerable to the cone phase of the disease. Phytophthora root rot is a problem in waterlogged soils.

The Extract or High-Alpha varieties include Brewer's Gold and Bullion and the new high-alpha varieties.

Brewer's Gold and Bullion were developed in England and introduced into the United States in the 1930s. They are medium to late maturing, with Bullion maturing 10 days earlier than Brewer's Gold. Both are vigorous and well-adapted to mechanical harvesting, with a yield potential of 2,500 lb/acre when grown seeded. They are less susceptible to downy mildew than the Cluster varieties. Brewer's Gold and Bullion are high in essential oils and have an alpha acid content of 8%.

Galena, derived from Brewer's Gold, was released by the Idaho Agricultural Experiment Station in 1978. Galena is generally strung and harvested later than Early Cluster (delayed training postpones the onset of maturity and enhances yield.) Galena is moderately resistant to the crown phase of downy mildew. It also shows tolerance to *Verticillium* wilt, although if planted in potato ground, some of the young plants may show symptoms of the disease. Galena is susceptible to frost damage and may be difficult to establish. Alpha acid levels average 12% (up to 300 lb/acre of alpha acids).

Eroica is a late maturing sibling of Galena released in 1980. In the Willamette Valley, Eroica is ready to be harvested in mid- September. Alpha acid levels are 10 to 13%, with the potential of yielding more than 300 lb/acre of alpha acids. Eroica is not as stable in storage as Galena or the Clusters. This variety has a moderately high degree of resistance to hop downy mildew and the potato strain of *Verticillium dahliae*.

Nugget, released by the Oregon Agricultural Experiment Station and the USDA in 1983, matures later than Galena but earlier than Eroica. Alpha acid content is similar to Galena and cone weight yield is similar to Eroica. Nugget has about 2% essential oils and appears to have good storage qualities. Nugget has good resistance to hop downy mildew, but appears to be susceptible to *Verticillium* wilt.

Olympic is a high alpha acid hop released in 1983 by the Washington Agricultural Experiment Station and the USDA. Olympic tends to produce an excessive amount of male flowers, reducing cone cluster density and yield. Olympic is easily trained and frost tolerant, but it does require meticulous pest control management. It has no resistance to the hop-damson aphid or the two-spotted mite. Olympic has moderate resistance to downy mildew, but shows some susceptibility to Verticillium.

Chinook was released by the Washington Agricultural Experiment Station in 1985. It is considered medium-early in maturity, although in Oregon it appears to be late in maturity. Chinook has 11 to 13% alpha acid and 0.5% oil. This variety has moderate resistance to downy mildew, as well as to the hop-damson aphid and the two-spotted spider mite. It appears to be free of PNRSV and apple mosaic virus.

F. Weed Control:

Mechanical cultivation should begin early and continue until the lateral branches are well developed. Deep cultivation (6 to 10 in.) early is recommended to incorporate surface organic matter, followed by shallow cultivation (2 to 4 in.) later in the season to avoid damaging the shallow feeder root system. Avoid late season cultivation if not required for weed control, as it may inhibit growth and lead to early ripening.

Chemical weed control in hop is usually unnecessary. Only one herbicide is registered for use in this crop in Minnesota and Wisconsin. A preplant incorporated application of Treflan (trifluralin) will kill many annual grasses and broadleaves. Apply and incorporate to 2 in. deep while hop is dormant. Weed control normally lasts 4 to 6 weeks or more. When weeds appear, cultivate as necessary.

G. Diseases and Their Control:

Disease problems can be minimized by selection of resistant varieties and removal of diseased plant tissues. Removing lower leaves on the bines at training time will help prevent the spread of disease and insect pests. Pruning should be performed with clean tools. Caution is advised to avoid damaging crowns during pruning and cultivation.

Downy mildew is most severe in areas of heavy spring rainfall, when the combination of moisture and temperature (60 to 70oF) are favorable for infection and disease development. The varieties that show greatest resistance to downy mildew are Willamette, Cascade, Nugget and Fuggle.

The first symptoms of the disease appear in early spring when a part or all of the new shoots arising from a hill may be infected. Badly infected shoots are unable to climb and are stunted, brittle and lighter in color than healthy shoots. These "spikes" are infected internally by the fungus and may carry millions of spores. The spores can be carried by wind or water to other shoots and can infect the tips of healthy shoots.

Flowers often become infected when blooming occurs during wet weather. Young cones that are infected stop growing and turn brown. When older cones are attacked, part or all of the petals turn brown and cones fail to develop properly.

The hop downy mildew fungus survives the winter as winter spores in infected roots or crowns. The Cluster varieties are particularly susceptible to root and crown infection.

Control of downy mildew requires a combination of sanitation practices and strategically timed applications of fungicides, in addition to the use of resistant cultivars. Roots for planting should be clean and disease-free. Spiked shoots should be removed promptly from the field and burned. Individual plants with infected crowns should be dug and removed from the field. Late pruning (end of April) shortens the time that new growth is exposed to favorable mildew conditions in the spring. It is advisable to treat yards that have spikes or those located near yards with spikes with fungicides before warm, wet weather to prevent new infections.

Sooty mold is caused by the fungi *Cladosporium* and *Fumago* spp., which grow on the honeydew excreted by aphids. Moldy cones are considered inferior in quality and may be difficult to sell. Sooty mold can be controlled by controlling the aphid.

Root rots are characterized by a brown or black discoloration and rot of the infected parts. To prevent this problem, growers should select only healthy cuttings for propagation. Well- drained sites usually have fewer problems.

***Verticillium* wilt** can best be avoided by starting with planting stock that is certified free of *Verticillium*. New hop yards should not be planted on sites known to be infested with *Verticillium* from previous cropping in potatoes, tomatoes, strawberries or peppermint. Only Galena, Eroica and the Cluster varieties show any degree of resistance to Verticillium wilt.

Viral disease symptoms include leaf and tip distortion, tip die-back, yellow spotting of the leaves, stunted growth, failure to climb and flower blasting. To avoid problems with viral diseases, use virus-free planting stock. Distinctly abnormal plants should be removed promptly, and cuttings should not be taken from such plants.

H. Insects and Other Predators and Their Control:

Hop plants are subject to attack by a large number of insects and other pests. Hop aphids and spider mites are the most important of these pests, but wire-worms, root weevils, omnivorous leaf tiers, western spotted cucumber beetles, corn earworms, and several species of cutworm may also require control measures in some years. Though hop growers in northern Wisconsin have produced good yields using little or no pesticides, applications of chemicals may occasionally be necessary.

Hop aphid infestations develop more rapidly during cool weather. Heavy populations of 8 to 10 aphids/leaf will weaken plants and reduce yields, and the application of an insecticide is recommended. Aphids should be controlled before or during the flowering stage to keep them from entering the young cones. Aphid predators, including lady beetles, green lacewings, and syrphid or hover fly larvae, can be used to help control aphids.

Spider mites feed by puncturing the lower leaf surfaces and withdrawing sap. Each puncture produces a small, light-colored spot. Eventually the leaves become bronzed, shrivel and die. Heavy mite infestation results in weak plants and reduced yield. Unlike aphids, spider mites are more likely to become a problem during periods of warm, dry weather. Mite predators useful in hop yards include the western predator mite and the small black lady beetle. During June, a miticide application is recommended if mite populations reach an average of 10/leaf. Good coverage, especially on the undersides of the foliage, is required to obtain good control.

Cutworms overwinter as larvae or pupae in the soil. The adult moths emerge in late spring and lay eggs. The larvae that emerge from the eggs feed on plant stems at night. Cutworms can generally be found just beneath the soil surface during the day.

Omnivorous leaf tier larvae feed on the growing tips of vines. They destroy the tips, thus stimulating growth of lateral shoots. This injury has minimal effect on yield, but when it occurs new shoots have to be trained.

I. Harvesting:

Hop harvest in the Northwest usually runs from mid-August to mid-September. In northern Wisconsin the aroma varieties Hallertauer and Tettnanger approach maturity in late August. Hop is in prime condition for picking for only 5 to 10 days. Premature harvest results in loss to the grower from dry-down (weight loss during drying). After the crop has reached full ripeness, shattering loss increases and cones rapidly become discolored. Because harvesting can be a lengthy process, growing varieties of differing maturities allows for a longer season of harvest.

Hop cones can be picked by hand or mechanically. Most hop growers who harvest the crop mechanically use stationary picking machines. The vines are cut loose from the hill and the trellis wires about 4 ft from the ground. The cut vines are laced into "combs" mounted on a flatbed truck and transported to the picking machine, which strips the hop and most of the leaves from the vines. The hop then passes through a forced air stream to remove debris.

J. Drying and Storage:

Moisture content of the hop cone must be reduced from 65 to 80% to 8 to 10% for storage. Continuous flow dryers blow 140 to 150°F air through layers of hop on a moving belt. Most hop are bleached and conditioned by sulfur dioxide fumes blown through the hop during the drying process (1 to 4 oz of sulfur/100 lb of green hop). After drying, the hop is moved to a cooling room for a week to allow the temperature and moisture content of the cones to level out (even up). As the cones even up, they also toughen up and acquire a finer aroma and better appearance. It may be necessary to humidify the air in the cooling room. The cured hop is then baled or pelletized. Cold storage and transport at temperatures below 40°F is the best protection against deterioration of hop.

VI. Yield Potential and Performance Results:

The yield and performance of hop in the Upper Midwest is competitive with that of the Northwest. In addition to the total yield in cones, it is important to consider the yield of alpha acids. The cultivars Galena, Eroica and Nugget produce the highest yield of alpha acid (300 lb/acre). Other quality characteristics brewers may value are color, oil content and aroma.

VII. Economics of Production and Markets:

The total cost for establishment and the first year operation of a hop yard (based on a 220 acre hop ranch in the Yakima Valley, Washington) is approximately $4,800/acre. Fixed costs, such as the cost of equipment, building and land ownership, amount to approximately 18% of the total cost. Variable costs make up the remaining 82% of total cost and include machinery operation, labor and the services and materials that are required. The total cost of operation of an established hop yard based on similar budget assumptions is $2,800/acre. Labor costs typically amount to close to 50% of the total cost of operation.

Gross receipts from production are difficult to estimate due to the variability in yield and of the commodities contract price. Most hop sales are contracted at a specific price for as long as 7 years in advance. In 1989 breweries paid $1.35 to $1.85/lb for standard domestic hop. Certain imported hops sold for as much as $6.00/lb.

There is an increasing market of small, local breweries producing specialty beers, which are increasing in popularity. These brewers tend to use a high hopping ratio and pay more for their hops. Other markets are home brewer supply stores, independent hop suppliers and organic herb shops.

Contracting a market and a careful cost analysis of establishment and production costs are important first steps in becoming a successful hop farmer.

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References to seed dealers and pesticide products in this publication are for your convenience and are not an endorsement of one product over other similar products. You are responsible for using pesticides according to the manufacturer's current label directions. Follow directions exactly to protect people and the environment from pesticide exposure. Failure to do so violates the law.

Jojoba

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I. History:

Jojoba (*Simmodsia chinensis* (Link) Schneider) is a perennial woody shrub native to the semiarid regions of southern Arizona, southern California and northwestern Mexico. Jojoba (pronounced ho-HO-ba) is being cultivated to provide a renewable source of a unique high-quality oil.

Native Americans extracted the oil from jojoba seeds to treat sores and wounds centuries ago. Collection and processing of seed from naturally occurring stands in the early 1970s marked the beginning of jojoba domestication. In addition, the ban on the importation of sperm whale products in 1971 led to the discovery that jojoba oil is in many regards superior to sperm oil for applications in the cosmetics and other industries.

Today, 40,000 acres of jojoba are under cultivation in the southwestern U.S. Much of the interest in jojoba worldwide is the result of the plant's ability to survive in a harsh desert environment. The utilization of marginal land that will not support more conventional agricultural crops could become a major asset to the global agricultural economy.

The oldest commercial jojoba plantings in the U.S. were established in the late 1970s, and present production of jojoba oil is in the range of thousands of tons per year. The major world producers are the United States and Mexico, with considerable quantities of oil being exported to Japan and Europe.

II. Uses:

Jojoba seed contains a light-gold colored liquid wax ester which is the primary storage lipid of the plant. This is unlike conventional oilseed crops, such as soybean, corn, olive, or peanut which produce oils as the primary storage lipid. Jojoba wax (called oil) makes up 50% of the seed's dry weight. The physical properties of jojoba oil are: high viscosity, high flash and fire point, high dielectric constant, high stability and low volatility. Its composition is little affected by temperatures up to 570°F (300°C). Jojoba oil contains straight- chained C_{20} and C_{22} fatty acids and alcohols and two unsaturated bonds, which make the oil susceptible to many different types of chemical manipulations. The extracted oil is relatively pure, non-toxic, biodegradable, and resistant to rancidity.

Most jojoba oil produced in the U.S. today is sold at a high price for use in cosmetics and hair care products. As many as 300 products containing jojoba have appeared in the U.S. in recent years. As the supply of oil increases and price decreases, more uses will become economically feasible. For example, the viscosity index of jojoba oil is much higher than that of petrolium oil; therefore, it may be used as a high temperature, high pressure lubricant. The stability of jojoba oil makes it attractive to the electronic and computer industries. And since jojoba oil contains no cholesterol or triglycerides and is not broken down by normal metabolic pathways, it may become an important low-calorie oil for human consumption. The oil can be used as an antifoam agent in antibiotics production and as a treatment for skin disorders. Other proposed uses include candles, plasticizers, detergents, fire retardents, transformer oil, and for the leather industry.

The meal contains up to 30% protein, but toxic compounds (simmondsins) make it currently hazardous as an animal feed.

III. Growth Habit:

Jojoba is a woody evergreen shrub or small multi-stemmed tree that typically grows to a height of 10 to 15 ft. Leaves are opposite, oval or lanceolate, gray green, and have a waxy cuticle that reduces moisture loss. The plant develops one or a few long tap roots (up to 40 ft) that can supply water and minerals from far below the soil surface.

Jojoba is usually dioecious (male and female flowers are borne on separate plants). Female flowers are small, pale green and commonly solitary or in clusters at the nodes. Male flowers are yellow, larger, and occur in clusters. Pollination occurs via wind or insect.

The fruit is a green capsule which encloses up to three seeds. When ripe (3 to 6 months after fertilization) the capsule splits and reveals the seed, which is brown, wrinkled and about the size of a small olive (300 to 1,000 seeds/lb). Seed production is generally limited until the fourth year of growth.

IV. Environment Requirements:

A. Climate:

Jojoba is best suited to areas that are frost free and is not grown in the northern midwest. When temperatures drop below 20°F, flowers and terminal portions of young branches of most jojoba plants are damaged. During early seedling development, excessive cold may kill an entire plantation. Frost may not damage taller plants to the same degree, but it can reduce yield. Jojoba is very tolerant of high temperatures.

Natural stands of jojoba occur in areas that receive 3 to 18 in. of precipitation annually. Irrigation has produced more luxuriant vegetative growth, but it is not known whether this increased growth results in higher seed yield. Jojoba requires the most water during late winter and early spring.

B. Soil:

Most wild jojoba populations occur on coarse, light or medium textured soils with good drainage and good water infiltration. Planting on heavy soil results in later blooming, slower growth and more problems with fungal diseases.

C. Seed Preparation and Germination:

Jojoba can be planted by direct seeding or by transplanting seedlings to the field. In the southwestern U.S. many growers prefer direct seeding because it is less expensive, faster and requires less hand labor. Seed can be germinated in vermiculite or sand at about 80°F. Emergence occurs in 15 to 20 days, and the seedlings are ready for transplanting when they are 6 to 12 in. tall (8 to 10 weeks). Emergence from direct-seeded fields occurs in 15 to 20 days. Propagation from clones or from tissue culture is a more rapid method of varietal improvement.

V. Cultural Practices:

A. Seedbed Preparation:

Jojoba plantations are established by clearing and leveling a site prior to seeding or planting seedlings, rooted cuttings or plantlets produced from tissue culture.

B. Seeding Date:

Jojoba can be seeded or transplanted to the field when the soil temperature reaches 70°F. Low soil temperature may delay emergence by as much as 2 to 3 months.

C. Method and Rate of Seeding:

Seeds are planted 1 in. deep, and emergence usually occurs within 20 days. The soil should be kept moist but not wet through emergence.

Individual seeds or seedlings are planted 12 to 18 in. apart in rows. Spacing between rows depends on the harvester to be used. With hand harvesting and cultivation, rows can be as close as 10 ft.

To obtain the proper female:male ratio (6:1), it is advisable to over-plant (7 to 9 lb/acre of seeds) and rogue out excess males later. As male plants flower, they should be thinned out to 1 male every 40 ft on the row. As female plants flower, usually in the third year, any slow-growing or unproductive plants are thinned out, leaving 1 female plant every 2 to 3 ft on the row.

D. Fertility and Lime Requirements:

Little information is available on the response of cultivated jojoba to lime or fertilizer applications. Jojoba grows wild on soils of marginal fertility with soil pH ranging from 5 to 8. The soils that jojoba is adapted to in the semiarid regions of Arizona, southern California and northwestern Mexico are generally slightly alkaline and have native high potassium levels. Based on this, one might assume that for best growth, soils should have a pH of 6 or more and available K levels of at least 100 ppm. Apply enough dolomitic lime according to soil test recommendations to raise soil pH to 6. Approximately 10 to 15 pounds of potash fertilizer should be applied if available K levels are less than 100 ppm. Yield trials conducted in California have not shown any improvement in vegetative growth with the addition of nitrogen or phosphorus, therefore no additional N or P_2O_5 fertilizers are recommended.

E. Variety Selection:

There are no improved varieties of jojoba. Some yield components that vary among wild jojoba stands include: seed size, oil content, number of flowers per node, early flowering, precocious seed production (starting before the fifth year), consistent high production from year to year, upright growth habit, and degree of frost tolerance. Work is underway to select for desired traits and plants suitable for mechanical harvest.

F. Weed Control:

Weeds must be controlled early in the establishment of the plantation. Weed control prior to planting and/or cultivation between rows during growth is needed until the jojoba plant is large enough to shade competing plants. No herbicides are registered for use on jojoba in the midwestern United States.

G. Diseases and Their Control:

On poorly drained soil, jojoba is susceptible to fungal wilts, including *Verticillium, Fusarium, Pithium* and *Phytopthora*.

H. Insects and Other Predators and Their Control:

More than 100 species of insects have been identified on jojoba, but few cause known economic damage. Infestations of spider mites, grasshoppers, and thrips may result in yield losses.

Fences may be necessary to eliminate browsing by wild animals who find the plant very palatable. This has been a major factor in the distribution of jojoba.

I. Harvesting:

All seeds on a jojoba shrub do not mature at the same time, and more than one harvest may be necessary. Most jojoba is currently harvested by hand. Over-the-row fruit and berry harvesting equipment is adaptable to jojoba harvesting.

J. Drying and Storage:

Jojoba seed that has been dried to around 10% moisture and protected from pest damage will keep for several years.

VI. Yield Potential and Performance Results:

Jojoba generally does not produce an economically useful yield until the fourth or fifth year after planting. Seed yields in natural stands of jojoba range from a few seeds to as much as 30 lb of clean, dry seed per plant. Production of seed varies greatly from plant to plant in a stand and from year to year for a particular plant.

Currently, the average yield of commercial jojoba plantations is less than 300 lb/acre. Plantations that were established with selected higher yielding clones are capable of producing up to 800 lb/acre. Crop improvement programs at the University of California-Riverside and the University of Arizona-Tucson are actively researching consistent productivity.

VII. Economics of Production and Markets:

In 1978, the cost of establishing jojoba in the southwestern U.S. (the first 3 years) was estimated to be $1,157/acre. Low yields and frost damage have resulted in financial losses for many farmers and investors. Successful long-term production of jojoba depends on improved yield and a strong market. Industry is typically hesitant to invest in new technology involving an agriculturally produced resource until a steady and continued supply of that resource can be demonstrated. The value of jojoba oil as an alternative industrial oil with multiple applications and as a replacement for non-renewable fossil petroleum has been demonstrated.

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Kenaf

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I. History:

Kenaf (*Hibiscus cannabinus* L.) is a fiber plant native to east-central Africa where it has been grown for several thousand years for food and fiber. It is a common wild plant of tropical and subtropical Africa and Asia. It has been a source of textile fiber for such products as rope, twine, bagging and rugs. Kenaf is a promising source of raw material fiber for pulp, paper and other fiber products, and has been introduced since WWII in China, USSR, Thailand, South Africa, Egypt, Mexico and Cuba.

Research in the United States to use the kenaf bast (outer bark) fibers for rope began in the 1940's when jute imports from Asia were interrupted by World War II. In the 1950's, the Agricultural Research Service (ARS) of the U.S. Department of Agriculture screened more than 500 plant species as potential fiber sources for pulp and paper manufacturing. As a result, kenaf was selected as the most promising nonwood fiber plant for this use. Continued research resulted in the development of high yielding, anthracnose resistant varieties. Today, research and development continues, primarily in Texas, Oklahoma, Mississippi and Southeastern U.S.A., with emphasis on development for newsprint manufacture.

II. Uses:

A. Fiber Uses:

Kenaf has a unique combination of long bast and short core fibers which makes it suitable for a range of paper and cardboard products. Scientists at the ARS have tested several kenaf pulping techniques, with the pulps being used to make several grades of paper including newsprint, bond, coating raw stock and surfaced sized. Results have been positive, particularly in terms of paper quality, durability, print quality and ink absorption.

Commercialization of kenaf for newsprint manufacturing is in its final stages. Commercial scale newsprint runs were conducted by the private sector in California, Texas and Florida. Newspapers made from kenaf pulp have been shown to be brighter and better looking, with better ink laydown, reduced ruboff, richer color photo reproduction and good print contrast. Quality analyses showed kenaf newsprint to have superior tear, tensile and burst ratings. Additionally, kenaf newsprint manufacturing requires less energy and chemicals for processing, an important advantage, both economically and environmentally.

B. Forage Uses:

The top leafy portion of the kenaf plant is not useful for pulping. Therefore, this part of the plant would be useful as forage if harvest equipment could be practically adapted to a dual collection operation.

Florida researchers found that immature plants at a height of 6 ft contained up to 20% protein. The kenaf ensiled successfully, both alone and with corn, and the silage was acceptable to heifers. They also found that kenaf leaf, dried and ground into a meal, had a greater crude protein digestibility than that of alfalfa meal. The amino acid composition of kenaf leaves is similar to that of alfalfa.

Oklahoma research showed that kenaf leaf and petiole (non-stalk) portions of the plant were readily consumed by lambs and contained low fiber and high N concentrations. Analysis of the leafy kenaf material showed values of 8.7% NDF, 3.5% ADF and 34.0% CP. Contrasted to this, total plant composition levels were 42.9%, 32.6% and 17.1% respectively. Clearly, the leaf and petiole portion of the plant contains the majority of the digestible nutrients.

C. Food Uses:

Where kenaf is grown in home gardens for fiber, the more tender upper leaves and shoots are sometimes eaten either raw or cooked.

III. Growth Habits:

Kenaf is a member of the mallow (Malvaceae) family, with okra and cotton as relatives. Kenaf plants grown in dense stands are largely unbranched and grow to a height of 8 to 14 ft and under certain conditions will reach 20 ft. The stem's outer bark contains the long soft bast fibers which are useful for cordage and textiles. Bast fibers make up 20 to 25% of the stem on a dry weight basis. Beneath the bark, a thick cylinder of short woody fibers surrounds a narrow central core of soft pith.

Stem color of most varieties is green, but there are several red-stemmed and purple-stemmed accessions. Leaf shape varies considerably. While the first few leaves of kenaf seedlings are not lobed, some varieties develop post-juvenile leaves that are very deeply lobed. The root system is very extensive, with a deep tap root and widespreading lateral roots.

Kenaf plants produce large cream-colored flowers only after day length reaches approximately 12.5 hours in the fall. Flower production is indeterminate. Kenaf is primarily self-fertile, but is considered an often cross-pollinated crop. Seeds are dark grayish-brown, flattened triangular shaped, 5 to 6 mm long. There are roughly 15,000 to 20,000 seeds/pound.

IV. Environment Requirements:

A. Climate:

The kenaf plant is said to have a wider range of adaptation to climates and soils than any other fiber plant in commercial production. Kenaf yields have been highest in regions with high temperatures, a long growing season and abundant soil moisture. It is quite sensitive to cool temperatures and grows slowly when temperatures are below 50°F.

Kenaf has performed well in the Gulf Coast region and the far southeastern United States. Yields in the Midwest U.S. have been high at times, but inconsistent. Length of frost-free season and availability of solar radiation may limit economic production of kenaf fibers in northern locations. Variety development for tolerance to cool air and soil temperatures could greatly expand kenaf's area of productive adaptation.

B. Soils:

Kenaf is adapted to a wide range of soil types, but performs best on the heavier, well drained, fertile soils. Kenaf does not perform well on soils with severe drainage problems. Prolonged periods of standing water, particularly during the seedling stage, can severely inhibit growth.

V. Cultural Practices:

A. Seedbed Preparation:

Kenaf seeds are relatively small and require good seed-soil contact for germination. Therefore, a fine, firm, well-prepared seedbed is necessary. Given the success of raised-bed kenaf production in Texas, ridge-till planting may be an effective option in northern areas.

B. Seeding Date:

Recommended planting dates are similar to those for soybeans. Warm, moist soils after danger of a killing frost has passed are the ideal planting conditions. Planting too early often results in poor emergence and slow, non-competitive growth. Planting too late will often result in reduced yield potential due to reduced solar radiation availability.

C. Method and Rate of Seeding:

The preferred plant population, row width and planting method may vary according to production region, growing conditions and cultivar used. More research is needed to determine interactions among these factors (particularly cultivar/population interactions) and to determine yield improvement potential through modification of these factors.

A harvest plant population of 75,000 to 100,000 plants/acre is generally recommended. However, as the crop is moved north, narrower rows and a population range of 100,000 to 120,000 plants/acre may be more desirable. Plants in stands that are too dense for the cultivar or seasonal growing conditions tend to be short, spindly and weak-stemmed. Plants in stands that are too sparse produce lateral branches that are too heavy. In both cases lodging is inevitable. Row spacing decisions should consider probable weed problems and control measures, harvest method and plant population goal.

Seed should be planted less than 1 in. deep if the soil moisture and seedbed texture are suitable. Kenaf can emerge from a depth of 2.5 in. under the most favorable conditions. The importance of high quality seed (germination over 80%), and equipment that gives uniform seed placement and good seed-soil contact cannot be overemphasized.

D. Fertility Requirements:

Kenaf's response to added fertilizers depends on soil nutrient levels, cropping history and other environmental and management factors. A range of fertility responses have been reported. In general, added nitrogen has increased kenaf yields. Some important considerations:

- Fertility programs should focus on vegetative needs rather than grain/reproductive needs. Kenaf, unlike cotton, for example, produces a vegetative fiber rather than a fruiting fiber.
- Kenaf, with its deep tap root and widespreading lateral root system, is considered to be an excellent user of residual nutrients from previous crops.
- At harvest, kenaf leaves are left in the field. It has been estimated that this leaf material can return from 50 to 100 pounds of nitrogen/acre.

E. Variety Selection:

In the U.S., the varieties used most extensively are those developed by ARS researchers in Florida - 'Everglades 41' and 'Everglades 71'. Both varieties are resistant to anthracnose. Since their development in the 1960's, there has been little variety development activity, although the ARS is initiating new breeding efforts. Genetic improvements for adaptation to northern environments may be feasible.

F. Weed Control:

In the southern U.S., kenaf emerges and grows so rapidly that it competes effectively with weeds. In cooler climates and with earlier planting dates, cultural and/or chemical weed control measures are more important. One weed species which is especially competitive with kenaf is velvetleaf, a relative of kenaf. At the seedling stage, velvet leaf and kenaf are very similar in appearance and rate of growth. Fields with high populations of this weed are not recommended for kenaf production.

Satisfactory weed control and crop tolerance have been demonstrated for many of the common preplant-incorporated, preemergence and postemergence herbicides. Special-Local-Need labeling, leading to full registration, is being pursued in some states.

Cultivation and other postemergence tillage practices such as rotary hoeing can be effective in controlling weeds. In the absence of herbicide registration for kenaf, and particularly in cooler climates which inhibit rapid early plant growth, mechanical weed control should be used.

G. Diseases and Nematodes:

Growers and researchers have found kenaf to be resistant to most plant diseases. Anthracnose is perhaps the most serious potential disease problem. The variety development work done by the ARS in Florida was very effective in breeding and selecting for anthracnose resistance. Damping-off is a moderate concern during seedling stages and seed treatments are being tested and registered for use.

Nematodes are viewed in some areas as the most serious constraint to kenaf production. In cotton growing areas, the root-knot nematode/fusarium wilt complex is expected to limit yield potential for both cotton and kenaf, and will create crop rotation challenges due to the common susceptibility of the two crops.

H. Insects:

There has been little economic damage to kenaf by insects in experimental production fields. Potential insect problems could arise in the early stages of seedling emergence and development. However, the kenaf plant tolerates a fairly high population of chewing and sucking insects, and since the production emphasis is biomass rather than root, seed, fruit or flower, the required level of insect protection for kenaf may be much less than for most commercial crops.

I. Harvesting, Drying and Storage:

Several harvest and storage methods have been tested. The preferred system will likely vary from one area to another because of differences in climate and milling requirements. Until recently, the most feasible method appeared to be chopping the green or air-dried plants with a forage chopper. The green material can be stored anaerobically like silage and the air-dried material can be piled or loosely stacked or baled.

The most recent innovation has been the development of an 8-row harvest machine which cuts the stalks and lays them down for drying in the field. The dried stalks are gathered, shredded at the field and transported to the fiber mill's storage area.

VI. Yield Potential and Performance Results:

Yields in research plots have varied widely, from 2.5 ton/acre at Rosemount, Minnesota, to 15 ton/acre at College Station, Texas. One-acre blocks at Fort Gibson, Oklahoma yielded nearly 10 ton/acre in 1988. Commercial scale production in Texas has produced dry-weight yields of 7.5 ton/acre under irrigation and 6.0 tons/acre on dryland.

Fiber production field trials in the southeast U.S. have shown that kenaf can yield three to five times more fiber/acre/year than southern pine. With U.S. annual consumption of newsprint at over 12 million tons (1988), and with 60% of that volume imported at a cost of approximately $4.5 billion, the further commercialization of kenaf as a source of paper pulp would appear promising. However, successful commercialization will be dependent upon local cost comparisons which will consider economies of scale, transportation costs and local processor demand.

VII. Economics of Production and Markets:

Successful introduction of any new crop depends on establishment of markets for the raw and processed crop materials, in concert with development of production areas. There appear to be significant markets for kenaf fibers in the manufacture of pulp, paper and paperboard products, and as synthetic fiber substitutes. Projections show that by the year 2000, over one million acres of kenaf would be needed annually to supply just the increase in U.S. newsprint demand over 1990 levels, without reducing the volume of newsprint imports or the consumption of wood fibers.

Production of kenaf as an industrial raw material will necessarily be localized in the same region as processing facilities. The unprocessed crop is too bulky to be transported great distances. As with many processed food crops, the actual price that producers receive for raw product will be determined by contract negotiation between them and the processors. That price must consider production costs, the comparable risks and profits of producing conventional crops and the comparable prices paid by potential customers for traditional fiber supplies. A producer would also need to consider kenaf's impact on government programs and its effects on crop rotations and on productivity of other crops in a rotation.

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Kochia

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I. History:

Kochia (*Kochia scoparia* (L.) Roth), also known as fireweed, burning bush or summer cypress, was introduced to the United States around 1900 as an ornamental from Eurasia. Gardeners like this annual plant for its bright red foliage in autumn.

Farmers in dry areas, including the Southwest, have grown kochia as a drought-resistant forage crop on lands where other crops are difficult to grow -- hence the nickname "poor man's alfalfa." Because of kochia's low water requirements and resistance to diseases and insects, interest in it as a forage crop has increased in the last decade. Researchers at South Dakota State College have selected seeds from wild plants and produced satisfactory yields of leafy foliage.

Kochia, with its high protein content, requires relatively large amounts of nitrogen (100 to 250 lb/acre). If too much nitrogen is applied at once, however, toxic levels of nitrate may accumulate in the plants. Oxalate toxicity, which causes rough hair, humpback, jaundice, photosensitization and a stiff gait in livestock, is another potential problem for cattle that graze only on kochia for periods of 90 to 120 days.

Kochia grows wild throughout most of the northern half of the United States, except for parts of the Pacific Northwest. **The plant has become a serious drought-resistant weed in the Plains states.** Because of the wide genetic variability in wild kochia, it is possible that the problems associated with the plant as a forage crop can be overcome with plant breeding.

II. Uses:

Kochia is grown as a forage crop for sheep and cattle and as an ornamental. As a forage crop its feed value is slightly lower than that of alfalfa. Protein content ranges from 11 to 22%, and decreases as the plant matures. When cut at the recommended stage, kochia hay contains up to 60% leaves and has good aroma. Palatability of kochia is better than that of grasses, such as bromegrass, but a little lower than that of alfalfa. No objectionable milk flavor results from feeding kochia hay.

Oxalate levels for kochia range from 6 to 9%. Feeding calcium phosphate and other kinds of feed (such as alfalfa) tends to reduce oxalate toxicity. Animals with symptoms of oxalate toxicity should be removed from kochia immediately.

Kochia can be used in revegetation programs for erosion control. It will germinate and grow at any time in the growing season, and it thrives in sandy, alkaline and other poor soils. Kochia can be sown by airplane on large areas that need revegetation, such as areas that have been devastated by fire. It provides a quick groundcover to protect topsoil and provide a food source for wildlife until native grasses take over.

III. Growth Habits:

Kochia is an annual forb that reproduces by seed. The bushy plants grow 1 to 7 ft tall and have taproots. The erect, striated stems are light green and much branched. The many alternate leaves are hairy, 1 to 2 in. long, narrow, pointed and attached directly to the stems. Small, green flowers and seeds are produced in narrow heads at the leaf axils. The plant is dark green when young and turns red as it matures. The seeds, when mature, are rough, flat, triangular and grayish-black in color. In the fall, the plants often break away from the roots and tumble over the ground, scattering the seeds.

IV. Environment Requirements:

A. Climate:

Kochia grows wild throughout much of the country, including the Upper Midwest. It can produce forage with as little as 6 in. of annual rainfall and is relatively cold hardy. It can be planted when soil temperatures are as low as 50°F.

B. Soil:

Kochia is grown on dry pastures, rangelands and cropland with alkaline soils. It will grow on land where other crops will not. Wild kochia has not spread to areas with very acid soils, and it is not known how well kochia would perform in such soils.

C. Seed Preparation and Germination:

The seed needs no treatment prior to planting. A properly managed kochia field will reseed itself. Grazed plants appear to produce more seed than the ungrazed ones, providing there is enough plant remaining at normal seeding time to provide seed shoots.

V. Cultural Practices:

A. Seedbed Preparation:

For best results, the soil should be plowed or disked to provide a firm, even and relatively weed-free seedbed. Nitrogen at 50 to 100 lb/acre should be applied prior to planting.

B. Seeding Date:

Kochia should be seeded as early as the soil temperature reaches 50°F (late April to early May) and anytime thereafter throughout the growing season.

C. Method and Rate of Seeding:

Seeding rates vary from 1 to 4 lb/acre, depending on the seeding method. Drilling as little as 1 lb/acre in 36 in. rows with a standard drill will result in a good stand; broadcast or airplane seeding requires more seed.

Though kochia seed does not need to be incorporated, research conducted in New Mexico indicates that a 1/4 in. seeding depth results in best emergence. Emergence is poor when seed is planted 3/4 in. deep or deeper.

Most kochia stands need thinning to prevent the crop from crowding itself out, particularly if a volunteer crop emerges the second year. The crop can be thinned to 2 to 10 plants/ft of row by chiseling at right angles or windrowing portions of the field and letting livestock clean up the dry feed as they graze the green material. Another method is to let cattle graze the kochia field for a short time when the plants are only 2 in. high.

D. Fertility and Lime Requirements:

Kochia is well adapted to alkaline soils, but it is not known how well it does on acid soils. Therefore, lime to a pH of 6.0; or try liming to different pH levels and observe the performance at each.

Because kochia is not a legume, nitrogen needs to be applied in proportion to the amount removed. This amounts to 40 to 60 lb N/ton of hay removed, or 100 to 250 lb N/acre. Do not apply more than 150 lb N/acre in one application, or nitrate toxicity can result. Apply 50 to 100 lb/acre prior to planting, and topdress the remainder later in the season based on anticipated yield.

Kochia responds very little to phosphorus and is low in this element. Cattle grazing on kochia should be fed supplemental phosphorus. Under conditions of adequate moisture, high phosphorus, zinc and boron levels suppress yield. The use of manure to supply nitrogen will likely result in excess phosphorus. Because the potash requirements of kochia are not known, adjust soil K to a medium level. Experiment with additional potash to find a rate suitable for your growing conditions. Suggested rates are 24 to 50 lb K_2O/ton of hay harvested.

E. Variety Selection:

Though there is wide genetic variability in wild kochia, no improved varieties have been developed.

F. Weed Control:

Kochia does not compete well with grasses. This will be a major limitation to use in the Upper Midwest. It is best to plant kochia on a relatively weed-free seedbed with no quackgrass or other grassy weed history. There are no herbicides registered for use in kochia.

Volunteer kochia will be a problem in crops following kochia, thus cultural or chemical control of kochia will be needed in these crops.

G. Diseases and Their Control:

Kochia appears to be free of diseases that cause commercial loss.

H. Insects and Other Predators and Their Control:

Kochia is relatively unharmed by grasshoppers. No information is available on other predators.

I. Harvesting:

1. For pasture: To prevent oxalate toxicity, livestock should not graze on only kochia for more than 90 to 120 days. Rotational grazing of other crops will prevent oxalate poisoning. In contrast to perennials, the entire kochia plant can be eaten.

2. For hay or silage: Kochia should be cut for hay or silage when it is 18 to 26 in. tall and before it has produced seed. In the Southwest, three or four cuttings are possible in a growing season if live branches are left on the stubble each time.

If the kochia crop is thin, it can be cut with a mower with a windrower attachment. Thick stands should be windrowed with a side-delivery rake. The hay can be cured in the windrow or in shocks.

3. For seed: Seed can be harvested using a combine.

J. Drying and Storage:

It may take up to one day longer to field cure kochia hay than it does for alfalfa hay. Because kochia plants are hairy, the cured forage has a gray color which may resemble mold or spoilage. Hay can be stored in stacks or bales.

VI. Yield Potential and Performance Results:

Kochia produces hay yields of 1 to 4 ton/acre (dry matter) and seed yields of 1,500 to 2,000 lb/acre.

VII. Economics of Production and Markets:

Kochia is relatively inexpensive to produce and well adapted for use on dry or low fertility land. Markets for seed are few in number and may be difficult to identify.

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References to seed dealers and pesticide products in this publication are for your convenience and are not an endorsement of one product over other similar products. You are responsible for using pesticides according to the manufacturer's current label directions. Follow directions exactly to protect people and the environment from pesticide exposure. Failure to do so violates the law.

Psyllium

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I. History:

Psyllium is the common name used for several members of the plant genus *Plantago* whose seeds are used commercially for the production of mucilage. The genus *Plantago* contains over 200 species. *P. ovata* and *P. psyllium* are produced commercially in several European countries, the former Soviet Union, Pakistan, and India. *Plantago* seed known commercially as black, French or Spanish psyllium is obtained from *P. psyllium* and *P. arenaria*. Seed produced from *P. ovata* is known in trading circles as white or blonde psyllium, Indian Plantago or Isabgol. Isabgol, the common name in India for *P. ovata*, comes from the Persian words "isap" and "ghol" that mean horse ear, which is descriptive of the shape of the seed. India dominates the world market in the production and export of psyllium. Psyllium research and field trials in the U.S. have been conducted mainly in Arizona and also in Washington.

Recent interest in psyllium has arisen primarily due to its use in high fiber breakfast cereals and from claims that these high fiber cereals containing psyllium are effective in reducing cholesterol. Several studies point to a cholesterol reduction attributed to a diet that includes dietary fiber such as psyllium. Research reported in The American Journal of Clinical Nutrition concludes that the use of soluble-fiber cereals is an effective and well tolerated part of a prudent diet for the treatment of mild to moderate hypercholesterolemia. Research also indicates that psyllium incorporated into food products is more effective at reducing blood glucose response than use of a soluble fiber supplement that is separate from the food. Although the cholesterol reducing properties and glycemic response properties of psyllium containing foods are fairly well documented, the effect of long term inclusion of psyllium in the diet has not been determined. Cases of allergic reaction to psyllium containing cereal have been documented.

II. Uses:

Psyllium is produced mainly for its mucilage content, which is highest in *P. ovata*. Mucilage describes a group of clear, colorless, gelling agents derived from plants. The mucilage obtained from psyllium comes from the seed coat. Mucilage is obtained by mechanical milling/grinding of the outer layer of the seed. Mucilage yield amounts to approximately 25% or more (by weight) of the total seed yield. *Plantago* seed mucilage is often referred to as husk or psyllium husk. The milled seed mucilage is a white fibrous material that is hydrophilic (water-loving). Upon absorbing water the clear colorless mucilaginous gel that forms increases in volume by ten-fold or more. Psyllium is mainly used as a dietary fiber, which is not digested by action in the small intestine. The purely mechanical action of psyllium mucilage absorbs excess water while stimulating normal bowel elimination. Although its main use has been as a laxative, it is more appropriately termed a true dietary fiber.

The United States is the world's largest importer of psyllium "husk" with over 60% of total imports going to pharmaceutical firms for use in products such as "Metamucil", "Effersyllium" and "Fiberall". Psyllium mucilage is also used as a natural dietary fiber for animals. The dehusked seed that remains after the seed coat is milled off is rich in starch and fatty acids and is used in India as chicken feed and as cattle feed.

Psyllium mucilage possesses several other desirable properties. As a thickener, it has been used in ice cream and frozen deserts. A 1.5% weight/volume ratio of psyllium mucilage exhibits binding properties that are superior to a 10% weight/volume ratio of starch mucilage. The viscosity of psyllium mucilage dispersions are relatively unaffected between temperatures of 68 to 122°F, by pH from 2 to 10 and by salt (sodium chloride) concentrations up to 0.15 M. These properties in combination with psyllium's natural fiber characteristic may lead to increased use by the food processing industry. Technical grade psyllium has been used as a hydrocolloidal agent to improve water retention for newly seeded grass areas and to improve transplanting success with woody plants.

III. Growth Habit:

Plantago ovata is an annual herb that grows to a height of 12 to 18 in. Leaves are opposite, linear or linear lanceolate (0.4 × 7.5 in.) The root system has a well developed tap root with few fibrous secondary roots. A large number of flowering shoots arise from the base of the plant. Flowers are numerous, small, and white. Plants flower about 60 days after planting. The seeds are enclosed in capsules that open at maturity.

IV. Environment Requirements:

A. Climate:

P. ovata is a 119 to 130 day crop that responds well to cool, dry weather. In India, *P. ovata* is cultivated mainly in North Gujarat as a "Rabi" or post rainy season crop (October to March). During this season, which follows the monsoons, average temperatures range between 60 to 85°F and moisture is deficient. Isabgol (*P. ovata*) which has a moderate water requirement, is given 5 to 6 light irrigations. A very important environmental requirement of this crop is clear, sunny and dry weather preceding harvest. High night temperature and cloudy wet weather close to harvest have a large negative impact on yield. Rainfall on the mature crop may result in shattering and therefore major field losses. The growing season in Wisconsin and Minnesota is not likely to be suitable for production of psyllium.

B. Soil:

Isabgol grows best on light, well drained, sandy loams. The nutrient requirements of the crop are low. In North Gujarat, the soil tends to be low in nitrogen and phosphorus and high in potash with a pH between 7.2 and 7.9. Nitrogen trials under these conditions have shown a maximum seed yield response with the addition of 20 lb/acre of nitrogen.

C. Seed Preparation and Germination:

P. ovata has small seeds, 1000 seeds weigh less than 2 grams. Under ideal conditions of adequate moisture and low temperature (50 to 68°F) 30% of the seed germinates in 5 to 8 days. The seed shows some innate dormancy (3 months) following harvest. Various treatments including wet and dry heat, cold, scarification, ethylene and CO_2 do not eliminate this dormancy period. Post-dormancy seeds show reliable germination in excess of 90% at 84°F and lower rates of germination as temperature is increased.

V. Cultural Practices:

The fields are generally irrigated prior to seeding to achieve ideal soil moisture, to enhance seed soil contact, and to avoid burying the seed too deeply as a result of later irrigations or rainfall. Maximum germination occurs at a seeding depth of 1/4 in. Emerging seedlings are frost sensitive, therefore planting should be delayed until conditions are expected to remain frost free. Seed is broadcast at 5 to 7.5 lb/acre in India. In Arizona trials, seeding rates of 20 to 25 lb/acre resulted in stands of 1 plant/in. in 6 in. rows produced excellent yields. Weed control is normally achieved by one or two hand weedings early in the growing season. Control of weeds by pre-plant irrigation that germinates weed seeds followed by shallow tillage may be effective on fields with minimal weed pressure. Psyllium is a poor competitor with most weed species.

Plantago wilt *Fusarium oxyspirum* and downy mildew are the major diseases of Isabgol. White grubs and aphids are the major insect pests.

The flower spikes turn reddish brown at ripening, the lower leaves dry and the upper leaves yellow. The crop is harvested in the morning after the dew is gone to minimize shattering and field losses. In India, mature plants are cut 6 in. above the ground and then bound, left for a few days to dry, thrashed, and winnowed.

Harvested seed must be dried below 12% moisture to allow for cleaning, milling, and storage. Seed stored for future crops has shown a significant loss in viability after 2 years in storage.

VI. Yield Potential and Performance Results:

The contract price for 95% purity psyllium husk set by the Indian Basic Chemical, Pharmaceutical and Cosmetic Export Promotion Council for April of 1988 was $1.65/lb F.O.B. This price is up from $1.14/lb set in 1985. The average seed yield of *P. ovata* in India often exceeds 1000 lb/acre. Net yield of 95% purity husk after milling would be 250 lb/acre. Average gross revenue from milled product at 1988 prices would be $412/acre. The costs of production and milling in the U.S. are unknown but would certainly need to be determined in order to analyze the potential profitability of a commercial psyllium venture.

VII. Economics of Production and Markets:

The U.S. currently imports and consumes approximately 8,000 metric tons of psyllium annually. A continued expansion of this market seems likely due to the high level of interest in natural dietary fibers. No variety has been tested in the Upper Midwest but it would seem that the varieties that are grown in India would not be suited to production in this area. A major cultural problem limiting psyllium production in this area is the shattering characteristic of the mature crop. Some success has been achieved by cross-breeding high yielding Indian varieties with varieties that are more shatter resistant. Until shatter resistant varieties are available, production of Isabgol is likely to be restricted to environments that consistently provide a cool dry harvest season.

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Sorghum—Forage

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I. History:

Sorghum (*Sorghum vulgare* Pers.) is indigenous to Africa, and many of today's varieties originated on that continent. Sorghum was also grown in India before recorded history and in Assyria as early as 700 BC. The crop reached China during the thirteenth century and the Western Hemisphere much later.

Sorghum was introduced to the United States from Africa in the early part of the seventeenth century. It was not grown extensively in this country until the 1850s, when the forage variety Black Amber (also called "Chinese sugarcane") was introduced by way of France. Since then many other varieties have been introduced from other countries and developed domestically.

Sorghum was grown primarily as a source of sugar for syrup until the settlement of the semiarid West created a demand for drought- resistant forage crops. By the 1950s, about 90% of the acreage of sweet sorghums in the United States was grown for forage.

Currently there are five major types of sorghum grown:

1. **Grain sorghum** with dwarf varieties that grow 2 to 5 ft tall for easier combining.
2. **Forage sorghum** which grows 6 to 12 ft tall, produces more dry matter tonnage than grain sorghum, is coarse stemmed and used for silage.
3. **Sudangrass**, a fine stemmed, short season sorghum grown to furnish pasture or green feed during mid-summer when perennial grasses are dormant.
4. **Sorghum-sudangrass** hybrids are a cross between the two forage types that have intermediate yield potential and can be used for pasture, hay or silage.
5. **Sorghum-almum**, also called Columbusgrass, sorghumgrass, sorgo negro or sudan negro.

Sorghum production is concentrated in areas where corn production is limited because the rainfall is insufficient or unfavorably distributed and the temperatures are too high. Thus most of the domestic sorghum acreage is in the southern Great Plains states, with Texas, Kansas and Nebraska the leading producers. However, some sweet sorghum has been grown for syrup or silage in Wisconsin since the state was settled.

Forage sorghum production has been limited in the Upper Midwest because the crop matures late and, except on droughty soils, does not generally produce as many total digestible nutrients per acre as well-adapted, high yielding corn hybrids. Recently, there has been renewed interest in the crop during seasons of high temperatures and drought.

II. Uses:

Forage sorghums are used primarily as silage for livestock. They are sometimes grown and harvested with soybeans to improve the protein content of the silage. Sudangrasses and sorghum- sudangrass hybrids are grazed by livestock or fed as green chop or hay.

Sorghum harvested at the soft dough stage of development and stored as silage contains 52 to 65% dry matter digestibility, 8 to 12% crude protein, 60 to 75% neutral detergent fiber, and 34 to 40% acid detergent fiber. The higher the grain content, the higher the digestibility. Ensiled grain has a digestibility of about 90%.

Forage sorghum usually produces as much silage per acre as corn. However, sorghum silage contains less grain and is higher in fiber than corn silage. Though the protein content of sorghum silage is similar to or slightly higher than that of corn, it is less digestible. Animal consumption of sorghum silage is also generally somewhat less than that of corn.

To obtain the optimum rate of gain for most livestock, sorghum silage must be supplemented with protein, minerals and vitamins. It is generally suggested that sorghum silage constitute not more than 50% of the forage in dairy cow rations but may be adequate alone for other categories of animals.

Sorghum plants, particularly young plants, contain an alkaloid which releases hydrocyanic, or prussic acid, when hydrolized. This can be toxic to livestock. Young plants, branches in the leaf axils of injured plants and new shoots from the crown at the soil surface contain more than twice as much acid as the mature leaves of normal plants. When the crop is cut and field-cured, or is ensiled, and the hydrocyanic acid degrades (2 to 3 weeks after ensiling), and the danger is greatly reduced. Sudangrass contains less than half as much hydrocyanic acid as most sorghums. A low-acid Sudangrass variety (Piper) was released by researchers in Wisconsin.

During periods of drought or other plant stress, sorghums tend to accumulate nitrates, which can poison livestock. If retarded crop growth is observed, analyze the forage for excessive nitrates before feeding it. In the case of high nitrate levels, the forage should be ensiled or combined with other feeds low in nitrate to reduce daily nitrate intake.

III. Growth Habits:

Sorghum is a coarse grass that grows as an annual in the Upper Midwest. Stems are erect and solid and reach a height of 2 to 12 ft. In many respects, the structure, growth, and general appearance of forage sorghums are similar to corn: stalks have a groove on one side between the nodes; grooved internodes alternate from side to side; a leaf is borne at each node on the grooved side, with the leaf sheath and blade arrangement also much like that of corn.

The buds which form at the nodes often develop into branches. Buds that form near the crown develop into grain-producing tillers. The tillers develop their own roots but remain attached to the old crown. The culms or stalks of forage sorghums are juicy. If the pith is not juicy, the midrib of the leaf is white in color because of the air spaces in the tissues; when the air spaces are filled with juice, the color is more neutral. Because of this difference in moisture content, juicy and non-juicy stalked varieties will be at different stages of maturity at the optimum time for silage. Otherwise, there is no difference between juicy and non-juicy stalked hybrids.

Another variation between varieties is the sweetness of the juice within the stalk. Sweetness is not related to juiciness; a dry-stalked sorghum can be either sweet or non-sweet, just as a juicy stalked sorghum can. A sweet forage sorghum is preferred by livestock and likely to be consumed in greater quantity if it is used as green chop, hay or bundle feed. Stalk sweetness appears to be of no concern if the crop is to be ensiled because most of the soluble plant sugars are converted to organic acids in the fermentation process.

Under drought conditions, sorghum leaves tend to fold rather than roll, as do corn leaves. A heavy white wax (bloom) usually covers sorghum leaf blades and sheaths, protecting them against water loss under hot, dry conditions.

In contrast to corn, both the male and female flowers of sorghums are in a panicle at the end of the culm. The panicle may be loose and open. About 95% of the flowers are self-pollinated, although this varies with the variety grown.

Seeds vary in color among the sorghum varieties, from white to dark brown. The endosperm is white, and the sorghums have a deficiency of Vitamin A, as does white corn. Though seed size varies considerably among the sorghums, it ranges from approximately 1,000 to 2,000 seeds/oz.

IV. Environment Requirements:

A. Climate:

Sorghums are fast-growing, warm weather annuals that will provide plenty of feed in mid-summer when many other forages slow down. Sorghums are best suited to warm, fertile soils; cool, wet soils limit their growth. Therefore, their production in the Upper Midwest may be limited. The crop tolerates drought relatively well, though adequate fertility and soil moisture maximize sorghum yields. The plant becomes dormant in the absence of adequate water, but it does not wilt readily. Growth resumes when moisture conditions improve.

Sudangrass and sorghum-sudangrass hybrids can be successfully grown where "95 RM" or later maturity corn hybrids can be produced for grain. However, early maturing varieties can be grown farther north on sandy soils which warm up quickly in the spring. Where moisture is limited, sorghums and sorghum- sudangrass hybrids generally produce more silage than corn. Forage sorghums, which are generally later in maturity than sudangrass, may not mature enough for silage even when grown in southern Wisconsin and Minnesota.

B. Soil:

Sorghums need a warm, fertile soil.

C. Seed Preparation and Germination:

Seed should be treated with a fungicide, such as Captan, to control seed rots and seedling blights. The effectiveness of the seed treatment will be reduced if germination and emergence are delayed due to cold, wet soil conditions. Soil temperature should be 60°F for germination; rapid germination and emergence occur when soil temperature is 70°F.

V. Cultural Practices:

A. Seedbed Preparation:

Seedbed preparation is similar to that for corn. A firm, well- prepared seedbed is essential for a full stand. Plow in the fall or just before planting; fall plowing will provide a firmer seedbed. For sandy soils, do not disk or harrow after plowing because of wind erosion hazards.

B. Seeding Date:

Sorghums are generally sown between May 20 and June 5. The soil should be warm (65 to 70°F) at 4 in. Sorghum seedlings are slow growing, especially in cool soils. Consequently weed control may be a problem under these conditions.

C. Method and Rate of Seeding:

The seeding rate and method depends on the use for the crop and the equipment available. Sow sudangrass or sorghum-sudangrass hybrids grown for pasture or green chop at 20 to 30 lb/acre with a grain drill or a broadcast seeder. If a broadcast seeder is used, cover the seed with about 1 in. of medium or heavy soil or 1 1/2 in. of sandy soil. For sudangrass pasture, plant 1/3 to 1/2 acre/cow. Delaying the seeding on one-half the area for 2 weeks will spread production over a longer grazing season. Surplus forage can be harvested and stored as silage or as hay.

For silage production, the usual procedure is to plant forage sorghum in rows at a seeding rate of 5 to 10 lb/acre. Plants grown in 30 to 40 in. rows usually yield as much as those grown in solid stands, and the lower leaves are retained on the plant longer. Planting in rows reduces lodging and permits harvesting with conventional silage equipment.

D. Fertility and Lime Requirements:

Soil fertility requirements are somewhat similar to those of corn at the same yield goals, although sorghums are usually more efficient in their use of phosphorus and potassium. Follow soil test recommendations to determine nutrient needs and fertilizer recommendations. A 5 to 7 ton forage sorghum crop will remove about 40 lb/acre P_2O_5 and 180 lb/acre K_2O. Follow soil test recommendations to determine nutrient requirements. Under dryland conditions, 60 to 120 lb/acre N is recommended, with soils higher in organic matter requiring the smaller amounts. On sandy soils apply half the nitrogen before planting and the remainder within 30 days after emergence. Where the sorghum is planted in rows, the nitrogen may be sidedressed when the crop is 8 to 16 in. tall.

Sorghum seed is sensitive to fertilizer burn. Therefore, for row planting place fertilizer 2 in. to the side and at or slightly below seed depth. For broadcast stands, work fertilizer into the soil thoroughly before sowing.

A soil pH of 6.0 is adequate for sorghum production.

E. Variety Selection:

Types of sorghum include sudangrass, sorghum-sudangrass hybrids, forage sorghums and *Sorghum almum*. *Sorghum almum* is not recommended because tests show no superiority as a silage or pasture crop in Wisconsin or Minnesota. Prussic acid content ranges from 4 to 10 times higher in *Sorghum almum* than in Piper sudangrass. Volunteer plants may also become weed problems in succeeding crops.

Sudangrass can be harvested as pasture, green chop or silage, but is superior in forage yields to other sorghums only when used for pasture. It provides abundant pasture in mid to late summer when perennial cool season forages, such as alfalfa, timothy, and bromegrass are generally dormant. Yields of 3 to 4 tons/acre of dry matter or 10 to 12 tons/acre of green feed or silage are possible. Sudangrass can be pastured 5 to 6 weeks after planting. The pasture may be cut or grazed when regrowth reaches 18 to 20 in., which may take 3 to 4 weeks under favorable weather conditions. In the Upper Midwest three or more cuttings per season are common. Hay as green chop should be made at or before the boot stage, approximately 7 to 8 weeks after planting. (45 to 60 days are required for regrowth before a second cutting.) Piper is an early maturing sudangrass variety that is preferred for pasture. Piper usually yields as much as any other variety for pasture, has a low prussic acid content and has more disease resistance than other sudangrass varieties.

Sorghum-sudangrass hybrids are taller, have larger stems and can be higher yielding than sudangrass. In Wisconsin, however, they have generally yielded no more than Piper sudangrass when harvested three times at pasture growth stages. At Rosemont, MN 'Sudan' sorghum sudangrass hybrid averaged about 1 ton/acre more than Piper sudangrass when cut twice. The hybrids seem more vigorous under less frequent cutting, so they may yield more than Piper. Sorghum-sudangrass hybrids have higher stalks than sudangrass and are normally harvested for green chop or silage but may be used for pasture or hay if chilled at a high seeding rate and harvested at immature stages (18 to 24 in. tall) when harvested as green chop or silage. The sorghum-sudangrass hybrids usually yield less than forage sorghums.

Forage sorghums are best harvested as silage. The feed value (TDN) of sorghum silage per acre is about 90% that of corn silage. On more productive soils, with favorable moisture and fertility, corn is a better silage crop, producing comparable yields and higher feed value than forage sorghums and sorghum- sudangrass hybrids, (Table 1). On light droughty soils, however, forage sorghums and sorghum-sudangrass hybrids are superior to corn in some years. Most forage sorghums and forage sorghum hybrids are medium to late maturing.

Table 1. Silage dry matter yield and quality of annual forages at Rosemount, Minnesota.[1,2,3]

Species	Variety	Yield (T/acre)	Forage quality		
			CP (%)	DDM (%)	NDF (%)
Dent corn	Pioneer 3732	9.4	6.7	67.6	41.3
Sorghum	Sweetreat	9.5	5.2	64.7	44.7
	Sorgo 10	7.6	7.1	58.9	52.1
	Pioneer 956	8.8	5.9	54.7	61.5
	Pioneer 931	10.1	6.1	47.6	69.3
Popcorn	Purdue 405	6.4	6.9	65.2	57.1
Sweet corn	Jubilee	5.6	9.3	73.6	35.4

[1]Forage seeded 7 May and fertilized with 150 lb N/A.
[2]Plant population: Corn-28,000 ppa; Sorghums-150,000 ppa.
[3]Harvest stage and data: All corn harvested at black layer, sorghums at hard dough; Pioneer 931 did not set seed.

F. Weed Control:

1. Mechanical: Sudangrass and sorghum-sudangrass hybrids planted in a well-prepared, warm seedbed germinate and grow rapidly and can compete well with most annual weeds. Weeds can be controlled with cultivation if the crop is planted in rows 20 in. or more wide.

2. Chemical: If weeds become a problem, it may be necessary to use herbicides to control weeds until a full leaf canopy is formed. Few of the herbicides registered for use in grain sorghum are specifically approved for use in forage sorghums. Check with your local extension office or crop consultant if you need information on herbicides.

G. Diseases and Their Control:

A seed treatment, such as Captan or Vitavax, should be used to control seed rots and seedling blights.

Stalk and root rots are not often problems in forage sorghum because harvest for silage generally takes place before the disease causes much damage. Charcoal rot, which develops under hot, dry conditions after the plants have bloomed, occasionally causes serious lodging problems. Early harvest may be necessary in the most severe cases.

Foliar diseases are rarely a problem when sorghum is to be harvested for silage, because they also generally appear at later stages of plant growth. Northern corn leaf blight has been a problem in the Upper Midwest. Maize dwarf mosaic (MDM), a virus carried from overwintering johnsongrass and other weeds by several aphid species, can be controlled by choosing resistant or tolerant hybrids. There are also strains resistant to anthracnose, which can attack leaves and/or stalks. Genetic resistance has not yet been developed for sorghum downy mildew, a soil-borne fungus disease which can be a serious problem for forage sorghum production. However, this disease has not occurred in the Upper Midwest.

Losses due to disease can be minimized by selecting resistant hybrids, planting disease-free seed, providing optimum growing conditions (soil fertility and pH), rotating with other crops and removing infested debris.

H. Insects and Other Predators and Their Control:

Forage sorghums are attacked by wireworms, seed beetles, cutworms, aphids (especially greenbugs), sorghum midge, chinch bugs, spider mites, armyworms and earworms. Some of these pests can be controlled with insecticide seed treatments in the planter box. However most of these insects do not normally occur in sufficient populations to warrant control in the Midwest.

I. Harvesting:

Sorghum and sorghum-sudangrass leaves and stems are coarse and high in moisture at time of harvest. Sweet sorghum and sorghum- sudangrass often cannot be stored as hay because of the difficulty in drying the forage to a safe storage moisture content of 25% or less.

Sudangrass should be harvested for hay whenever it reaches the boot stage. Harvesting solid stands that have been allowed to reach 4 ft or more in height may be difficult with conventional equipment. Forage cut at earlier stages of growth is easier to handle and higher in feeding value. Cut at a 6 in. height to allow more rapid regrowth.

1. For pasture: Sudangrass and sorghum-sudangrass hybrids are usually ready for grazing 5 to 6 weeks after planting. Since prussic acid is highest in the immature plant parts, new shoots may be dangerous until they reach a height of at least 18 in. Rotational grazing will provide maximum production at a nutritious, yet safe stage of growth. Allow time for 18 in. or more of regrowth before regrazing. Livestock may selectively graze and trample the crop if the plants are too tall (over 40 in.). There is increased danger of prussic acid poisoning when frost kills the top-growth, leaving the base of the plant from which new shoots may emerge. Cattle will frequently avoid the tall frosted growth and graze the young shoots, which may contain toxic levels of prussic acid. Harvesting the crop for silage may be the best way to handle frost injured sudangrass or sorghum-sudangrass hybrids.

Under adequate soil moisture conditions, productive stands of sudangrass may be expected to carry 2 to 3 head of mature livestock per acre from early July until frost.

2. For hay: Harvesting sudangrass and sorghum-sudangrass hybrids when the seed is in the soft to dough stage gives highest yields, but curing is difficult at this stage. A more practical plan is to harvest when the forage is about 30 in. high. This method results in a better quality hay that is easier to cure, and one or two additional crops may be produced.

Sudangrass and sorghum-sudangrass for haylage should be crimped and windrowed, wilted to 40 to 50% moisture, and then chopped as fine as possible.

3. For silage: Harvest sudangrass, sorghum-sudangrass hybrids and forage sorghums in the medium dough stage when total plant moisture is 65 to 70%. For beef cattle, the crop can be harvested a few days later.

4. For green chop: Sudangrass and sorghum-sudangrass hybrids can be used for green chop to bolster summer feed supplies. The forage is nutritious over a wide range of plant heights and can produce large yields. To be sure of a second crop, harvest the first cut by the heading stage, leaving 6 to 8 in. of stubble. Do not allow green chop to sit in the wagon long enough to heat; this will increase prussic acid levels.

5. For green manure: Sorghums are generally not recommended for green manure. They do not supply nitrogen to the soil, as do the legume crops. However, a crop of sudangrass or a sorghum- sudangrass hybrid can supply up to 5 tons of dry matter per acre as organic material. Apply nitrogen fertilizer or barnyard manure for a balance of nutrients.

VI. Yield Potential and Performance Results:

Tests conducted in Wisconsin in the 1960s indicate that yields of dry matter were highest under the silage management program, followed by the green chop and then the pasture management program. Silage yields ranged from 4 to 12 tons of dry matter per acre.

Several of the sorghum-sudangrass hybrids and the forage sorghum varieties produced higher yields than the sudangrass varieties under silage management. Sudangrass and sorghum-sudangrass hybrids are generally earlier in maturity than forage sorghums, and thus provide a better chance of obtaining a crop at the desired stage of development before frost. There were no differences among varieties and hybrids when used as pasture.

VII. Economics of Production and Markets:

On-farm utilization as feed may be the best alternative for forage sorghum growers in the Upper Midwest. Otherwise, it is advisable to secure a market for the crop before planting.

VIII. Information Sources:

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- Hughes, H.D., and D.S. Metcalfe. 1972. Crop Production. Third Ed. The Macmillan Company, New York.

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Vernonia

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I. History:

Vernonia (*Vernonia galamensis* L.) or ironweed, is one of 6,500 wild plant species screened by the USDA for production of desirable seed oils. This potential oilseed crop is native to eastern Africa. There are over 1,000 species in the genus ranging from tropical herbaceous species to North American shrubs. Another vernonia species, *V. anthelmintica* Willd., was evaluated earlier during the 1950s for its vernolic (epoxy) acid content. Consistent problems with seed shattering, disease, and low yield of vernolic acid resulted in an end to further agronomic and breeding studies on this species. Developmental research on use of the oil and vernolic acid from Vernonia species has been conducted since the 1960s.

II. Uses:

Vernonia seed contains about 40 to 42% oil of which 73 to 80% is vernolic acid. This is about 30% more vernolic acid than the best varieties of *V. anthelmintica*. Products that can be made from vernonia include epoxies for manufacturing adhesives, varnishes and paints, and industrial coatings. The low viscosity of vernonia oil would allow it to be used as a nonvolatile solvent in oil-based paints since it will become incorporated in the dry paint rather than evaporating into the air. Consequently, it is possible that emissions associated with photochemical pollution can be reduced by up to 160 million pounds per year if this crop is fully exploited.

Vernonia could also serve as a natural source of plasticizers and stabilizers (binders) for producing polyvinyl chloride (PVC plastic), which currently is manufactured from petroleum. The potential use of vernonia as a petroleum substitute is important since the demand for petroleum each year in the USA is approximately 8,500 pounds per person, of which about 500 pounds per person is needed for production of plastics and industrial petrochemicals. Some vernonia species have been reported to have medicinal properties.

III. Growth Habits:

Vernonia is an annual, herbaceous plant in the Compositae (Daisy) family. This plant will not flower until the daylengths are shorter, which is typical of most tropical plants. Plants are thornless and vary in height and number of flowers. Plant habits vary from those that are 8 in. tall with a single flower head, to those with vigorous, shrubby plants with multiple stems and flower heads that may reach 9 ft in height. The stems do not branch until after the terminal flower head is formed. The lavender terminal flowers, and lateral flowers that develop in the uppermost leaf axils, have a thistle-like appearance. If sufficient moisture is present for continued growth, the lateral branches with secondary flower heads will grow above the first-formed flower head. Brown seeds develop in seed heads that are 1 in. in diameter. Leaves are alternate and sessile, and have toothed margins with taper-pointed tips and wedge-shaped bases. Leaves are 1/4 to 2 in. wide and up to 10 in. in length. In Zimbabwe (southern Africa) the crop requires five to seven months from planting seed to harvest. However, in Zambia (central Africa) the seed was mature four months after planting. Plants observed by Gilbert (1986) in eastern Africa were shorter (8 in.) and apparently matured much earlier than four months after germination.

IV. Environment Requirements:

A. Climate:

Vernonia is a crop adaptable to the latitudes within 20 degrees north or south of the equator since this comprises its natural distribution. It has also been grown successfully in Pakistan, which indicates a broader adaptation. Hawaii, Puerto Rico, and the semiarid areas of the subtropics and tropics, such as in Africa, Central and South America, Australia, and India, would be suitable growing regions. This crop is adaptable to areas with as little as 20 in. of annual rainfall. Sufficient moisture must be present to establish good stands and permit the first flower heads on each stem to mature. But rainfall levels that allow secondary flower heads to develop will result in poor uniformity of seed maturation and seed shattering during subsequent rainfall or harvesting.

The effort to develop this species as a new crop must concentrate on production areas where a short rainy season occurs during a period of four, or at most five months, to promote good growth and flowering. The subsequent period for seed development and maturation should have one or two months when there is very little or no precipitation. Dry conditions promote seed retention. It seems that natural selection has favored a plant type in vernonia that does not disperse seed at maturity, but rather will retain it until rainfall is adequate for germination and growth of the seedlings. Rainfall pattern is evidently more important than total amount for maximum productivity of vernonia.

B. Soil:

Porous, well-drained soils are required to grow this crop successfully. Field trials in Zimbabwe on well-drained soil found that plants grow erect with a single stem until the first flower head appears, after which lateral branches develop. However, on poorly-drained soils the terminal growth stops before flowering and the upper portion of the plant dies. Branches will subsequently grow from the base of the plant, but also wither and die without flowering. Soil with intermediate drainage will produce plants that develop a few flower heads, but with very low seed yields.

C. Seed Preparation and Germination:

Seeds germinate quickly, but seedling vigor is poor. A western African variety from northern Ghana has vigorous seedlings and could be used in developing varieties with better seedling vigor.

V. Cultural Practices:

Considerable agronomic research was conducted on *V. anthelmintica* in the 1960s and 1970s. Research on this species was stopped when yields continued to be low due primarily to poor seed retention. Agronomic studies on *V. galamensis* began in Zimbabwe during 1983, which are currently unpublished. These studies used the unimproved, yet very uniform germplasm from Ethiopia. Additional vernonia germplasm is being collected in Zimbabwe for future evaluations.

A. Seedbed Preparation:

Since seed of vernonia is relatively small, a firm, level seedbed with few weeds should help promote the rapid establishment of a good stand as with most crops.

B. Seeding Date:

A seeding-date trial to determine the best planting time was conducted in Zimbabwe during 1985-1986. Seed was sown at mid-month from December to April, which is comparable to June through October in the northern hemisphere. All plants flowered and produced mature seed. The plot seeded in December flowered when plants were almost 9 ft tall, while the last plot seeded in April had flowering plants that were only 3 ft tall. This study indicated that later planting dates are preferred, if the number of frost-free days in the growing season will permit it.

C. Method and Rate of Seeding:

Preliminary results of unpublished research on the effect of plant spacing conducted in Zimbabwe during 1985 and 1986, and continued in 1987 were inconclusive. More information was deemed necessary before reliable conclusions could be drawn.

D. Fertility Requirements:

Studies on the response to fertilizer were also performed in Zimbabwe, but will not be reported until further research is conducted in this area.

E. Variety Selection:

Varietal development for vernonia is still in the early stages. Wild types of vernonia are still being collected to obtain sufficient genetic resources to develop more productive varieties. No released varieties of *V. galamensis* have been reported.

F. Weed Control:

Weed control after germination is a problem due to the poor seedling vigor. Recommendations for weed control by cultural or chemical methods are not currently available. No herbicides are currently cleared for use in vernonia.

G. Diseases and Control:

No serious disease problems as yet have been reported for vernonia.

H. Insects and Other Predators:

Insect damage has not been reported in research trials.

I. Harvesting:

A standard harvesting method has not been reported. Perdue et al. (1986) mentioned that seeds will stay on plants for 30 or more days after ripening. Growers can therefore wait until most of the seeds are ripe before harvest, which is especially important when seed ripens unevenly among plants. More uniform ripening of the seeds was discovered to occur when plants were "topped" earlier in the growing season, that is, pruned back to a height of 6 in. above the ground. This practice promotes production of many lateral branches that tend to flower and develop seed at the same time, which results in more uniform ripening of seeds and a shorter time from planting to maturity.

J. Drying and Storage:

Specific procedures for the drying and storage of vernonia have not been determined.

VI. Yield Potential and Performance Results:

Vernonia has limited possibilities as an oilseed crop for the northern continental United States. This crop flowers and sets seed too late in the growing season because shorter days are required for flower initiation and development. Frosts follow flowering too quickly to allow complete seed development and maturation. Trial plantings conducted at Experiment, Georgia in the 1960s produced few flowers and no seed. Trials planted in greenhouses in Glenn Dale, Maryland flowered in November and seed matured in December, which is much too late for a field crop in that area. Failure of vernonia to produce a mature crop in preliminary field trials was due most likely to unsuitable environments with excessive moisture, poorly drained soil and/or insufficient length of growing season.

However, a variety was found in Nigeria during the 1980s, at about 11 degrees north and south of the equator, which flowers about six weeks earlier than any plants found previously. If a variety can be found that flowers early enough in the United States to allow for maturation of the seed, does not shatter readily, and is resistant to disease and insect problems, then this oilseed crop may be suitable for the Southwest when planted in late summer or early fall. Areas that do not have a well-defined, severe dry season and soils without good drainage should be avoided. On the other hand, Perdue (personal communication, 1991) did not feel there was good potential for growing vernonia in the southwestern USA due to low and variable yields. This crop is clearly not adapted or recommended for the Upper Midwest. Tropical and subtropical areas would be climates in which this potential oilseed crop could be grown.

Seed yields improved from 1,627 to over 2,200 lb/acre in Zimbabwe during 1986 to 1987. The yield of vernolic oil in the Zimbabwe trials (1987) was 891 lb/acre, which would mean that about 365,000 acres of vernonia would need to be planted to supply the solvent needs for the production of alkyd-resin paint in the United States. This production figure does not include the needs for paint production in other countries and the possible demands from other uses of vernonia oil. Researchers have indicated that seed yields can be doubled or tripled with better cultural practices and by breeding for improved varieties after more wild germplasm is collected and made available to plant breeders. Additional agronomic and utilization research on *V. galamensis* needs to continue before it can be established as a new crop.

VII. Economics of Production and Markets:

The current market for vernonia is small. Utilization research for vernonia has shown there are at least three areas with strong potential markets: (1) as a plasticizer and stabilizer for polyvinyl chloride - a current market, (2) a component in protective coatings, and (3) use in interpenetrating polymer networks with polystyrene to make unique plastics. The best potential market for this crop in the near future is in development of epoxy coatings. By bringing the oil or seed to the international market, even if in small quantities, the agricultural sector would prove it can provide a reliable supply of seed. It has also been suggested that the oil should be extracted from the seed and refined in the producing countries before export, in order to realize a higher price for the product, and reduce shipping costs. Vernonia will not be considered seriously as a new industrial crop until a vernonia product is in commerce and agriculture has shown it can produce a reliable supply at a reasonable cost.

VIII. Information Sources:

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