SAFFLOWER PRODUCTION *in California*

UNIVERSITY *of* CALIFORNIA
Agriculture & Natural Resources

Publication 21565

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Publication 21565
ISBN-13: 978-1-60107-341-9

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web-8/2019-SB/VFG/WS

SAFFLOWER PRODUCTION *in California*

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Contents

Acknowledgments

Safflower Production in California expands and updates the information presented in *Safflower in California* (University of California Division of Agricultural Sciences Circular 532, 1965). The authors gratefully acknowledge their debt to the authors of *Safflower in California*: Milton D. Miller, Professor Emeritus, Department of Agronomy and Range Science, University of California, Davis, and the late Paul D. Knowles, Professor of Agronomy, University of California, Davis, and Agronomist, California Agricultural Experiment Station. Thanks are also given to John Duniway for his advice on the life cycle of rust and Phytophthora.

Credits: Jack Kelly Clark, cover and plates 5, 6; Franz Kegel, fig. 6; John Klisiewicz, plates 11, 14, 16, 17, 18, 20, 21; Jacqueline Lockwood, illustrations, figs. 3, 4, 13, 15; Robert Salisbery, plate 3; Joe Smith, plate 9; Mary Wadsworth, fig. 16; Art Weisker, plates 8, 12, 19.

Safflower Production in California

HISTORY AND USES OF SAFFLOWER

Although safflower (*Carthamus tinctorius* L.) has been grown commercially in California only since 1949, it is one of the world's oldest crops. Safflower seed have been found in Egyptian tombs that are over 4,000 years old, and its use was recorded in China 2,200 years ago. The flowers have long been used as a source of yellow and red dyes for clothing and food. In traditional Chinese medicine, safflower petals are thought to stimulate blood circulation and phlegm reduction, to promote the healing of fractures, contusions, and strains, and as a women's health remedy. In Europe and the Middle East, the petals are sometimes used as an adulterant for saffron. Prior to the 1960s in the United States, safflower oil was used primarily as a base for superior-quality paints. More recently, it has been used in infant formulas and cosmetics.

Currently, safflower is used mainly as a salad and cooking oil. An important by-product of safflower oil production is the press cake, or meal, which is used as a livestock feed. Safflower can also be grazed and is cut as hay in some countries.

Worldwide, India is the largest producer of safflower for oil, but most of its production is consumed internally. California, the world's second-largest producer of safflower, exports much of its oil to Japan. Mexico has also produced large quantities of safflower oil for domestic consumption and export. Other countries growing safflower include Argentina, Australia, Canada, China, Spain, Italy, Turkey, Iraq, Iran, Egypt, Ethiopia, and the former Soviet Union.

SAFFLOWER CULTIVATION IN CALIFORNIA

The earliest reference to safflower culture in the United States is in a report from the University of California's Chino research station (1899–1901). Although the report concluded that safflower would thrive over a large part of California and that it was easy to produce, safflower was not established commercially in California at that time. From 1930 to 1940, attempts were made to adapt safflower to commercial production in the Great Plains, but the cultivars available then were too low in oil to be of interest to processors. The development of 'Nebraska' cultivars in the next decade by Carl Claassen, some with oil contents up to 36 percent, improved the usefulness of safflower.

Because safflower did not succeed at first in the Great Plains states, Claassen shifted his efforts to California, which has one of the best climates in the world for safflower production. In partnership with Pacific Vegetable Oil Corporation, he pioneered the commercial development of safflower in California, which at that time was one of the newest "alternative" crops available to farmers. A substantial research and plant breeding effort at the University of California was led by Paul Knowles. His program has contributed significantly to safflower production in California and worldwide since the end of the Second World War by developing cultivars with higher oil contents and other useful properties. He also identified safflower types with high levels of oleic fatty acid that could produce an oil similar to olive oil. Knowles' discovery led to the development of commercial safflower cultivars with high oleic acid contents, different from the common types that are high in linoleic acid, and now both types are available to growers.

Safflower cultivation in California has varied widely over the last 40 years (fig. 1), from nearly 400,000 acres in the late 1960s to nearly 50,000 acres in the mid- to late 1970s. Seed yields rose significantly from the 1950s until the 1970s but have remained relatively stable since that time. Currently, the majority of land planted with safflower in California is used for oleic types. Growers who produce both oleic and linoleic types do not mix the types at harvest because the oil is marketed by type and mixing the two makes the har-

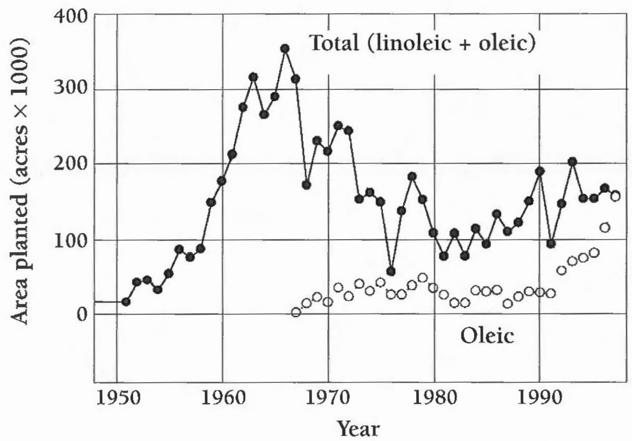

Figure 1A. Safflower acreage in California, 1950 to 1997, showing the total acreage planted to safflower and the subset of acres planted to oleic types. Recently, oleic types have almost completely displaced linoleic types of safflower in California. *Source:* Adapted from Smith 1996 and Gyulai 1997.

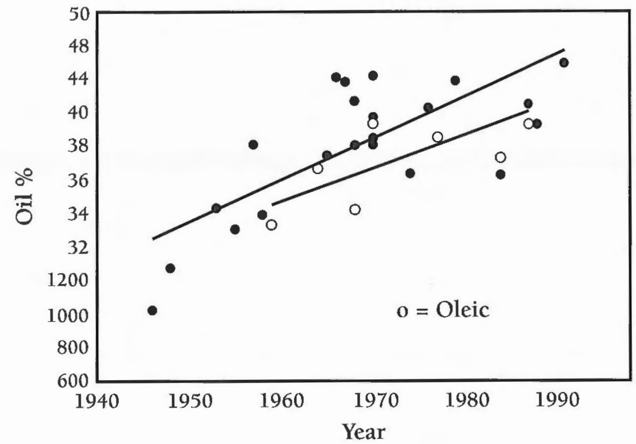

Figure 2. Oil content of selected safflower cultivars, 1940 to 1995. The oil content of safflower cultivars used in California and Arizona has increased at approximately 0.2% per year since approximately 1950. Linoleic oil % = 20.8 + 0.29 (year) (r^2= 0.59); oleic oil % = 22.9 + 0.23 (year) (r^2=0.55). Source: Adapted from Smith 1996.

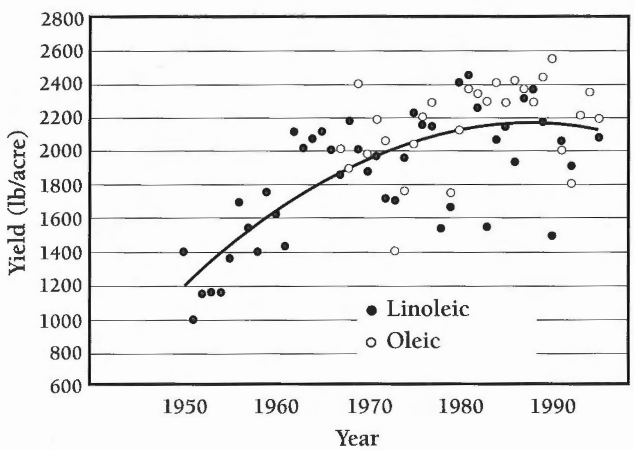

Figure 1B. Safflower yields in California, 1950 to 1995. Yields increased at approximately 120 pounds per acre (134.4 kg/ha) per year during the first two decades of production in California, but have remained relatively stable since. Yield = –3,078 lb/acre + 119.8 lb/acre/yr–0.7 year^2 (R^2 = 0.48). *Source:* Adapted from Smith 1996.

vest essentially worthless. Plant breeders have developed important new safflower cultivars with increased oil content (fig. 2).

OIL TYPES AND QUALITY

Safflower is thought to be one of the highest-quality vegetable oils. To understand why this is so, some understanding of oil types and quality is required. Oils, which are liquid at room temperature, and fats, which are solid at room temperature, are composed of chains of carbon atoms (fatty acids) of varying length combined with glycerol. The carbon atoms that form the backbone of these fatty acids can form four chemical bonds, including bonds with other carbon atoms. Oils and fats are "saturated" if all the bonds between carbon atoms in the carbon atom chain are single bonds (C-C-C). Oils are "unsaturated" if one or more of the carbon atom pairs share a double bond (C-C=C-C).

Two of the most important fatty acids are oleic acid and linoleic acid. Oleic acids are "monounsaturated," meaning that they have 1 pair of carbon atoms among the 18 making up the carbon chain that share a double bond (denominated 18:1). Linoleic acid (18:2) is "polyunsaturated," meaning that there are in this case 2 pairs of carbon atoms in the carbon chain that share a bond. Table 1 compares the fatty acid composition and other characteristics of linoleic and oleic acids. The iodine value in table 1 quantifies the degree of

Table 1. Comparison of typical fatty acid composition and other edible grade specifications of linoleic acid and oleic acid

Characteristic	Linoleic acid*	Oleic acid†
Fatty acids		
C_{16} Palmitic %	5.0	5.0
C_{18} Stearic %	5.2	2.0
18:1 Oleic %	15.0	77.0
18:2 Linoleic %	77.0	15.0
18:3 Linolenic %	<1.0	<1.0
Others %	0.7	1.3
Free fatty acids (as oleic) %	0.03	0.03
Iodine value	144.0	92.0
Peroxide value at shipment	0.1	0.1
Refractive index (25% C)	1.474	1.690

Source: Adapted from Smith 1996 and Gyulai 1997.
Note: Short-chain fatty acids ($\leq C_{14}$) are solid at room temperature and are not considered.
*On average, linoleic types of safflower oil have approx. 78% polyunsaturated, 15% monounsaturated, and 7% saturated fatty acids.
†On average, oleic types of safflower oil have approx. 78% monounsaturated, 15% polyunsaturated, and 7% saturated fatty acids.

unsaturation of the total fatty acids in an oil. A higher value means less saturation. Linoleic types of safflower have a higher iodine value and less saturation than oleic types of safflower.

"Hydrogenated" oils become fats by the catalytic conversion of unsaturated fatty acids to saturated fatty acids through the substitution of hydrogen-carbon bonds for carbon-carbon bonds. Butter, an animal fat, is composed primarily of short-chain fatty acids (less than 14 carbon atoms in a row, or $<C_{14}$), which are mostly saturated fatty acids. Because of the high degree of saturation, butter and other compounds with predominantly short-chain fatty acids are naturally solid at most ambient temperatures. In contrast, unsaturated vegetable oils have a bend or crook in the base carbon chain where the double bond occurs ("cis"-unsaturated fatty acids). Because these bends or crooks tend to keep the fatty acid molecules from lying close together, the compounds remain liquid at room temperatures. To make margarine from vegetable oils, the fatty acids are modified to allow them to solidify. When vegetable oils are hydrogenated, some unsaturated bonds remain, but the geometry of the unsaturated carbon-carbon bonds in the carbon chains is changed from "cis" to "trans". Transunsaturated fatty acids can lie parallel to each other, allowing the oils to act like fats and become solid at lower temperatures.

The only essential fatty acid that the human body needs but cannot make from other precursors is linoleic acid. Some nutritionists also believe that the omega-3 fatty acids are essential. Beyond these, the nutritional value of oils becomes a controversial and ever-changing subject. Currently, the consumption of unsaturated oils, particularly those with oleic fatty acids, is thought to be healthier than the consumption of mostly saturated fats, particularly those that also contain some transunsaturated carbon-carbon bonds.

Oils for human consumption should not be allowed to go rancid and should be clear, not murky. They should have desirable taste characteristics and be free of any undesirable secondary compounds. The presence in a vegetable oil of high peroxide values leads to instability. Safflower produced in California is low in peroxides. Some consumers prefer strong-flavored oils such as olive and peanut, while others want salad or cooking oil that does not impart flavor. Oleic safflower oil is similar in composition to olive oil (see table 2), but has less of the saturated fatty acids found in olive oil and a milder taste. Like canola oil, it has a very low saturated fat content but is free of canola oil's unpleasant cooking odor. The oil content of the seed and the oil quality of safflower grown in California are the highest produced anywhere in the world because the crop is ideally suited to California's climate.

BIOLOGY AND DEVELOPMENT

Biology

Safflower, a member of the sunflower (Compositae) family, belongs to a large genus (*Carthamus*) of thistle-like plants originating in the Mediterranean and Middle East. In California it grows to a height of 1.5 to 6 feet (0.5 to 1.8 m), depending primarily on the planting date and plant spacing (late planting and lower populations reduce plant height). The plant can produce many branches, each with a terminal flower head (involucre) that is densely filled with 20 to 180 flowers. Surrounding the flowers are modified leaves (bracts). The flowers are tubular and are attached to a flattened receptacle. There are bristles or hairs interspersed among the flowers. Each flower can produce a seed (achene) if conditions are favorable.

Branching depends on plant population and sowing date (see fig. 3) and environmental factors such as moisture supply. Depending on its location on the plant and on crop management and environmental conditions, an individual flower head can produce from 20 to 100 seeds. The seed weighs from 39 to 46 pounds per bushel (0.5 to 0.6 kg/l), depending on crop growth conditions and cultivar. Although safflower cultivars grown in California vary in oil content, most are greater than 40 percent oil and 15 percent or more

Table 2. Comparison of percentage of major fatty acids in edible vegetable oils

Fatty acids		Safflower		Canola*	Soybean	Corn	Sunflower	Peanut	Olive
Denomination	Name	Oleic	Linoleic						
14:0	—	—	—	0.75	0.1	—	—	0.1	—
16:0	Palmitic	5	5–7	4.0	10.8	11.4	6.0–7.0	10.0	11.0
18:0	Stearic	<1	2	1.6	4.0	1.9	4.0–5.0	2.3	2.2
20:0	—	—	—	0.5	—	—	—	—	—
22:0	—	—	—	0.4	—	—	—	—	—
Total saturated	—	7.0	10.4	6.0–9.0	15.1	13.3	10.8	17.8	13.5
16:1	—	—	—	0.25	0.2	—	—	0.1	0.8
18:1	Oleic	77	15	61.0	23.8	25.3	17.0–20.0	47.1	75.8
20:1	—	—	—	1.5	0.2	—	—	1.4	0.3
22:1	—	—	—	0.2	—	—	—	—	—
Total monounsaturated		77	15	61.0–64.0	24.3	25.3	20.4	48.6	77.1
18:2	Linoleic	15	77	19.0–26.0	53.3	60.7	68.8	33.6	8.3
18:3	Linolenic	—	—	8.0–13.0	7.1	0.7	—	—	0.6
Total polyunsaturated		15	77	27.0–35.0	60.6	61.4	68.8	33.6	8.8

Source: Adapted from Smith 1996; Ackman 1990; Dorrell 1978.
Note: Figures are rounded or are estimates. Ranges represent various cultivars and locations.
*Average of several types.

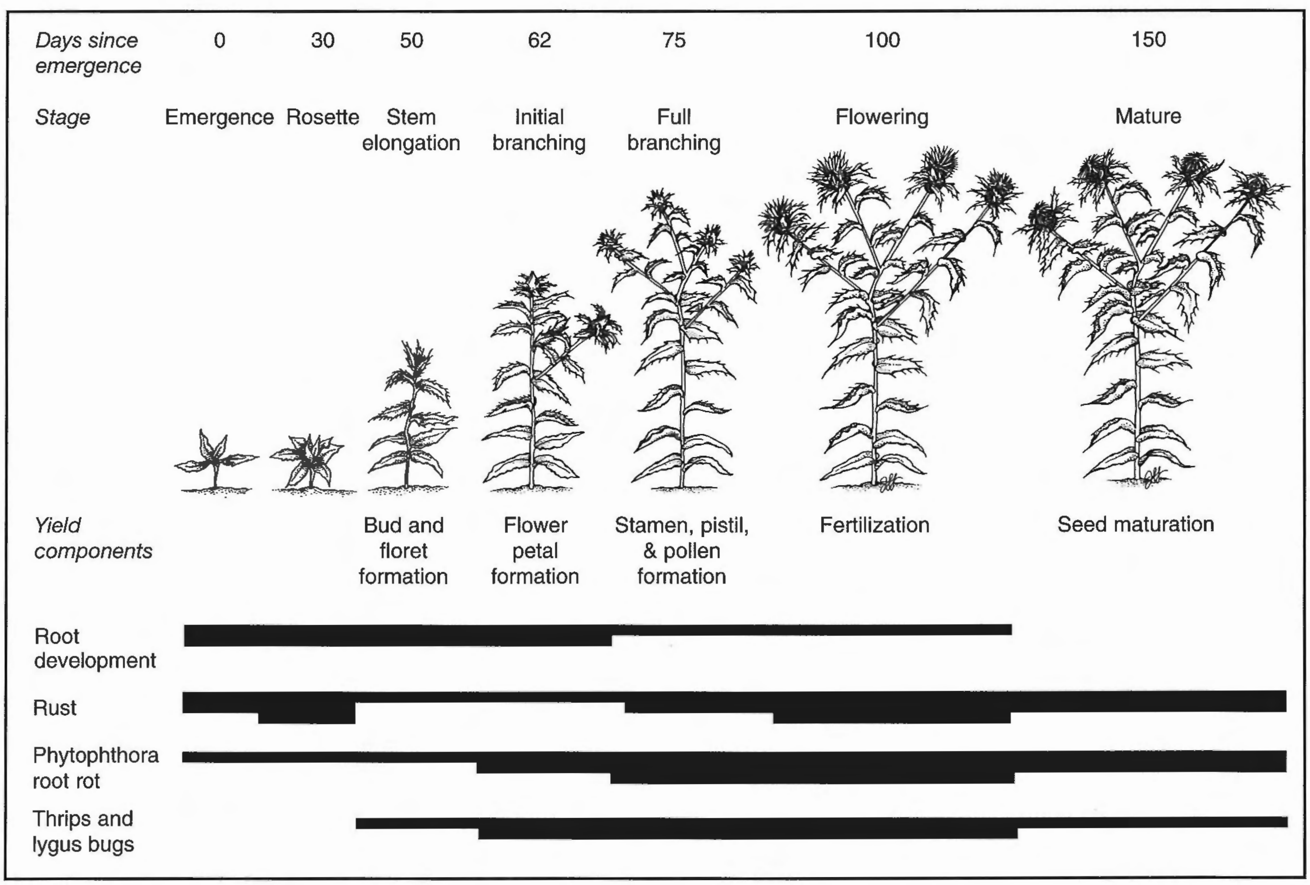

Figure 3. Development stages of safflower and corresponding susceptibility to selected pests and diseases. Susceptibility is indicated by the thickness of the bar and is meant to be illustrative rather than quantitative.

protein. The remainder of the seed consists of fibrous constituents, carbohydrates, and ash. Hulls make up about 35 to 38 percent of seed dry matter.

The flower color varies with cultivar, from red to orange-yellow to white. Commercial cultivars grown in California are yellow. On drying, these turn a yellowish red. The seed of present California cultivars have white to cream or sometimes light brown hulls that can appear striped and are shaped like small sunflower seeds. Cultivars grown for birdseed, primarily in the Midwest and Canada, are white even though color has no effect on birdseed quality or bird preferences. Commercial cultivars of safflower have spines on the leaves and the modified leaves associated with flower heads. The spines develop late as the plants form flower heads. A less thorny white-seeded cultivar (UC28) is sometimes grown for dried flowers.

Growth and Development

Safflower requires a minimum of about 120 days to produce a crop. Crops planted in March commonly require 140 to 170 days. This allows enough time for seed moisture to reach 8 percent, the level required for harvest. The development stages of safflower are shown in figure 3.

Safflower emerges at soil temperatures above 40°F (4.4°C) but emergence is much more rapid at temperatures of 60°F (15.6°C) or greater. Emergence at minimum temperatures is slow, requiring up to 3 weeks. During late spring, germination occurs rapidly and seedlings appear 3 to 4 days after planting at normal depth. After emerging, seedlings develop a number of leaves but remain low growing, forming a modified rosette. Stem development and elongation is influenced by increasing day length and increasing average temperatures. In a test under greenhouse conditions at approximately constant temperatures, increasing day length from 10 to 14 hours shortened the average length of the rosette stage from 39 to 23 days for a group of 6 different safflower genotypes (Zimmerman 1973). If sown in late fall in California (October or November), the plants will remain in the rosette stage for 2 or 3 months, but when sown in late spring (late April or early May), the rosette stage may last less than 4 weeks. Fall sowing is not recommended in California.

At Davis in the southern Sacramento Valley (38.5°N latitude), stem growth starts in the latter part of March in safflower sown during January or February and in the latter part of April when sown during the first part of March. In the San Joaquin Valley and Southern California, stem growth begins in early March if the crop is planted in December or January. Stem growth is rapid after it begins.

Branching begins from the central stem when the plant is 8 to 15 inches (20.5 to 38 cm) tall. Each primary stem branches to form 1 to 5 (or more) flower heads. Wide plant spacing and early planting dates increase branching and bud formation (see fig. 4). For example, a plant sown in November may reach 6 feet (1.8 m) tall and have over 50 viable flower heads, while the same cultivar planted in April may only reach 18 inches (0.5 m) and have 3 to 5 flower heads. Depending on date of planting, safflower reaches its full height, which varies from 18 inches to 6 feet (0.5 to 1.8 m) or more, at the time it flowers. Buds open into blossoms within 4 to 5 weeks after they appear.

Flowering dates are remarkably consistent. At Davis, when safflower is planted at intervals from November to March, all plantings mature over a range of about 10 days in early August. Maturation in the southern San Joaquin Valley occurs 1 or 2 weeks earlier. Individual seeds mature physiologically about 25 days after flowering. Within a head, however, the flowering and maturation of individual florets and seeds occurs over a period of up to 7 days. Because of the variation among florets, all seed in a flower head are physiologically mature from 35 to 40 days after the peak of flowering. Safflower should be harvested at a moisture content of 8 percent or less. In California, it commonly takes 50 to 60 days from peak flowering for seed to reach a moisture content of 8 percent, even though the seed may be physiologically mature sooner.

Despite being an annual, safflower is among the deepest-rooted of all crops. Safflower roots have been found at a depth of 12 feet (3.7 m) at Davis on a deep, well-drained Yolo loam soil. Other research trials have documented substantial water depletion by safflower roots at 10 feet (3 m) in a permeable soil. The depth of root penetration influences the amount of water available to the crop. Soils vary in permeability and depth, and this variation influences the depth of root penetration. When safflower is sown late in the season, it does not develop as deep a taproot by the time it flowers as it does when planted earlier, effectively reducing the available water supply.

CLIMATE REQUIREMENTS

Atmospheric Humidity

In early growth stages, safflower is tolerant of high atmospheric humidity, but after flower buds form, prolonged rain or fog can promote Botrytis head rot on the buds or flowers (see "Diseases," p. 22). Because there are no resistant cultivars and the disease cannot be con-

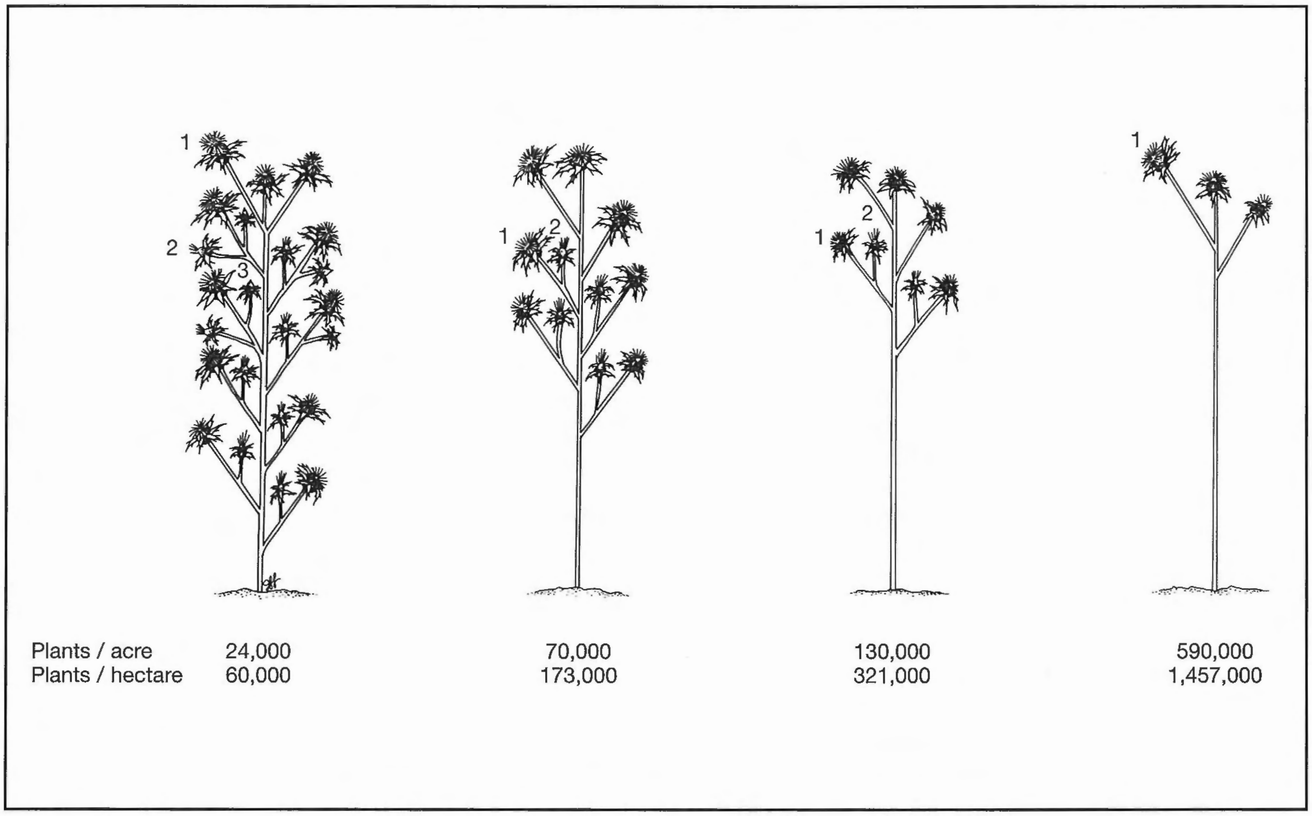

Figure 4. Plant density and branching patterns. Primary, secondary, and tertiary buds are indicated. ***Source:*** **Adapted from Weiss 1971.**

trolled economically, this disease inhibits the production of commercial cultivars in coastal areas of California. Another disease caused by rain late in the development of the crop, Alternaria leaf spot, is rare in California but seriously limits safflower production east of the Rocky Mountains and in other locations worldwide. High relative humidity in early spring encourages the development of rust. Because of these and other disease limitations, safflower production is limited to locations having a rain- and fog-free climate during most of the growing season, particularly in the late summer.

Temperature

The frost resistance of safflower depends on the cultivar, stage of development, and plant density. In the seedling stage, most cultivars tolerate temperatures as low as 20°F (-6.7°C), and some experimental lines have been reported to withstand a temperature of 10°F (-12.2°C). Seedlings spaced 3 to 4 inches (7.5 to 10 cm) apart are reported to survive low temperatures better than those spaced more closely, though it is not clear why this should be so. Once stems have begun to develop, safflower becomes more sensitive to frost damage, and temperatures of 25°F (-3.9°C) will damage the cultivars grown in California. In the bud stage or after flowering begins, any temperature below 32°F (0°C) causes damage to the developing flowers or seeds.

If soil moisture is adequate, safflower tolerates the high summer temperatures (100° to 115°F [37.8° to 46.1°C]) of the Sacramento and San Joaquin Valleys. Because it is difficult for plants to recover enough water from the soil when they are exposed suddenly to high temperatures, even when soils are moist, yields generally are highest in years when daytime temperatures at flowering and immediately thereafter are moderate (75° to 90°F [23.9° to 32.2°C]).

Wind

Safflower does not lodge or shatter under the normal range of wind velocities in the Central Valley and inland coastal foothills of California. If plants have become very tall due to early planting and long periods of vegetative growth, some lodging may occur. Seedling rust may cause affected plants to lodge later in the season.

WATER USE

Water Requirements

The amount of water available to safflower is a key factor in determining yield. Safflower is thought to be a drought-resistant crop. While it tolerates high temperatures and requires low atmospheric humidity, safflower does not produce a satisfactory crop without adequate soil moisture. Because it can explore a large, deep soil volume to recover water, it is able to grow when other crops with less aggressive root systems cannot. Cotton, wheat, tomatoes, sugarbeets, and most vegetable and tree crops are known as "C3" species because the first products of the photosynthetic pathway formed in them are 3 carbon molecules. Corn (maize) and sorghum are known as "C4" species because they produce 4 carbon molecules as the first products of photosynthesis. C4 species tend to use water more efficiently than C3 species, and most C3 species have comparable water requirements per unit of dry matter produced. Safflower is a C3 crop, like tomatoes and cotton. To grow and produce an economic yield of safflower, approximately the same amount of water is required per unit of dry matter produced as is required by other C3 crops experiencing comparable conditions.

The water requirement of safflower is determined by temperature and atmospheric humidity and the amount of green leaf area maintained by the crop while it grows and develops. Together these factors vary somewhat from season to season and especially by location. A safflower leaf canopy experiencing hot, dry conditions requires more water to produce an equivalent amount of plant or seed biomass than a canopy experiencing cooler, less arid conditions. This amount can equal as much as 0.5 inch (125 mm) per day for a crop with a complete leaf canopy.

The moisture available to the crop during the season depends on soil depth, stored soil moisture, soil physical properties, and whether the crop is irrigated. Although safflower grows best in soils that are well supplied with moisture, it will survive and produce a low yield if it can transpire a minimum of 16 to 18 inches (40.5 to 45.5 cm) of water, as long as the plants have not developed a large leaf canopy early and exhausted soil reserves before seed maturation begins. In countries where subsistence farming is practiced, however, safflower production is attempted and low yields achieved on lesser amounts of available water. In California, experience indicates that a total of about 20 to 25 inches (51 to 63.5 cm) of available water is required for economic yields of approximately 2,000 pounds per acre (2,240 kg/ha) under nonirrigated conditions. Under irrigation in the Central Valley, 25 to 44 inches (63.5 to 112 cm) of water, including water derived from rainfall, will be used by a high-yielding crop due to the larger leaf canopy that tends to develop and the longer period of growth. Depending on the efficiency of the irrigation system and the amount of precipitation or stored soil moisture present, a larger amount of water than the amount transpired must be applied to account for irrigation losses, including an amount needed for a leaching fraction under saline conditions. An approximate relationship between yield and evapotranspiration (ET) in the San Joaquin Valley is 100 pounds of seed per inch (4.4 kg/mm) of ET (see fig. 5).

Some of the highest yields in California are obtained in locations where subirrigation from shallow groundwater occurs, such as in the Sacramento–San Joaquin Delta (fig. 6) and the Tulare Lake Basin, and on deep soils that store moisture to a depth of 6 to 12 feet (1.8 to 3.7 m) from winter rainfall, preirrigation, or early-season irrigation. Where there is no shallow water table, soils must be capable of storing the majority of this water, since in California's safflower-growing climate, rainfall usually ceases by the time the crop begins to grow. The low yields of some fields appear to be associated with the presence of continuously dry soil starting at a depth of 3 to 4 feet (0.9 to 1.2 m). Shallow upland soils in the coastal and valley foothills have not produced large yields because of insufficient reserves of moisture in the subsoil. In upland farming conditions without irrigation (dry farming), yields of safflower have been much better after a fallow year than on continuously cropped land. On deep soils in

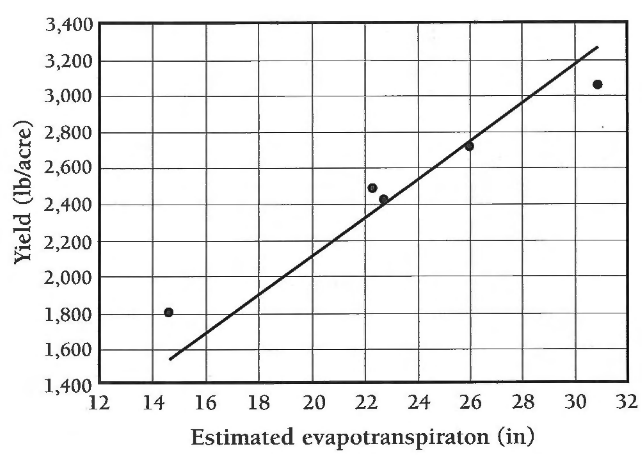

Figure 5. Estimated yield and evapotranspiration in the San Joaquin Valley. Yield (lb/acre) = 105.2 ET. Average Boswell data. ***Source:*** **Adapted from Fisher, Yamada, and Pomeroy 1967.**

Figure 6. Subirrigation of safflower grown on organic soils in the Sacramento–San Joaquin Delta.

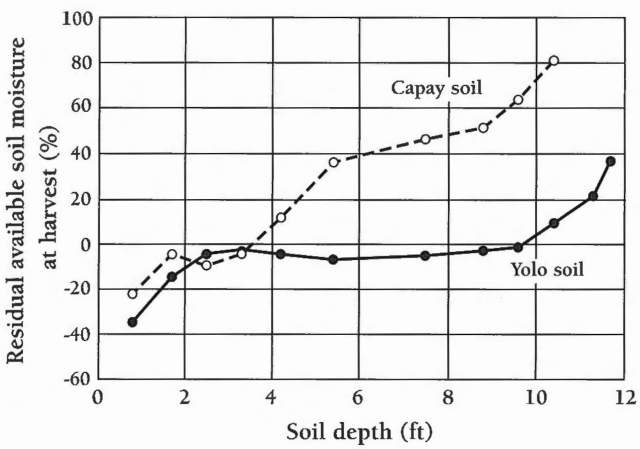

Figure 7. Safflower soil moisture use and depth for selected Sacramento Valley soils. Both soil profiles were estimated to contain approximately 100% of their potential available soil moisture at the start of measurement. The Yolo soil is a Class I soil; the Capay soil is regarded as a Class III. *Source:* Adapted from Henderson 1981.

the Sacramento Valley, safflower can be grown without irrigation and without a fallow period if rainfall fills the soil profile or if previously irrigated crops have not fully used the available soil moisture to safflower's rooting depth. On clay soils, which restrict root growth, however, safflower may not be able to recover all the moisture present (see fig. 7).

Sometimes safflower plants fail to produce a satisfactory seed crop even though large, vigorous plants have developed. This can be caused by depletion of available soil moisture by the time flowering occurs.

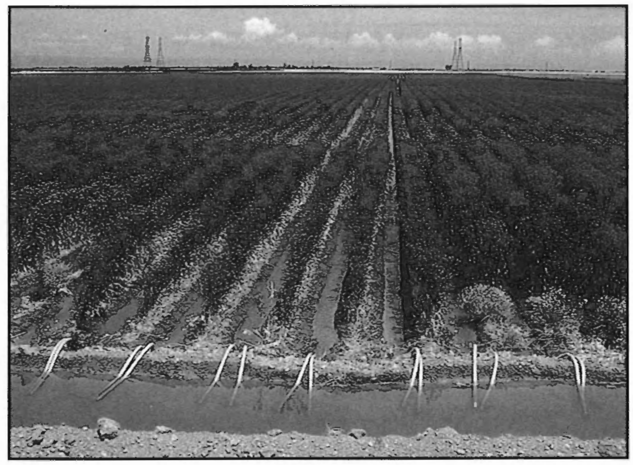

Figure 8. Furrow irrigation of safflower grown in beds.

Hot, dry weather at flowering may also cause seed set failure, though it is likely that this failure is due to moisture stress rather than any special sensitivity of safflower blossoms to high temperatures.

Damage from Excess Moisture

If safflower is irrigated, the soil need not store as much moisture. Irrigating safflower can be risky, however, especially late in the crop's development. Standing water or saturated soil near the base of the plant can lead to Phytophthora root rot (see "Diseases," p.22). Raised beds are advisable if the crop will be irrigated (fig. 8). During the summer, when soil temperatures are high and the plants have developed a stem or flowers, safflower can be killed by standing water or waterlogged soil. Young plants may withstand temporary waterlogging if the soil temperature is 60°F (15.6°C) or lower.

SOILS

Soil Series

High yields of safflower are produced on deep, fertile, well-drained soils. Class I and II soils characteristically produce good yields. Class III and IV soils are problematic, and crop stands on them are more likely to experience root rot losses and available water limitations (see fig. 7). Sandy soils may not have sufficient water-holding capacity to produce good yields of safflower unless irrigated frequently during the growing season.

Salinity

Safflower tolerates salinity better than many other crops. It is, however, more sensitive to salinity at germination than at later growth stages. Salinity in soils and drainage water has diverse effects on safflower. It reduces the rate and percentage of germination, and salinity-damaged plants are smaller and more succulent. Transpiration rates are lowered, leaf cell structure is altered, and stomatal numbers are reduced. Flowering and maturation are hastened (plate 1) and seed yield is reduced in flower heads, particularly in those that develop late (tertiary flower heads). To a lesser degree, the oil percentage in seed may also be reduced. Lower oil content in seed is likely related to shortened seed development (faster physiological maturity). A similar phenomenon occurs with grain crops and bushel weight (thousand grain weight). Because seed develop less well, the hull percentage increases.

Varying tolerance to salinity among safflower cultivars has been reported. There appears to be some genetic variation in tolerance, and the effects of other interacting factors, including climate and weather, irrigation management and technology, soil physical factors, soil fertility, and the growth stage of the crop, cause crop performance to deviate from predictions based on results from experiments under controlled conditions.

In experiments conducted by the USDA Salinity Laboratory at Riverside in which increasingly saline irrigation water was applied to different nonsaline plots, a salt concentration (measured as electrical conductivity of a saturated paste extract, or EC_e) in the top 12 inches (30.5 cm) of soil equal to 7 dS m^{-1} reduced safflower yield 10 to 15 percent (Francois and Bernstein 1964; Francois, Yermanos, and Bernstein 1964). An EC_e of 11 dS m^{-1} reduced yield about 25 percent. A sharp drop-off in yield occurred with irrigation water of 12 dS m^{-1} or greater. Crop maturity was hastened at the rate of 1 week per 3 to 4 dS m^{-1} increase in irrigation water salinity compared to the control. Later estimates of safflower's tolerance of saline irrigation water predict that a 50 percent yield decrease will occur in soils with an EC_e of 9.9 dS m^{-1} (Ayers and Westcott 1976).

Germination and emergence are more sensitive to salinity than subsequent crop growth. In laboratory trials at 6.8 dS m^{-1}, time to emergence was doubled for all the cultivars tested, suggesting that safflower may be twice as sensitive to salinity at that stage than subsequently (Francois and Bernstein 1964). Final germination was reduced by 10 percent at 8.3 dS m^{-1}.

In the Tulare Lake area in the southern San Joaquin Valley, safflower grows on saline soils with shallow, perched water tables. It uses water from this saturated soil zone for a substantial portion of its growth and is thought to lower the depth of perched water from 3 to 4 feet (0.9 to 1.2 m) to as much as 10 feet (3 m) during the growing season. The shallow groundwater used by safflower in this region typically varies over the range of 6 to 12 dS m^{-1} and soil extracts vary between 5 to 8 dS m^{-1} at 3 to 5 feet (0.9 to 1.5 m) deep. Safflower yields under these conditions can be among the highest in the state.

In experiments conducted on these soils, saline irrigation water was applied to cotton for 2 successive years and followed by safflower in the third year, and the safflower was grown largely without irrigation (Rains et al. 1987). This cycle was repeated three times. In the first cycle, safflower yields were largely unaffected in plots that had received irrigation water ranging from approximately 1 to 7 dS m^{-1} in the previous 2 years, but fell by approximately 40 percent from control plot levels in plots that had been treated with 11.6 dS m^{-1} irrigation water every year. Plant density was also reduced by approximately 30 percent over the same range of irrigation treatments. In later cycles, safflower yields were significantly affected at higher salinity levels, in part because plant numbers were reduced by poor germination and emergence under very saline conditions.

Sodium (Na), distinct from overall salinity, has been shown to stimulate vegetative growth and improve safflower yields under controlled conditions (Aslam 1975). The adverse effects of salinity are unrelated to sodium content as such. But if soils are sodic and have poor structure, or if salt concentrations are high (EC_e greater that 9.9 dS m^{-1}), sodium may lower safflower yields indirectly. Boron (B) injury has been observed in some cultivars. When injury occurs, leaf margins turn brown, and the affected areas enlarge until the entire leaf is killed. On soils with relatively high boron content (3 to 5 ppm) in Yolo County, however, safflower has consistently produced yields of 1 to 2 tons per acre (2,240 to 4,480 kg/ha) with irrigation.

CROP ROTATION

Safflower has many benefits for crop rotations in California. Its aggressive and deep-penetrating root system can improve water infiltration rates. Safflower is frequently grown without irrigation as a soil-conditioning and weed-control measure on land that otherwise is irrigated. It is a good rotation crop for wheat, barley, tomatoes, corn, or sugarbeets in either a dry-farmed (nonirrigated) or irrigated crop rotation system. In years with adequate to abundant winter rainfall, dryland wheat crops following safflower tend to produce high yields. Successive safflower crops should not

Table 3. Feeding value of safflower residues remaining after harvest

Residue	%
Crude protein (CP)	7.2
Acid detergent fiber (ADF)	4.3
Total dissolved nutrients (TDN)	45.0

be planted, however, because of the danger of serious damage from rust (see “Diseases,” p.22).

Under nonirrigated conditions, if the annual rainfall is sufficient to wet the soil to a depth of 4 feet (1.2 m), safflower usually can be inserted as a crop in an annual cropping program. Where rainfall averages less than 17 inches (43 cm) or where weeds are a problem, the practice of preceding safflower crops with a year of fallow is advisable. Growers who operate combination livestock-grain systems value safflower in their rotation because safflower residues provide good aftermath grazing for sheep and cattle (see table 3).

Safflower is often used in rotation with cotton in the San Joaquin Valley. Cotton yields following safflower are higher than yields following cotton. Safflower tolerates the saline soils and water in this area and uses the shallow groundwater found in some locations, lowering the saturated zone for following crops.

Safflower is also grown in the rice-producing regions of the Sacramento Valley. Safflower benefits from the abundant supply of moisture stored by these soils and does not require additional water. Its ability to dry out these soils to considerable depths improves the soils for succeeding crops. Rotation with safflower also aids weed management in subsequent rice crops. Some rice growers, however, have experienced poor safflower growth, except on old levee areas (see plate 3). Safflower crops grown on soils previously planted to rice have been harmed by phosphorus deficiency (see “Fertilizer Rates and Application,” p. 15).

CULTURAL PRACTICES

Planting Date

The date of planting for safflower depends on the location and year-to-year variations in the traffic-handling ability of the soil and in the estimated soil water supplies (see table 4). When established very early, plants are more susceptible to frost and pathogens. Early plantings also result in taller plants than later plantings. Excessive vegetative growth may exhaust stored soil water before the seed matures. Best results on Sacramento Valley rice lands are derived from fields planted before May 1. In the southern San Joaquin Valley, planting may take place from January through mid-March, and in the Imperial Valley in January and early February. In other areas and in years with low soil moisture, late March and early April are usually the best planting times. By March, dryland producers will know better how much moisture will be available for their crop. Later spring seedings under these conditions result in smaller plants (1.5 to 2 feet [0.5 to 0.6 m] tall), with sufficient moisture remaining for grain filling.

Late plantings. Safflower is often planted in the Yolo Bypass area near the city of Sacramento and other seasonally flooded areas in very late spring (mid-May to June) when soils dry sufficiently for cultivation. Other growers plant safflower late on occasion because of crop failure or a lack of other alternatives. Although safflower grows when planted this late, blossoming is delayed until late July or early August. Yields under these conditions vary from 800 to 2,000 pounds per acre (896 to 2,240 kg/ha), but are often reduced by 50 percent or more compared to optimal planting times at the same location. Also, the risk that early fall rains will damage an unharvested crop are greater. Mature safflower seed will sprout if they receive sufficient moisture, making them worthless.

Table 4. Safflower planting dates and rates for various locations in California

Location	Typical planting dates	Seeding rates (lb/acre)		
		30-inch rows	60-inch beds	Drilled*
San Joaquin Valley	Feb. to early Mar.	20–25	—	—
Sacramento Valley	late Feb. to early May	20–25	20–30	—
Coastal dryland	Mar.	—	—	20–30
Sacramento Valley dryland	Mar.	—	—	20–30

*Grain drill, 12-inch rows.
†Typically from Mar. 5 to Apr. 15.

Seedbed Preparation

Seedbed preparation practices for safflower in California depend on the location, the previous crop, and the soil type. Any seedbed prepared for a preirrigated, drilled, small-grain crop usually works well for safflower. Soil moisture should be conserved near the surface while preparing the seedbed. Clay soils require special care: after the winter rains it may not be possible to work them until late spring, when cultivation and winds can dry out the seedbed to the depth of tillage. Seeding equipment must then be used that has special openers to push aside the dry soil and plant the seed down into moisture. On loam or clay-loam soils, with plantings made during the winter, heavy rains followed by dry winds can cause crusts to form, which have occasionally reduced emergence. When crusts form, harrowing or ring rolling after planting but before emergence has been beneficial.

Raised beds can reduce root rot problems. Bedding practices vary depending on the equipment available and grower experience (see figs. 9, 10, and 11). In the Sacramento Valley, the 60-inch (1.5-m) beds commonly used for tomatoes are increasingly preferred for safflower as well. In the San Joaquin Valley, beds used for cotton and sugarbeets with rows 30 to 40 inches (76 to 101.5 cm) apart have been successful. Other planting arrangements, however, can be successful as well.

Figure 9. Safflower planted with a grain drill in a dry-farmed system.

Fertilizer Rates and Application

A number of factors influence fertilizer recommendations for safflower. These include yield expectations, available soil moisture, previous cropping and fertilization practices, and planting date. Aside from nitrogen (N), phosphorus (P), and potassium (K), no other plant nutrient deficiency has been found to limit safflower production in California.

Nitrogen is frequently applied in amounts ranging from 75 to 175 pounds per acre (84 to 196 kg/ha) for irrigated safflower and about 30 to 60 pounds (33.6 to 67.2 kg/ha) for dry-farmed safflower grown on shallow upland soils in the coastal foothills. In a series of trials in the Sacramento Valley, maximum yields were achieved by nitrogen fertilizer applications of 100 to 150 pounds per acre (112 to 168 kg/ha; see fig. 12) (Werkhoven et al. 1968). In several other trials, some with low and some with high yields, there was essentially no response to fertilizer: soils were high in fertility, or some other soil limitation, possibly associated with soil moisture, reduced crop response (Kearney 1997). In an experiment carried out with increasing levels of irrigation water, yields failed to increase significantly with application of more than 120 pounds per acre (134.4 kg/ha) of nitrogen, although there was a tendency for increasing numbers of tertiary buds to set seed at higher rates. Nitrogen fertilizer rates must be related to yield expectations. In the Sacramento Valley, sufficient rainfall may allow for minimal irrigation of safflower. If soils are deep and reasonable yield expectations are 2,000 to 3,000 pounds per acre (2,240 to 3,375 kg/ha) of seed, fertilization should be similar to irrigated safflower in the same region.

If more than 1.5 tons per acre (3,375 kg/ha) of straw or dry crop residue is returned to the soil by the preceding crop, the larger fertilizer amounts indicated should be applied to help decompose the crop residues while providing sufficient nutrients to fertilize the safflower crop. Fertilizer rates applied to safflower following a legume such as alfalfa or a heavily fertilized vegetable crop such as tomatoes should be adjusted for residual soil nitrogen. Yields may be reduced by an

Figure 10. Three rows of safflower planted on 60-inch (1.5-m) beds in the Sacramento Valley.

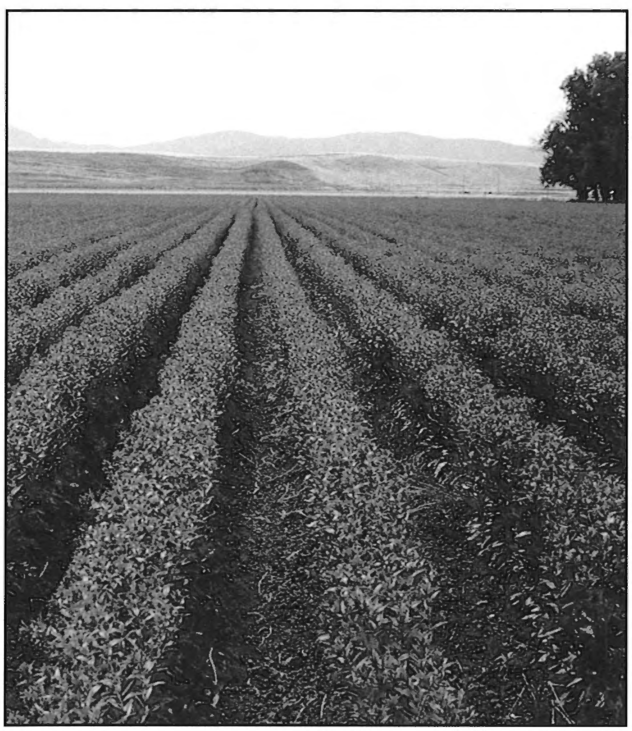

Figure 11. Safflower planted on 30-inch (76-cm) rows.

excessive nitrogen supply, which can lead to exhaustion of soil moisture by the vegetative growth of the safflower. Similarly, yields of dry-farmed safflower, even in fallow systems, will be reduced if the fertilization rate produces excessive vegetative growth that exhausts soil moisture prior to seed maturation.

When planted following rice, phosphorus deficiency can develop in safflower. If phosphorus deficiency occurs, the seedlings turn yellow, develop a leaf tip burn, and may fail to grow normally (plate 2). Phosphorus is less available to rotational crops on soils that have been flooded (anaerobic) for long periods, and additional phosphorus fertilizer may be required (plate 3). When phosphorus is needed, 40 to 60 pounds per acre (44.8 to 67.2 kg/ha) of P_2O_5 or 17 to 26 pounds per acre (19 to 29.1 kg/ha) of elemental phosphorus are typically applied. Because phosphorus is not very mobile in most soils, the fertilizer should be placed near the seed. Safflower grown after long-term rice production may not have yields as high as after other crops that require well-aerated soils, even if phosphorus fertilizer is applied.

Potassium deficiency in safflower is rare (plate 4). Although safflower recovers a large amount of potassium from the soil, it has responded occasionally to application of potassium. Significant yield increases were obtained by supplying potassium to mineral soils with perched water tables in the Sacramento–San Joaquin Delta region when soil test (ammonium acetate) results indicated very low potassium levels. In such cases, 75 to 90 pounds per acre (84 to 100.8 kg/ha) of K_2O have been sufficient.

Seed Treatments

Safflower seed is typically treated with a fungicide to reduce the occurrence of seedling rust. Rust spores can contaminate warehouses and seed cleaning equipment. Some safflower is grown organically, or without pesticides (including fungicides), to meet special marketing niches. Seed for these programs may not be allowed to be treated.

Seeding Rates

Matching the density of a safflower stand to the moisture available to the crop is the key to successful production. Because light interception limits crop yield, the objective in safflower stand establishment is to obtain a complete leaf canopy as soon as possible in the growing season without exhausting soil moisture reserves before the end of the seed maturation period. Seeding rates depend on the moisture available to the crop during the growing season, the time of seeding,

Plate 1. Safflower damaged by high-salinity soils (left) and undamaged by low-salinity soils (right) on plots receiving equivalent amounts of water.

Plate 2. Phosphorus-deficient safflower seedlings.

Plate 3. Safflower takes up phosphorus from aerobic levee soil but not from flooded soil.

Plate 4. Potassium-deficient safflower seedlings.

Plate 5. Western flower thrips (*Frankliniella occidentalis* Perg.).

Plate 6. Adult lygus bug (*Lygus hesperus* Knight).

Plate 7. Immature safflower buds damaged by lygus feeding.

Plate 8. Mature safflower buds damaged by lygus feeding.

Plate 9. Grasshopper damage to dryland safflower.

Plate 10. Phytophthora root rot in safflower in a wet spot in a field.

Plate 11. Vascular discoloration in safflower caused by Phytophthora root rot.

Plate 12. Seedling rust (*Puccinia carthami*) on an immature safflower plant.

Plate 13. Leaf and stem rust on a mature safflower plant.

Plate 14. Rust spores and associated girdling of the stem at the base of a safflower seedling.

Plate 15. Fusarium wilt on a safflower seedling.

Plate 16. Fusarium wilt on a mature safflower plant.

Plate 17. Verticillium wilt on mature safflower plants. From left to right, complete infection, partial infection, and a healthy plant.

Plate 18. Botrytis head rot on safflower heads.

Plate 19. Damage to safflower heads caused by *Alternaria* spp.

Plate 20. Bacterial blight on safflower leaves.

Plate 21. Sclerotinia stem rot on safflower stems.

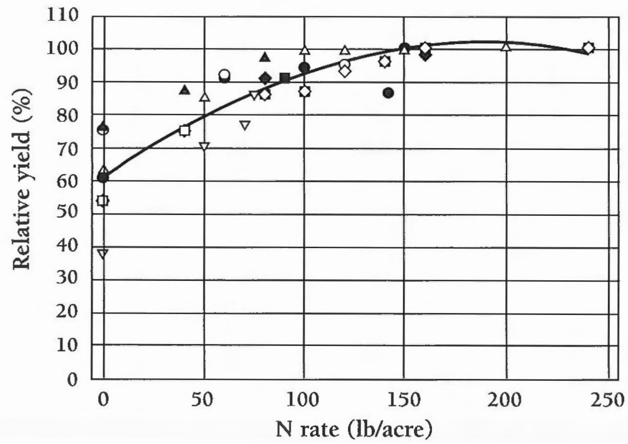

Figure 12. Relative yield and nitrogen fertilizer rates from a number of trials in the Sacramento Valley. Data are summarized from trials conducted in the 1960s. Maximum yields ranged from 1,500 to greater than 3,000 lb/acre (1,680 to 3,360 kg/ha), similar to current yield levels achieved in the same locations. Relative yield = 61.5 + 0.42 N (lb/acre)– 1.1 N^2 (lb/acre) (R_2= 0.83). ***Source:*** **Adapted from Werkhoven et al. 1968; Kearney 1997.**

row spacing, seed size, and seeding method. Typical seeding rates are given in table 4. Some additional factors must be considered, however, when determining rates. On shallower upland soils where dry farming is practiced, seeding rates should be lower than under other conditions, since the available soil moisture will probably be limiting. If soil moisture is thought to be limiting, a closed crop canopy may not be desirable. Close rows planted with a grain drill require higher seeding rates than those planted with row planters. Broadcast seeding requires approximately 10 pounds per acre (11.2 kg/ha) more seed than drill or row planting to compensate for seed lost during the covering operation (harrowing), when some seed is buried too deeply and some not deeply enough. For late plantings where seed must be planted deeper to reach moist soil, seeding rates should be increased by 5 pounds per acre (5.6 kg/ha) to compensate for lower emergence.

Plant populations for a satisfactory stand. Safflower yields do not vary over a wide range of seeding rates as long as there is enough soil moisture available to supply a complete crop leaf canopy through the grain-filling period. Growers should seek to have a complete crop canopy no later than first bloom, preferably by flower bud formation (see fig. 3).

For seedings using a grain drill, rows may be 6 to 12 inches (15 to 30.5 cm) apart. In row plantings, the rows should be from 18 to 30 inches (45.5 to 76 cm) apart if the crop is grown on dry land. Under irrigation, rows should not be more than 30 inches (76 cm) apart. Safflower in rows 20 to 30 inches (51 to 76 cm) apart (either irrigated or dry farmed) should average 5 to 12 plants per linear foot (16 to 39 plants per m) of row. Late-sown stands produce smaller plants with fewer heads and require narrower row spacing to achieve complete row cover. For example, growers using 60-inch (1.5-m) beds use two rows if they plant early in the season and three late in the season.

For solid stands planted with a grain drill in upland dry-farming systems, a population of 3 to 5 plants per square foot (32 to 54 per square meter) is adequate. On irrigated or high-water tableland, up to 5 to 10 plants per square foot (54 to 108 per square meter) is desirable. Stands of less than 2 plants per square foot (22 per square meter) usually result in excess weed competition, especially if herbicides are not used. Under dry-farmed conditions, if the stand exceeds 6 plants per square foot (65 per square meter), overcrowding, especially in years with moisture limitations, may reduce yields.

Seeding Methods

Different types of planters are used successfully with safflower. Hoe-opener drills are used frequently for both solid and row plantings by stopping an appropriate number of seed feeds or runs. Row crop planters are used on raised beds. For plantings in rows that are 20 to 30 inches (51 to 76 cm) apart, most conventional row planters can be adapted for safflower.

Safflower seed must be placed in moist soil. Late-spring plantings, when the surface soil is drying out very rapidly, should be made only with a corn shoe-opener drill to make sure the seed is placed into moist soil. The seed should not be planted into the moisture deeper than 2 to 2.5 inches (5 to 6.5 cm), although seedlings will emerge from a depth of 3.5 inches (9 cm) if a surface crust does not develop. If seed is broadcast, harrowing should cover seed to a depth of 2 to 3.5 inches (5 to 9 cm).

IRRIGATION

Safflower can be irrigated, and yields are highest in many locations in California when irrigation is used, even on deep, permeable soils. But caution is always required. Any condition created by irrigation or rainfall that initiates and promotes infection by *Phytophthora* will result in significant yield loss. The irrigation guidelines below are focused on the ways to reduce the likelihood of an outbreak of Phytophthora root rot. The deep, vigorous root system of safflower allows the crop to use moisture stored in the subsoil, making it desirable to preirrigate, filling a deep soil profile with water. If winter rainfall is adequate, or if water is available in the soil profile that was missed by shallower-rooted crops, irrigation may be avoided altogether. Deep rooting by safflower can also allow growers to minimize the number of irrigations required during the cropping season and thereby reduce the possibility of root rot injury.

Irrigation practice must vary with soil conditions affecting water penetration, drainage, water storage, and root development. If the soil is sandy or shallow but drains readily, safflower requires the same irrigation as other crops growing at the same time. Deeper soils with a high water-storage capacity permit longer intervals between irrigations as long as the subsoil is moist in an uninterrupted column. Root rot will be less likely to occur under these conditions. On soils with poor internal drainage, careful early irrigation is possible, but late-season irrigation is risky. Raised beds are necessary if safflower is to be irrigated because they reduce the danger of root rot.

There is a wide range of soil textures between the extremes of coarse and fine soil where surface and sprinkler irrigation of safflower can be effective. A balance between supplying adequate water and avoiding injury from excess water must be achieved. The following general guidelines for irrigation must be modified by the grower's own experience.

Irrigation Guidelines

1. Preirrigate whenever possible, filling the soil profile completely. Preirrigation should raise the soil to field capacity to a depth of at least 6 feet (1.8 m) and preferably to 10 feet (3.0 m).

2. Provide complete surface drainage.

3. Keep irrigations short, especially during hot weather. In general, it is better to avoid irrigating during hot weather.

4. Irrigate before drought symptoms appear. The drying of lower leaves ("firing") can indicate moisture stress. Drought and plant water stress are correlated with increased disease occurrence.

5. Minimize the number of irrigations needed after planting by storing water in the soil prior to planting (rainfall or preirrigation).

6. Plant in beds if furrow or sprinkler irrigation is used.

7. Do not plant safflower on soils with slow internal drainage if it will be necessary to irrigate during warm weather. Typically, these are clay soils, stratified soils, and all soils with clay pans or other hardpans.

One special characteristic of safflower deserves mention. Safflower is well adapted to the use of water from saturated soil horizons within its rooting depth. It does very well with subirrigation alone under conditions where most other summer crops would require supplemental irrigation. The highest yields of safflower in California often come from areas with shallow water tables, such as the Sacramento–San Joaquin Delta region and the Tulare Lake Basin. In the Tulare Lake area, growers estimate average safflower water use at approximately 26 to 28 inches (66 to 71 cm). Up to 60 percent of this water is applied in a single irrigation, and the remaining 8 to 12 inches (20.5 to 30.5 cm) is derived from the soil.

WEED MANAGEMENT

Weeds damage safflower yields in several ways. Early weeds may compete with safflower for moisture, sunlight, and nutrients, lowering production and increasing cultivation costs. Heavy infestations of weeds later in the season may interfere with mechanical harvesting and in extreme cases cause abandonment of fields. Since safflower often matures before many common weed species, green weed matter taken in by the harvester impairs quality and must be cleaned at the grower's expense.

Cultural Control

The most effective weed control is achieved by practicing a sound crop rotation that reduces weed numbers and minimizes the accumulation of weed seed in the soil. It is good practice to allow weed seed to germinate with winter rains or a preirrigation before any initial tillage. Spring operations can then be timed to destroy one or two crops of germinating weed seed before planting.

Planting date also is important in weed control. Early-winter seeding, especially in the Sacramento Valley, prolongs the period when safflower grows slowly, and winter weeds may develop ahead of the safflower and smother it. It is better to plant after the winter weeds are destroyed and before the summer weeds are established.

If a field is not heavily infested and if perennial weeds are not a serious problem, adequate weed control can be achieved with well-timed crop cultivation. Safflower planted in rows can be cultivated 2 or 3

Table 5. Herbicides registered for use on safflower in California, 1997

Trade name	Chemical name/description	Type
Dual	Metolachlor 2-chloro-N-(2 ethyl-6-methylphenyl)- N-(2-methoxy-1-methylethyl) acetimide	Preemergence, selective
Eptam (EPTC)	S-Ethyl dipropylthiocarbomate	Preemergence, selective
Goal	Oxyflourfen 2-chloro-1-3-(3-ethoxy-4- nitrophenoxy)-4-(trifluoromethyl) benzene	Preemergence, selective
[redacted]		
Roundup	Glyphosate Isopropyl salt of N-(phosphoro-methyl) glycine	For fallow weed control, prior to planting; may be used up to 30 days before planting for some specialty safflower markets
Treflan, Trilin, Trifluralin	Trifluralin a,a,a-Trifluro-2,6 dinitro-N,N- dipropyl-p- toludine	Preemergence, selective

Note: Restrictions governing the use of pesticides change frequently. Check with the County Agricultural Commissioner, Cooperative Extension Farm Advisor, or a licensed pest control adviser. Always follow the directions and restrictions on the label with respect to application, reentry, and disposal of residual material and containers.

times, or as often as necessary, until just before flowering. It is very important that the last cultivation be made as late as possible but without causing mechanical damage to the crop. When safflower is planted with a grain drill, which does not allow cultivation between rows, shallow harrowing or light cultivation has been used to control seedling weeds before the safflower emerges and in young stands when the safflower is 3 to 6 inches (7.5 cm to 15 cm) tall. Harrows that disturb the soil surface but do not uproot the safflower plants can be used perpendicular to the safflower rows. Early in the day and on cooler days, safflower plants become less flexible and brittle. To prevent damage, safflower should be cultivated later in the day and only on warm days when the plants are less turgid and more flexible.

Herbicides

The currently labeled herbicides for safflower in California are listed in table 5. Trifluralin (Treflan) and EPTC (Eptam) are the most commonly used herbicides. They usually provide effective control of early-season weeds, after which competition by the safflower itself reduces or eliminates further weed germination and growth. Of the two, Trifluralin is the most commonly used. It is available in liquid and granular formulations. It controls annual grasses such as barnyardgrass (*Echinochloa crus-galli*), green and yellow foxtails (*Setaria* spp.), crabgrass (*Digitaria sanguinalis*), wild oats (*Avena fatua*), and broadleaf weeds including velvetleaf (*Abutilon theophrasti*), wild mustard (*Brassica rapa*), and wild sunflowers (*Helianthus annuus*). It resists leaching and can present a carryover problem to sensitive crops such as grain sorghum, corn, and sugarbeets.

EPTC is a preplant-incorporated material that controls many kinds of grasses, including barnyardgrass, crabgrass, green and yellow foxtails, fall panicum (*Panicum dichotomiflorum*), witchgrass (*Panicum capillare*), and several broadleaf weeds such as pigweed (*Amaranthus* spp.), lambsquarter (*Chenopodium album*), and yellow nutsedge (*Cyperus esculentus*). This herbicide should be incorporated immediately after application by multiple disking or by a power-driven rotary tiller. EPTC has a short residual period in the soil and should not present a carryover problem to following crops. For fallow-season weed control and for dryland systems before planting in the spring, glyphosate (Roundup) is commonly used.

Pesticide labels are constantly changing. Current information about the registration status of a particular pesticide is available to those with access to the Internet from the California Department of Pesticide Regulation at http://www.cdpr.ca.gov (listed by active ingredients only), or from UC Cooperative Extension personnel or licensed pest control advisers.

Table 6. Insect and mite pests of safflower

Scientific name	Common name	Description of damage	Control threshold	Control
Agrotis spp.	Cutworm	Stand reduction	No control is necessary unless damage is severe	Labeled pesticides
Aphis fabae Scop.	Black bean aphid	Stunting and death of plants	50 to 60 aphids per plant; large areas of the field must be affected	Labeled pesticides
Frankliniella occidentalis Perg.	Western flower thrips	Bronzing or blasting of flower buds	25 to 30 of the early buds are bronzed or blasted prior to bloom	Labeled pesticides
Limonius spp.	Wireworm	Stand reduction	None	Seed treatment
Lygus hesperus Knight	Lygus bug	Bud browning and blasting	25 to 30 per sweep of a standard insect net; 40 per sweep are needed to cause significant damage	Labeled pesticides
Melanoplus spp.; *Schistocera* spp.	Grasshopper	Leaf chewing	None; may be severe on occasion, especially on field edges or under dry land conditions during drought	Labeled pesticides
Myzus persicae (Sulzer)	Green peach aphid	Damages or destroys primary seed head; may reduce crop yield by one-third	None	Labeled pesticides

Note: Other insects or mites have occasionally been reported at damaging levels in safflower. These include leaf-curl plum aphid (*Brachycaudus helichrysi* Kalenbach); leafhoppers (*Empoasca filamenta* DeLong, *E. abrupta* DeLong); loopers (*Trichoplusia* spp.); leafminers (*Liriomyza* spp.); stem miner (*Liriomyza* spp.); sunflower moths (*Homoeosoma electellum* Hulst.); stinkbugs (*Chlorochroa sayi* Stal., *Euschistus conspersus* Uhler); spider mites (*Tetranychus urticae* [K], *T. pacificus* McGregor).

INSECT MANAGEMENT

Many species of insects can be found in safflower fields (see table 6). Although some use safflower as a food source, they rarely affect yield. Safflower yields are based on the number of plants per acre, the number of viable flower heads per plant, the number of seeds per flower head, and to a lesser degree, the size of the seed. Like wheat, barley, rye, and oats, compensation among these diverse yield components is possible in safflower (see fig. 3). Safflower plants can also form additional buds if primary buds are damaged. Because this compensation is possible, insect damage rarely influences yield in a significant way. In practice, wireworms and cutworms, which can affect stand establishment, and lygus bugs, which migrate from safflower to cotton, are the only insects commonly controlled with pesticides in safflower. Other insects mentioned here are seen only occasionally.

Insect damage to safflower can occur at crop establishment, during seedling and stem growth, and during the bud-to-flower stage. The most susceptible period is generally the bud-to-flower stage. Thrips and lygus bugs are the most potentially damaging pests. Bud removal experiments (simulating bud loss from insect damage) indicate that as late as full bloom, substantial bud loss can occur without significant loss of yield (Knowles and Miller 1965). Removal of more than 50 percent of the buds of 'Gila' safflower (an older cultivar) by mechanical debudding at the onset of bloom did not reduce yields in one experiment (Knowles and Miller 1965). Buds removed were younger and less than 0.25 inch (6.5 mm) in diameter, and most of the buds remaining after mechanical removal were close to blooming. Removing buds at this period reduced the number of good seed heads, but the number of seed in the remaining heads was nearly doubled, providing yield compensation. The seed formed by debudded plants were similar in size to those from plants that were not debudded. Insecticides used to reduce bud loss from insect pests had no significant effect on yield. Most safflower cultivars appear to react similarly to 'Gila.' Insect pests must occur at a high level over an extended period for crop loss to be measurable.

Planting safflower at a locally optimal time from the perspective of crop development and water use usually allows the crop to develop vigorously enough to tolerate most insect damage. The use of insecticides against safflower pests is generally not required. In cotton-growing regions of the state, however, safflower may be sprayed to control lygus bugs as the crop begins to mature to prevent those insects from migrating to nearby cotton fields. This control is for the sake of the cotton, rather than the safflower.

Insects Observed in Spring or at Stand Establishment

Cutworms (*Agrotis* spp.) are caterpillars that live below ground and cut off seedlings at or just below the soil line. Other species (*Peridroma saucia* and *Euxoa auxiliaris*) that are nocturnal and feed above ground may occasionally be encountered in safflower. Cutworm feeding may cause areas in fields to be barren of plants. Cutworms are encouraged by previous crops of alfalfa or small-grain crops and by grassy weeds. If sufficient plants are present, safflower can compensate for some seedling loss. If damage is severe, protection of seedlings with insecticides may be necessary. Carbaryl (Sevin) can be used as a bait after damage is observed. The bacterial insecticide Bt (*Bacillus thuringiensis*) may be used if seedlings are large enough to withstand moderate damage while the bacteria infests the insects' digestive system (1 to 2 days). Observe current label restrictions for all pesticides.

Wireworms (*Limonius* spp.) occasionally attack safflower plantings. They may reduce the number of plants by destroying some of the germinating seed or by damaging roots. In a stand with sufficient plants, modest wireworm damage does not reduce yield significantly. If significant damage is anticipated, Isotox (Lindane) may be used as a seed treatment.

Seed corn maggots (*Delia platura* [Meigea]) have damaged safflower stands in research trials in plots with especially high levels of cover crop residues and organic matter, conditions that favor this insect. Excessive moisture or cool, wet periods slowing seedling growth and prolonging the plants' susceptible stage may encourage damage.

Green peach aphids (*Myzus persicae* [Sulzer]) may become abundant enough in the spring to damage primary buds and seed heads, causing them to become a spotty or mottled yellow. Seed production can be reduced by as much as one-third on individual plants that are severely affected. Vigorous crops usually compensate for loss to green peach aphids, and the insects are rarely controlled.

Black bean aphids (*Aphis fabae* Scop.) can develop high populations on leaves and terminals of single plants. Small to medium-sized groups of plants generally become infested near the margins of fields. As many as 1,200 or more black bean aphids can develop on one plant and severely stunt or completely destroy it. More moderate infestations of about 500 aphids per plant can still cause appreciable stunting. Light infestations of less than 50 to 60 aphids per plant can be tolerated. Individual plants, when severely infested, have lost on average 50 to 75 percent of the seed. Despite the losses from individual plants, control has usually been unnecessary because only small areas of fields tend to be affected. Labeled insecticides may be considered if large numbers of plants are moderately to severely infested or if a large number of aphid colonies are found throughout the field.

Onion thrips (*Thrips tabaci* Lind.) are an occasional pest of minor or local importance on safflower. Silvering and bronzing of young seedlings can occur when onion thrips emigrate in large numbers from newly harvested nearby small-grain fields. Infestation is brief and the damage minor. Control has not been necessary.

Insects Affecting Safflower during Vegetative and Reproductive Stages

Western flower thrips (*Frankliniella occidentalis* Perg.) (plate 5) cause most of the early- to midsummer browning, bronzing, and blasting of buds observed in safflower fields. Damage occurs on developing buds largely before bloom and before high populations of lygus bugs appear. Bud loss can be caused by 20 to 25 thrips nymphs per bud. When infestations average 150 nymphs or more per bud, the nymphs can destroy all the buds on a plant. Plants must lose approximately 40 percent of their buds before a measurable loss of seed occurs. Insecticides are not recommended for the control of thrips until 25 to 30 percent of the early buds are bronzed and blasted prior to the onset of bloom. Such high losses to thrips are rare.

Lygus bugs (*Lygus hesperus* Knight) (plate 6) must be present in large numbers—40 per sweep of a standard 15-inch (38-cm) diameter insect net—to cause significant seed losses. They can cause a moderate degree of bud browning and blasting only when they feed in large numbers on the developing buds prior to bloom (plate 7). Usually lygus-damaged buds can be distinguished from those injured and blasted by thrips by their sickle shape. Most buds fed on by lygus bend over and turn brown, while buds browned and blasted by thrips remain upright. Lygus bugs usually cause economic damage (bud loss) only in late-sown fields after high lygus population densities have had time to develop on safflower or neighboring crops. Insecticides are not recommended until at least 25 to 30 lygus bugs (including nymphs) per sweep of a standard insect net are present before the primary buds begin to bloom.

Lygus bugs and flower thrips generally remain to feed on seed heads developed from the buds. However, most of this later injury is superficial, causes very little loss of seed heads, and only occasionally results in the loss of a few seeds (plate 8). As it matures, the head becomes too tough for more than localized injury. Insecticides are not required after seed heads develop from primary and secondary buds. The discolored or dirty appearance of seed heads and the corresponding prevalence of lygus bugs is misleading. If lygus must be controlled to prevent migration to cotton or other crops, labeled insecticides should be applied before lygus nymphs have developed wings. In the San Joaquin Valley, controls should be applied by the time 667 degree days (above 52°F [11.1°C] base temperature) have accumulated after April 1 or after planting, whichever occurs first. Two organophosphate pesticides are currently available (dimethoate and methidathion), but their effectiveness against lygus has diminished in recent years. Labeling restrictions change rapidly, so growers should consult Cooperative Extension personnel or licensed pest control advisers before using a material.

Grasshoppers (*Melanoplus* spp., *Schistocera* spp.) will feed on safflower and can cause severe damage to individual plants (plate 9). Chewing is seen most commonly on plants near the edges of fields, particularly in dry-farmed areas where safflower may be the only green plant available late in the season and alternative food sources for the grasshoppers are unavailable. Damage to the crop as a whole usually is minor, though it may vary. In the majority of instances, control is unnecessary.

DISEASES

Safflower grows best with low atmospheric humidity and in deep soils with good internal drainage. Most of the diseases to which it is susceptible occur when conditions differ from these ideals. Several diseases affect safflower in California (see table 7). Some are widespread and others are more limited in occurrence. Crop rotation, careful irrigation practices, and planting treated and disease-free seed are important methods for controlling losses from disease. Planting safflower where coastal fog is persistent in summer is not recommended because higher atmospheric humidity promotes Botrytis head rot, resulting in crop loss. Present commercial cultivars have partial or complete resistance to Fusarium wilt and limited resistance to Phytophthora root rot. The severity of Phytophthora root rot may vary depending on whether the crop is surface-irrigated, subirrigated, or not irrigated at all. Diseases that occur occasionally on safflower (Alternaria leaf spot, bacterial blight, pythium, and sclerotinia) are not discussed in detail below but are listed in table 7.

Phytophthora Root Rot

Phytophthora root rots (*Phytophthora crytogea* and *P. dreschleri*) are widespread and are the most serious diseases of irrigated safflower in California. Many races of the causal fungi that are endemic in California soils attack the roots and lower stem under favorable environmental conditions. No commercial cultivars are immune. Plants are susceptible at all stages of growth, but the visible symptoms become more apparent from flowering onward. Infected plants become light colored, wilt, and die (plate 10). In the early states of infection, roots may show a reddening of tissue. Infected roots and lower stems later become darkly discolored (plate 11). Phytophthora root rot can be devastating, particularly when crops are irrigated late in the season and plants have developed symptoms of moisture stress prior to irrigation. It may also occur in nonirrigated fields if heavy rains occur, especially late in the spring.

Infectious motile spores of *Phytophthora* are released from fruiting bodies present in the soil when soils become saturated (fig. 13). The organism is most active when soils are completely saturated. A modest decline in soil moisture reduces the activity of the pathogen substantially (fig. 14). Longer or repeated periods of soil saturation may be necessary for significant infection to take place on otherwise permeable soils, especially if initial inoculum levels are low and the cultivar has some resistance. Damage may be minor during earlier irrigations and then become widespread once a sufficient spore population has developed.

The resistance of safflower to infection by *Phytophthora* is not constant. The crop appears to be more susceptible to infection if drought stress has occurred, as shown by firing or browning of the lower leaves. The extremes of overirrigating and allowing drought stress to occur should be avoided. Although safflower apparently becomes more susceptible to Phytophthora root rot the closer it gets to bloom, other factors may contribute to susceptibility. As safflower matures, temperatures also rise and reach the range where the disease is most active. The likelihood that the crop has started to experience some water stress when the canopy has reached full size is greater and disease inoculum levels may be higher than earlier in the season.

The combined effects of different irrigation systems and soils with different drainage characteristics on the susceptibility of safflower to Phytophthora root

Table 7. Diseases of safflower

Disease	Scientific name of causal organism	Damage	Damage control*
Alternaria leaf spot	*Alternaria carthami*; *A. alternata*	Brown, irregularly shaped spots on leaves and floral bracts (plate 19); entire plants may become darkened; partial to complete crop loss	Rare in California but common in the Plains States and Mexico; partial tolerance is available in some cultivars, but resistance is not available; no effective fungicides
Bacterial blight	*Pseudomonas syringae*	Brownish necrotic spots and pale leaf margins (plate 20); lesions on stems and petioles; as disease progresses, rotted flower heads	Rare in California but common in the Plains States, Mexico, and other safflower-growing regions with higher atmospheric humidity
Botrytis head rot	*Botrytis cinerea*	Seed heads become infected, rot, and may fall off	Do not plant safflower in areas with persistent coastal fog in summer
Fusarium wilt	*Fusarium oxysporum* f. sp. *carthami*	Infects roots and spreads to branches; yellowing, wilting, and death; vascular tissue discolored	Crop rotation; use partially resistant cultivars; if the disease is suspected, plant when soil temperatures are cooler
Phytophthora root rot	*Phytophthora dreschleri*; *P. cryptogea*	Infected plants wilt, become light colored, and die; vascular tissue in roots and stem becomes discolored	Irrigate before moisture stress occurs (do not saturate soil near base of plant); seed treatment (partial control); crop rotation
Pythium	*Pythium* spp.	Several species of soil fungi attack seedlings; preemergence or postemergence damping off of seedlings; usually in waterlogged or wet portions of the field	Avoid waterlogged conditions in planted fields
Rust	*Puccinia carthami*; several races	Seedling girdling and death	Rotate safflower with other crops to avoid seedling infection; use treated seed
Sclerotinia stem rot	*Sclerotinia sclerotiorum*	Infected plants turn yellow, wilt, and die; sclerotia are formed at the base of the seed head or in the stem (plate 21); heads may fall off as the disease progresses	Very rare in California, but occurs in other safflower-growing regions with higher atmospheric humidity
Verticillium wilt	*Verticillium dahliae*	Early maturation and death prior to seed formation; interveinal chlorosis of lower leaves	Rotation with nonsusceptible crops like small grains, corn, rice, sorghum, and sugarbeets

*None of these diseases have an economic threshold for control.

rot should be anticipated. On soils with poorer internal drainage or higher levels of inoculum, the risk of disease increases with succeeding irrigations. On shallow soils where preirrigation cannot supply sufficient moisture for a crop to mature, growing safflower based on frequent in-season irrigation is risky.

Good irrigation practice is made easier if preirrigation is applied or if a full soil profile is available. Furrow irrigation can be efficient and is an inexpensive way to apply water to safflower, but soils may become more completely saturated compared to sprinklers. Sprinkler irrigation may allow water application at low enough rates to avoid excessive soil saturation. In turn, this reduces inoculum buildup and shortens the period when soil near the base of the plant is saturated. However, sprinkler irrigation is expensive and is not available on all farms. For furrow irrigation, shorter and more frequent irrigation applications may be superior to less frequent, longer applications, especially if the soil has poor drainage characteristics. Only amounts of water sufficient to replace crop water use should be applied, whatever irrigation method is used.

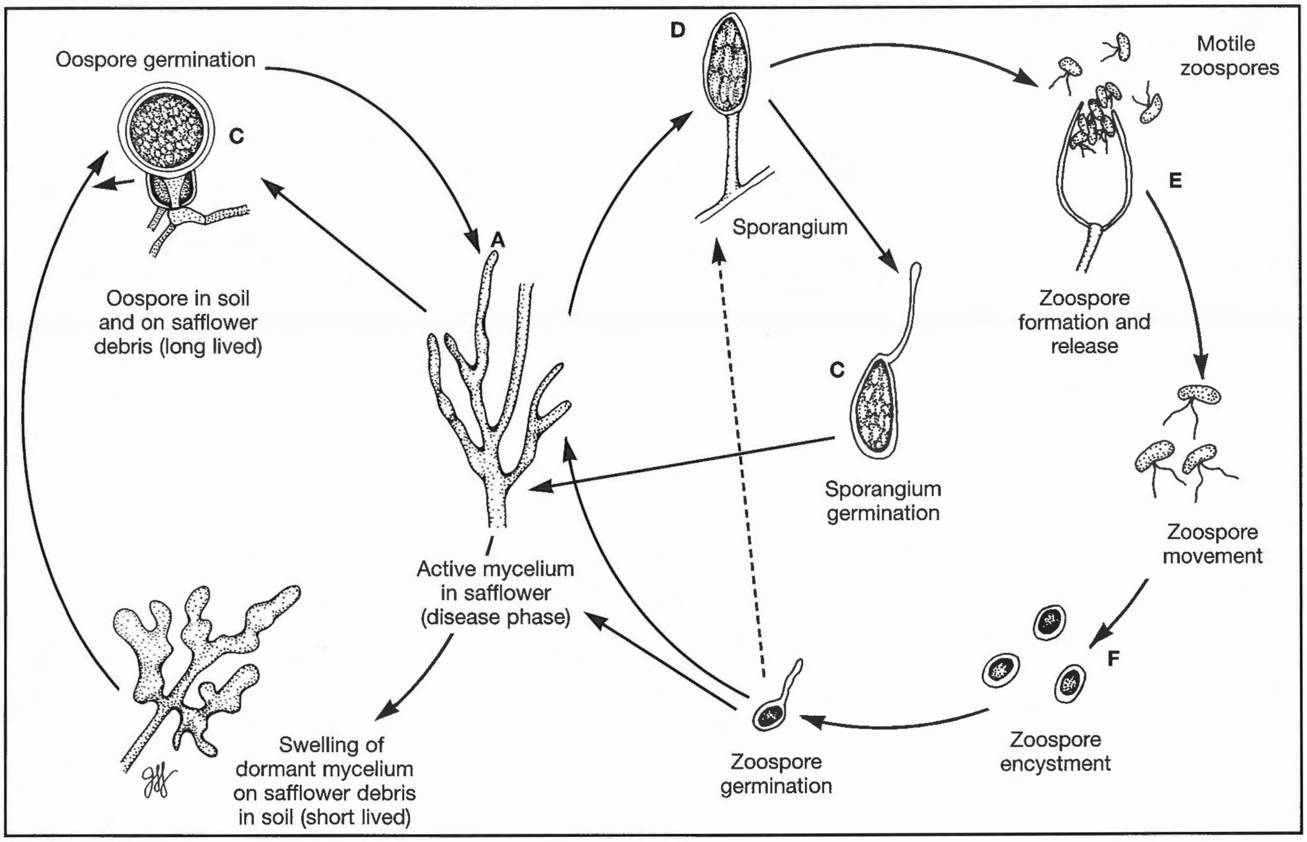

Figure 13. **The life cycle of *Phytophthora cryptogea*. Mycelia actively invade safflower roots, causing disease symptoms and death (A). Mycelia remain viable for several months on safflower residues in the soil following harvest (B) or form oospores (C), which can remain in the soil for years. In the presence of safflower roots, oospores may germinate and form mycelia. The mycelia infect roots directly or form sporangia (D). Subsequently, when soils are rewetted from irrigation or rainfall, the sporangia formed on roots release motile zoospores (E), which disperse through the soil. Zoospores can infect additional roots or stems and can form dormant cysts (F) that await further irrigations to form more mycelium, repeating the cycle. Zoospore formation and dispersal increase the amount of inoculum and the chance for subsequent infection.**

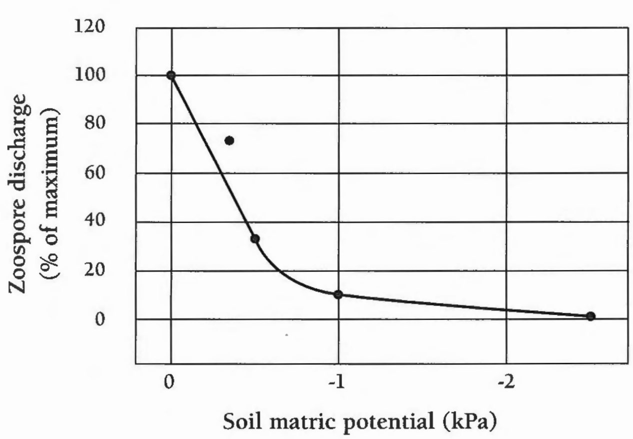

Figure 14. ***Phytophthora* zoospore discharge and soil matric potential. *Source:* Adapted from MacDonald and Duniway 1978.**

Rust

Safflower rust (*Puccinia carthami*) is widespread in all areas of commercial production in California. The rust fungus has a complex life cycle and produces different types of spores, depending on the stage of the life cycle present (fig. 15). Black teliospores appear at the end of the crop growth cycle and can infest seeds or persist on the soil. These spores produce basidiospores that then infect seedlings developing from infected seed or seedlings grown in a field that had safflower the previous year. Aeciospores and teliospores initiate the foliage stage of the disease on older plants and are windborne. The foliar infection is characterized by chestnut-brown pustules containing urediospores on cotyledons, leaves, and bracts. These can reinfect the foliage in a number of recurring cycles.

Rust is more damaging when it occurs at the seedling stage (plate 12) than near crop maturity (plate 13), when its occurrence usually has little affect on yield. Rust infection of seedlings can devastate safflower stands. Seedling infection occurs if seed are contaminated with teliospores or if safflower has been grown in the field in the previous year. Infection at this stage results in girdling of the stem (plate 14). Some plants die, while others grow but fail to set seed. Girdled plants wilt from lack of water or can lodge in the wind.

A number of distinct physiological races of rust have been identified, and others may well exist. Commercial safflower cultivars resistant to all races are not available, although some cultivars are resistant to some of the races. The use of rust-free seed is recommended for control, but even uncontaminated seed may become infected from equipment used to clean and handle seed. Seed treatment with recommended fungicides will give some, but not complete, control of stand loss from seedborne spores. Crop rotation, an essential practice, is effective in reducing stand loss from the soilborne spores and prevents buildup of spores in the soil from successive cropping. In general, late-planted and early-spring-flooded fields have less rust infection than early-planted fields. Rust can be more severe on dense and heavily branched canopies.

Fusarium Wilt

Fusarium wilt (*Fusarium oxysporum* f. sp. *carthami*) is found in Yolo, Solano, and Colusa Counties and in the Sutter Basin. In other areas of Northern California it has been reported in fields near the Sacramento River. This disease has the potential to spread and may become more widespread and serious. Characteristic symptoms are wilting and yellowing on one side of the plant beginning on the lower leaves (plates 15 and 16). Older plants may be killed or lateral branches may die on the affected side of the plant. Young plants are usually killed. A brown discoloration of the vascular tissue occurs in the stem and roots.

The causal fungus invades the roots and spreads systemically into the stem, branches, and leaves through the vascular tissue. The fungus persists in the soil and on plant debris and is seedborne in internal tissue of the hull and seed coat. Some safflower cultivars have partial, and a few are thought to have complete, resistance to all the known races of *Fusarium*. Growers should not save seed harvested from diseased fields for reuse, since the fungus can be disseminated to disease-free areas. Once fields are infected, there is a high likelihood of reinfection of subsequent crops. If infection by *Fusarium* is a possibility, earlier planting dates may help avoid serious infection.

Verticillium Wilt

Verticillium wilt (*Verticillium dahliae*) (plate 17) is a potentially serious disease that occurs in most safflower-producing areas of the state. Although plants are attacked at any stage of growth during cool weather, the disease does not rapidly kill the plants. Affected plants generally mature and dry up earlier than normal. A characteristic early symptom is interveinal and marginal chlorosis of the lower leaves. The leaves of the entire plant then progressively become mottled in appearance from the lower leaves upward. A dark discoloration may be evident in the vascular tissue of infected plants.

The causal fungus is soil- and seedborne. It is widely distributed in California soils, infecting cotton, tomato, melons, strawberries, and a number of other crops. *Verticillium* is favored by cool temperatures and fine-textured soils high in nitrogen and moisture. The fungus invades the roots and spreads into the stem and leaves through the vascular tissue. All current commercial cultivars are susceptible. Seed from diseased fields should not be replanted. Crop rotation with nonsusceptible crops such as small grains, corn, rice, sorghum, and sugarbeets is recommended.

Botrytis Head Rot

Botrytis head rot (*Botrytis cinerea*) is a severe disease in coastal areas subject to continuously high atmospheric moisture. Infected seed heads become light green followed by complete bleaching (plate 18). Whether seed is lacking, light in weight, or fully developed depends on the state of seed development at the time the seed head is infected. The entire infected seed head can be readily detached from its supporting stem because the tissue around the bract is damaged.

Spores of the fungus are windborne and widely distributed. Infection of seed heads may occur under favorable environmental conditions at any time from emergence of blossoms to seed head maturity. No current commercial cultivar is resistant. Safflower should not be produced in areas where fog persists because fog favors severe disease development.

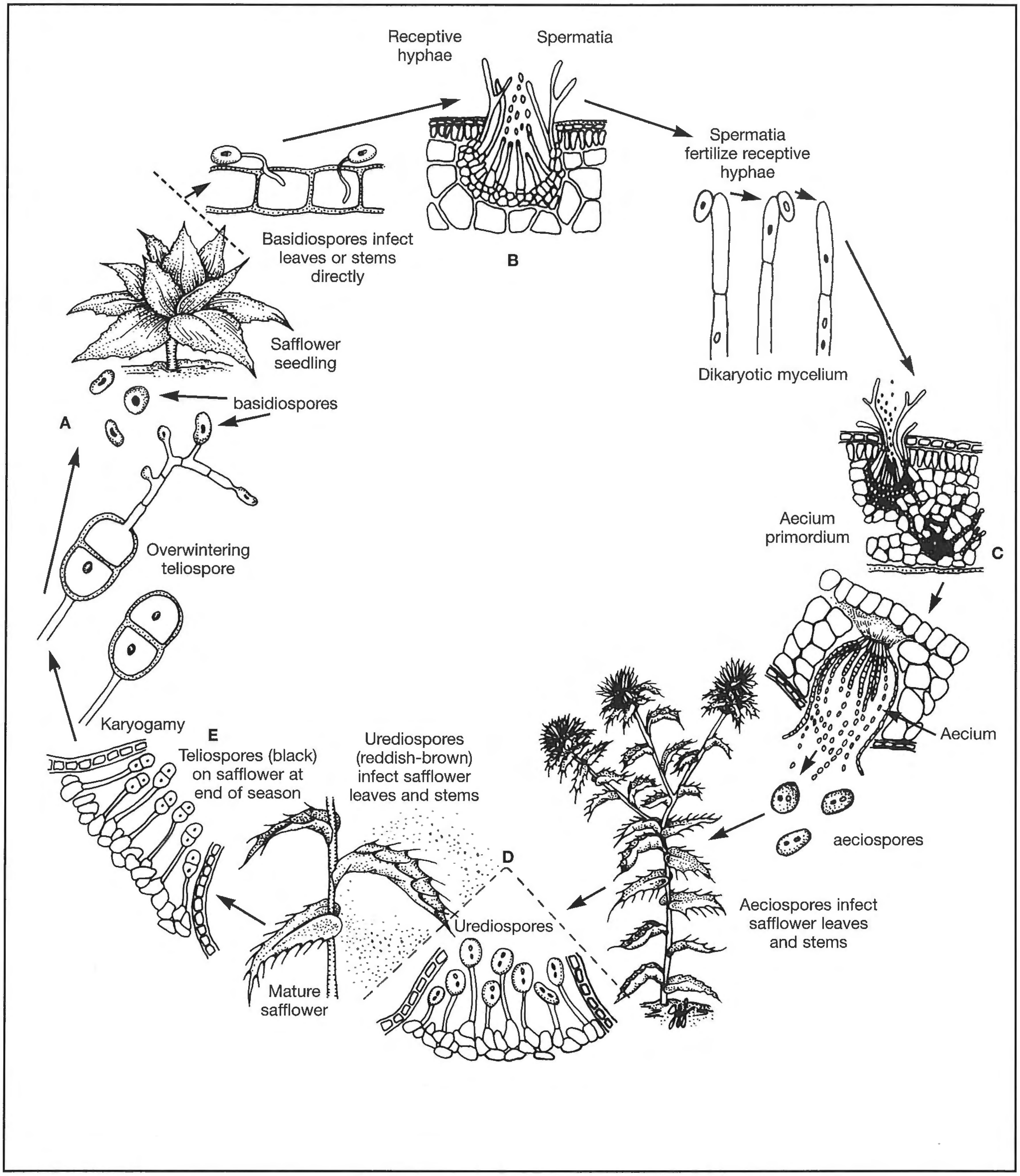

Figure 15. The life cycle of safflower rust (*Puccinia carthami*). There are two distinct phases of the disease. Seedlings are infected by basidiospores (A) developing from teliospores (E) present on the soil or carried by the seed. After infection, the rust enters a reproductive phase (B) giving rise to aeciua and aeciospores (C). These are windblown and infect safflower plants on the leaves, stems, and buds. Pustules develop containing reddish-brown urediospores (D), which can reinfect the foliage giving rise to more pustules. At the end of the season, teliospores develop (E), which can persist over winter and infest seed at harvest. *Source:* Adapted from Zimmer 1963.

HARVESTING

Safflower should be harvested when the moisture content of the seed is 8 percent or less, as required by safflower buyers. This low moisture requirement prevents heating, molding, and deterioration in storage. Experience also indicates that a good job of harvesting cannot be done until seed moisture is below 8 percent. Careful adjustment and operation of the combine will reduce seed losses and increase the seed quality. Factors that influence the maturation of safflower include soil moisture, cultivar, locality, weather, and other growing conditions. In general, harvesting can begin when leaves become dry and brown, with only a little green remaining on the late flower heads. Some late flower heads will be small and contain undeveloped seed. These add little to crop yield and should be ignored. All the seed in the larger heads will be hard and can be hand-threshed readily.

Profit depends on careful harvesting. This means that growers must give continuous attention to the maturity of the crop, the condition of the threshed seed, and seed losses. With careful adjustment, grain combines with rasp-bar, angle-bar, or spike-tooth cylinders can harvest safflower satisfactorily. The shoe screens normally used for barley, wheat, or rice are recommended for safflower. When the crop is direct-combined, a reel will not be necessary unless the stand is too thin for proper feeding onto the header platform. If the stand is not thin, cut only enough of the plant to get the whole seed crop. If a reel is used, its speed should be no faster than the forward speed of the combine.

Windrowing

Windrowing should be used only when a serious weed problem has occurred or when harvest schedules preclude timely safflower harvest. Direct harvesting at the proper time costs less and reduces the chance of seed loss resulting from wind or overdrying in the windrow. Windrowing can be done up to 10 days before direct-combining would normally be started without yield or oil content reduction. Seed moisture may be as high as 25 percent when windrowing is started but must dry to below 8 percent when harvest is completed. Usually 4 to 7 days of drying in the windrow will be required in late summer in California.

Figure 16. Harvesting safflower in large fields in the Tulare Lake Basin.

Standard self-propelled windrowers do an excellent job of windowing safflower (fig. 16). Subsequently, harvester adjustments are the same as for direct-combining and the use of a belt-type pickup attachment is recommended.

Safflower Meal

An important by-product of safflower oil production is the press cake, or meal, which is used as a livestock feed. Table 8 compares the characteristics of safflower meal with soybean meal, another common feed. Three different technologies are used to extract oil from oilseeds. Expeller meal comes from hydraulic presses in which oil is forced through holes in the bottom plates of the press. Solvent-extracted oil is extracted from cracked, ground, or crushed seed by petroleum ether, hexane, or some other volatile solvent; the solvent is then removed by distillation, leaving the pure oil. Soybean oil is commonly extracted by mechanical means.

Table 8. Characteristics of safflower meals compared with soybean meal

Characteristic	Safflower meal		Soybean meal
	Expeller meal	Solvent-extracted	Mechanical-extracted
Crude protein (CP) %	22.1*	25.4*	47.7
Crude fat %	6.7	1.5	5.3
Moisture %	9.0	8.0	10.0
Crude fiber %	35.4	32.5	6.6
Neutral detergent fiber (NDF) %	59.0	58.0	NA
Acid detergent fiber (ADF) %	41.0	41.0	NA
Ash %	3.7-4.1*	5.9*	6.7
Calcium %	0.27	0.37	0.29
Total phosphorus %	0.78	0.81	0.28
Total dissolved nutrients (TDN) %	60.0	57.0	85.0
Digestible energy (DE) (Mcal/kg)†	2.65	2.51	3.75
Metabolic energy (ME) (Mcal/kg)†	2.22	2.09	3.34

Source: National Research Council 1988.
* *Source:* Smith 1996.
†Mcal/kg: Megacalories per kilogram. Caloric values are based on the nutrition of dairy cows.

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