# SAFFLOWER (*CARTHAMUS TINCTORIUS* L.) A POTENTIAL OILSEED CROP FOR WASHINGTON

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Research Bulletin
XB 0920 1982

# Safflower (*Carthamus tinctorius* L.)—A Potential Oilseed Crop for Washington

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## Summary

Safflower has been grown extensively as an oilseed crop under dryland conditions in the Western United States. In California, Arizona, Montana, Wyoming, and Colorado it tends to be grown in rotation with either rice or wheat. Safflower was introduced on a commercial scale to eastern Washington in 1955, when about 3,000 ha were grown (Morrison, personal communication). Although safflower is planted in the spring as a dryland crop, it has been used as an infrequent replacement for spring, winter wheat, and barley. Recently, safflower production has been reestablished on a limited acreage of dryland in eastern Washington as a result of favorable information on newly released cultivars being grown in California and Montana.

The objectives of this study were to evaluate the adaptation of safflower to eastern and central Washington conditions, and to determine best adapted cultivars for seed yield, oil yield, and insect and disease resistance.

Performance trials of 10 to 13 cultivars were planted for 2 years on the Roza Unit of Washington State University's Irrigated Agriculture Research and Extension Center near Prosser and under dryland conditions at Lind, St. John, and Pullman. Annual precipitation at these four locations during the 2-year study ranged from 17 to 20 cm at Prosser, 24 to 34 cm at Lind, 41 to 44 cm at St. John, and 48 to 55 cm at Pullman. Additional water was applied to safflower grown at Prosser, by furrow irrigation. Nitrogen and phosphorus fertilization practices normally followed in each locality for small grain production were used for safflower. At Prosser Treflan (Trifluralin) herbicide was incorporated into the top 10 cm of the soil at 1.12 kg ai/ha before seeding.

Yield of safflower seed increased dramatically with available soil moisture. Yields ranged from 870 kg/ha at Lind to 3,670 kg/ha at Prosser. There were shifts in relative yields among the 13 cultivars depending upon location and year of study. 'S208' and 'S541' were among the highest yielding cultivars tested in both years at all locations. 'Partial Hull' was the lowest yielding cultivar tested at all four locations in 1979, with yields of 500, 2,450, and 1,040 kg/ha at Lind, St. John, and Pullman, respectively. Under irrigation at Prosser, however, Partial Hull yielded 1,990 to 2,610 kg/ha in 1979 and 1980.

The average test weight of all cultivars at each location ranged from 50 kg/hl at Prosser in 1979 to 53 kg/hl at St. John the same year. Partial Hull was the leading cultivar with respect to oil content, with 48.4% at Pullman and 52.5% oil at St. John in 1979. Under irrigation, Partial Hull had oil contents of 49.1% and 50.4% in 1979 and 1980, respectively. The high oil percentage was due mainly to the Partial Hull trait. The lowest oil-producing cultivar was consistently Sidwill. Most of the cultivars tested in Washington yielded over 40% oil content. Though test weight and oil content varied with cultivar and location, values were comparable for both years.

These results indicate that most of the newly released cultivars can be grown commercially in the central irrigated and eastern dryland areas of Washington. Yield is strongly influenced by the supply of available soil water.

## Introduction

Very limited experimental work has been done with safflower under either irrigated central Washington or dryland eastern Washington conditions (6,13). Some of the newly released cultivars for northern states have been grown commercially on a limited basis in eastern Washington.

Safflower has been grown since ancient times in semiarid regions of the Middle East and North Africa. It is used both as an oilseed crop and as a source of dye for clothing and food. Safflower is well adapted to the western part of the northern Great Plains, certain areas between the Cascade and Rocky Mountains, and the Southwestern United States (4,8).

Safflower belongs to the composite family of annual plants and usually grows 50 to 100 cm in height. Seed does not germinate until soil temperatures reach 4° to 5°C (39° to 41°F) or higher. Emergence requires 5 to 20 days, depending on soil temperature (4). Young seedlings can stand low termperatures from −12° to −9°C (10° to 16°F) but plants cannot withstand freezing temperatures after flowering. Safflower seedlings grow slowly, with more rapid growth evident during the second month. Branching begins when plants are 30 to 40 cm tall. Wide row spacings and an abundance of soil moisture increases branching. Cultivars vary markedly in degree of spininess, some spineless types having been developed for ornamental purposes. Most cultivars are from 5% to 30% cross pollinated.

Dry atmospheric conditions during and after flowering are necessary for proper seed set and high oil content. Frequent rains or periods of high humidity during ripening and harvesting may reduce yields (14). Moist soil to a depth of 91 cm prior to planting has been reported as necessary for satisfactory crop production (8), but the total water requirement of safflower has not been accurately determined. Experience in California suggests that the crop needs approximately 400 mm of soil moisture for satisfactory development (8), which is approximately the total annual precipitation of the dryland safflower-producing areas in the United States.

Yields of safflower on fallow land in the western part of the northern Great Plains have reached 560 to 2,240 kg/ha, with most yields averaging 840 to 1,350 kg/ha. These can be compared with yields of 390 to 840 kg/ha on non-fallow land (4). Such yields are representative of results reported from Australia, China, and Israel (7, 8, and 9).

Results from test plots and commercial fields in the Pacific Northwest include dryland safflower yields from 720 to 2,200 kg/ha, with 19.0% to 36.9% oil, in Idaho (1). This can be compared with yields of 1,120 to 1,340 kg/ha in southern Alberta, Canada (11). Domestic safflower yields on irrigated land usually range from 1,120 to 4,480 kg/ha (4,12). Limited irrigation in California has produced yields averaging 2,690 kg/ha. Irrigated safflower grown at Prosser in the 1960s yielded from 3,000 to 3,490 kg/ha (12). On irrigated land safflower does best following potatoes, beans, or beets (4).

Safflower may fit well into farming systems of Washington, where dry or irrigated cropland is available in combination with the dry atmospheric conditions which are conducive to high yields and high oil contents. Expansion of irrigation in the Columbia Basin, with the potential to grow a wide range of crops, creates a demand for high-yielding crops. However, any new crop proposed must meet or exceed the economic returns of crops currently grown in the area (e.g., potatoes, corn, alfalfa hay, and wheat.) Given the high price of oilseed, safflower may compete well with wheat in the Pacific Northwest, where potato contracts and market demands tend to limit potato acreage each year.

This study was conducted to select high-yielding cultivars of safflower which can be grown commercially in central and eastern Washington.

## Materials and Methods

A 2-year study was conducted on the adaptability of safflower cultivars to Washington growing conditions. Each year experiments were located at dryland sites with low (Lind) 24 cm, intermediate (St. John) 41 cm, and high (Pullman) 51 cm rainfall. Experiments were also conducted under irrigation on the Roza unit of Washington State University's Irrigated Agriculture Research and Extension Center at Prosser. The experiments at Lind and Pullman were on Washington State University's Dryland Research Unit and the Spillman Agronomy Farm, respectively. At St. John the experiments were on the Marvin and Rick Repp Farm. A summary of all cultural practices is presented in table 1.

### Irrigated Experiments

Soil of the irrigated experimental area located on the Roza Unit 14 km NE of Prosser, WA, was a Warden loam (coarse-silty, mixed, mesic Xerollic camborthids). The 1979 plantings were on summer fallow, whereas in 1980 the trial followed an onion crop. Each year the experimental plots received the indicated rates of ammonium nitrate, treble super phosphate and Zn-MNS (a mixture of zinc, manganese, nitrogen, and sulfur), with all fertilizer incorporated into the top 10 cm of soil prior to seeding. Treflan was also rototilled into the top 10 cm of the soil to control weeds. Twelve safflower cultivars (table 2) were seeded with a belt planter in 1979, in 5.5 x 5.6 m plots with rows 23 cm apart. The same 12 cultivars plus UC-1 were seeded in 1980 in 5.5 x 12.2 m plots. Water was supplied by 24-hour furrow irrigations five times during the maximum crop growth stage, to keep the plants in optimum growing condition. All plots were harvested by a small plot combine.

In 1980, most of one experimental replication was destroyed by gophers following seeding. Only three replications were harvested.

Table 1. Summary of cultural operations at Lind, St. John, Pullman, and Prosser, WA, 1979-1980.

| | Fertilizer | Weed control | Seeding rate | Planting date | Harvest date |
|---|---|---|---|---|---|
| | kg/ha | | | | |
| 1979 | | | | | |
| Dryland | | | | | |
| Lind | 60N | (hand-weeded) | 35 | 4/10 | 8/27 |
| St. John | 90N | (hand-weeded) | 35 | 5/01 | 10/17 |
| Pullman | 100N | (hand-weeded) | 35 | 5/24 | 10/18 |
| Irrigated land | | | | | |
| Prosser | 112N-56P –11 Zn | Treflan: 1.12 ai | 22 | 4/30 | 10/14 |
| 1980 | | | | | |
| Dryland | | | | | |
| Lind | 60N | (hand-weeded) | 35 | 3/18 | 9/19 |
| St. John | 90N | (hand-weeded) | 35 | 4/18 | 10/22 |
| Pullman | 100N | (hand-weeded) | 35 | 4/17 | 10/24 |
| Irrigated land | | | | | |
| Prosser | 112N-56P | Treflan: 1.12 ai | 22 | 4/03 | 10/01 |

Table 2. Agronomic performance of safflower cultivars at Prosser, 1979-1980.

| Cultivar | Days to flowering[1] 1979 | Days to flowering[1] 1980 | Maturity | Plant height[2] 1979 | Plant height[2] 1980 | Yield* 1979 | Yield* 1980 | Test weight* 1979 | Test weight* 1980 | Oil content* 1979 | Oil content* 1980 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | —cm— | | —kg/ha— | | —kg/hl— | | —%— | |
| S-112 | 70 | 84 | early | 75 | 100 | 2800a-c | 3950ab | 49.9b-e | 47.6f | 43.1c-e | 42.4b |
| S-208 | 73 | 96 | medium | 76 | 102 | 2680bc | 4150a | 51.9bc | 52.7a-d | 42.2de | 42.2b |
| S-317 | 76 | 85 | medium | 87 | 108 | 3050ab | 3860ab | 49.5c-e | 50.7b-f | 45.0bc | 42.8b |
| S-400 | 75 | 87 | late | 92 | 112 | 2690bc | 3550a-c | 48.2de | 48.4ef | 44.0cd | 42.5b |
| S-541 | 75 | 85 | medium | 84 | 110 | 3230a | 3740ab | 50.6b-d | 52.1a-d | 46.9b | 44.5b |
| S-742 | 71 | 86 | medium | 78 | 105 | 2350cd | 3530a-c | 47.6e | 49.5d-f | 45.3bc | 44.0b |
| UC14-5 | 72 | 85 | medium | 81 | 110 | 2740bc | 3080bc | 49.1de | 50.1c-f | 34.7g | 37.2c |
| Gila | 71 | 84 | early | 61 | 95 | 2430cd | 4210a | 49.3c-e | 54.3a | 39.8f | 42.3b |
| Partial Hull | 78 | 90 | very late | 80 | 103 | 1990d | 2610 | 49.6c-e | 51.2a-e | 49.1a | 50.4a |
| Sidwill | 74 | 83 | early | 87 | 108 | 2430cd | 3240a-c | 54.8a | 53.7ab | 34.7g | 35.6c |
| Carmex 353 | 70 | 86 | medium | 75 | 101 | 2480c | 4170a | 52.1b | 50.3b-f | 41.3ef | 42.8b |
| Calwest 74 | 76 | 84 | early | 76 | 102 | 3160ab | 4210a | 50.2b-d | 49.3d-f | 44.2cd | 43.4b |
| UC-1[3] | | 89 | late | — | 105 | — | 3350a-c | — | 53.1a-c | — | 41.6b |
| Mean | 73 | 86 | | 79 | 105 | 2670 | 3670 | 50.2 | 51.0 | 42.4 | 42.4 |
| df | | | | | | 47 | 38 | 47 | 38 | 47 | 38 |
| Sx | | | | | | 66.6 | 101.5 | 0.33 | 0.40 | 0.63 | 0.71 |
| CV% | | | | | | 17.3 | 17.3 | 4.6 | 4.9 | 3.4 | 4.0 |

Note: Means within a column marked by an asterisk (*) not followed by the same letter differ at the 5% level by Duncan's new multiple range test. Seed moisture is 6.2%. Dates of planting: April 30, 1979 and April 3, 1980.

[1]Days from emergence to 80% flowering.

[2]Data were pooled. No statistical analyses.

[3]Not included in 1979 trial.

### Dryland Experiments

In 1979 12 safflower cultivars (table 3) were seeded at Lind, St. John, and Pullman. In 1980 only 10 cultivars (table 4) were planted. At Lind and St. John the soil was a Ritzville silt loam (coarse-silty, mixed, mesic, silty Calciorthidic Haploxerolls, well drained.) The soil at Pullman was a Palouse silt loam (mixed, mesic, fine-silty Pachic Ultic Haploxerolls).

For 1979 and 1980 precipitation at Lind was approximately 24 and 32 cm, at St. John 41 and 44 cm, and at Pullman 48 and 55 cm, respectively. The plantings at St. John and Pullman were on small grain recrop ground, while those at Lind were planted on summer fallow. Safflower was seeded with a small plot planter in 4.9 x 1.5 m plots, with four rows per plot at a 30-cm spacing. Each year ammonium nitrate was broadcast and incorporated before planting at Lind and Pullman, whereas at St. John nitrogen was supplied as a preplant injection of anhydrous ammonia. All trials were harvested with a small plot combine.

Each experiment was conducted using a randomized complete block design, with four replications. Data collected for all trials included seed (achene) yield, test weight as determined by a standard test weight device, plant height at maturity, and oil percentage as determined by a standard Nuclear Magnetic Resonance (NMR) procedure. The latter analyses were performed by Dr. Jerry Bergman at the Eastern Montana Agricultural Experiment Station, Sidney, Montana. Bloom dates were recorded at Pullman and Prosser both years. Hundred-seed weight was determined in 1980 from all locations except Prosser.

## Results and Discussion

### Irrigated Experiments

### (Roza experimental unit)

Safflower seeded on April 30, 1979 and April 3, 1980 emerged 7 and 14 days after seeding, respectively. Cool temperatures during early April may have delayed germination of the early April seeding. All cultivars tested at Prosser showed similar germination rates and growth rates. Seedlings of all cultivars grew slowly during the first month after germination. Claassen (4) and Knowles (8) also reported slow growth of safflower seedlings during the rosette stage in sep-

Table 3. Agronomic performance of 12 cultivars of safflower at three locations in eastern Washington, 1979.

| | Lind | | | | St. John | | | | Pullman | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cultivar | Seed yield* | Test weight* | Plant height[1] | Oil[1] | Seed yield* | Test weight* | Plant height[1] | Oil[1] | Seed yield* | Test weight* | Plant height[1] | Bloom on 8/9 | Oil[1] |
| | kg/ha | kg/hl | cm | % | kg/ha | kg/hl | cm | % | kg/ha | kg/hl | cm | % | % |
| S-112 | 950ab | 49.7de | 47f | 43.4 | 3020bc | 51.0de | 80de | 43.8 | 1380b-d | 49.7de | 73a-c | 55a | 41.5 |
| S-208 | 1028a | 50.4cd | 50d-f | 43.5 | 2814b-d | 52.6b-d | 83cd | 43.7 | 1550 | 52.2ab | 75a-c | 21b | 40.3 |
| S-317 | 830a-c | 51.7bc | 56a | 46.4 | 3520ab | 52.4b-d | 92ab | 45.6 | 1660ab | 51.7a-c | 78ab | 10b | 42.7 |
| S-400 | 720b-d | 49.4de | 52b-e | 45.1 | 3010bc | 50.1e | 87bc | 45.2 | 1140de | 49.0e | 72bc | 10b | 42.7 |
| S-541 | 990ab | 52.5ab | 54a-c | 48.4 | 3190ab | 52.8b-d | 90b | 47.3 | 1220c-e | 52.5ab | 78ab | 15b | 44.4 |
| UC-1 | 960ab | 51.7bc | 50c-f | 42.1 | 2660cd | 53.4bc | 78de | 42.8 | 1820 | 53.4a | 74a-c | 38ab | 38.6 |
| Gila | 850a-c | 53.3a | 48f | 41.2 | 2670cd | 54.4cd | 74e | 42.6 | 1360b-d | 51.2b-d | 69c | 36ab | 37.3 |
| Sidwill | 610cd | 53.4a | 56ab | 35.1 | 2760b-d | 57.0a | 97a | 36.2 | 1390b-d | 53.7a | 73a-c | 28ab | 33.6 |
| Partial Hull | 500d | 53.5a | 49ef | 51.3 | 2450d | 52.2b-d | 89bc | 52.5 | 1040e | 51.0b-e | 75a-c | 13b | 48.4 |
| UC14-5 | 1060a | 50.8c | 53a-d | 37.2 | 2900b-d | 51.7c-e | 88bc | 37.3 | 1520a-c | 50.7b-e | 81a | 27ab | 35.1 |
| Carmex 353 | 1040a | 52.5ab | 53a-e | 43.0 | 2620cd | 52.5b-d | 80de | 43.4 | 1440b-d | 52.0a-c | 75a-e | 18b | 40.2 |
| Calwest 74 | 930ab | 48.6e | 54a-c | 43.3 | 3070bc | 51c-e | 89bc | 44.4 | 1480bc | 50.1c-e | 74a-c | 27ab | 42.1 |
| Means | 870 | 51.4 | 52 | 43.3 | 2890 | 53.0 | 86 | 43.7 | 1420 | 51.0 | 75 | 25 | 40.6 |
| S.E. | 25.7 | .10 | 0.35 | — | 40.8 | 0.19 | 0.58 | — | 28.3 | 0.17 | 0.69 | 2.6 | — |
| C.V. | 20.4 | 1.6 | 4.7 | — | 9.8 | 2.6 | 4.7 | — | 13.9 | 2.4 | 6.5 | 72.9 | — |
| D.F. | 47 | 47 | 47 | — | 47 | 47 | 47 | — | 47 | 47 | 47 | 47 | — |

Note: Means within a column marked by an asterisk (*) not followed by the same letter differ at the 5% level of probability by Duncan's new multiple range test.

[1]Data not statistically analyzed. Data taken on the four-replication bulk samples.

arate experiments in Nebraska and California. Cool temperatures usually extend the rosette stage, while early seeding enhances plant height (all other factors being equal). The taller plants in 1980 may have been due to a longer growing season (table 2).

In both years, early maturing cultivars reached harvest stage around the last week of September. Late and very late cultivars matured 2 and 3 weeks later, respectively.

The yield ranking of cultivars shifted from one year to the next (table 2). Yield varied from 1,900 kg/ha (cv. Partial Hull) to 3,230 kg/ha (cv. S541) in 1979 and from 2,610 kg/ha (cv. Partial Hull) to 4,210 kg/ha (cv. Gila and Carmex) in 1980. Average yield in 1980 was higher than in 1979. Like most crops, the yield potential of safflower seems to be influenced by changes in seasonal weather patterns each year.

Test weight of the 13 cultivars (table 2) did not seem to be affected by environment. There was little or no correlation between test weight and yield for the various cultivars.

Safflower planted in early April 1980 required an average of 13 days longer to reach 80% bloom than safflower planted in late April 1979. Cultivars 'S112', 'Gila', 'Sidwill', and 'Calwest' matured early and were ready to harvest about a week before medium-maturing cultivars such as 'S208', 'S317', 'S541', 'S742', 'UC14-5', and 'Carmex 353'. Partial Hull matured late even though it flowered about the same time as the other cultivars.

Among the 13 cultivars tested at Prosser, Partial Hull ranked highest with 49.1% and 50.4% oil content in 1979 and 1980, respectively, followed by S-541 and S-317 (table 2). All S-cultivars produced more than 40% seed oil content on a dry weight basis under irrigation. The high oil content in the seed of Partial Hull was due to its low hull content, for there is generally a high negative correlation between oil content and hull content (3). Oil content was low in two cultivars (Sidwill and UC14-5) over the years. Calwest 74 was the only cultivar to rank in the top four with respect to total oil production (yield x oil content) each season. Other high-ranking cultivars in this regard were S-112, S-317 and S-541 in 1979, and S-208, Gila, and Carmex 353 in 1980 (table 5).

## Dryland Experiments

In general, seed yields were largely a response to annual precipitation or available soil moisture levels (tables 3 and 4). The increasing precipitation gradient from Lind to Pullman was reflected by a 160% increase in mean yields at Pullman as compared with Lind each season. Yield results at St. John, in the intermediate rainfall zone followed the precipitation gradient in 1980 but not in 1979. In 1979 the average yield of 2,890kg/ha at St. John was 204% of the average yield at Pullman. Annual precipitation in 1979 was 41 cm at St. John, compared with 48 cm at Pullman. The trial at St. John, however, was on a flat, which was appar-

Table 4. Agronomic performance of 10 cultivars of safflower at three locations in eastern Washington, 1980.

| | Lind | | | | | St. John | | | | | Pullman | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cultivar | Seed yield* | Test weight* | 100 Seed weight[1] | Plant height | Oil[1] | Seed yield* | Test weight* | 100 Seed weight[1] | Plant height | Oil[1] | Seed yield* | Test weight* | 100 Seed weight[1] | Plant height | 50% Bloom | Oil[1] |
| | kg/ha | kg/hl | g | cm | % | kg/ha | kg/hl | g | cm | % | kg/ha | kg/hl | g | cm | days[2] | % |
| S-208 | 1340ab | 52.2b-e | 3.3 | 87b | 34.3 | 1370a | 51.8b | 3.6 | 111b-d | 31.2 | 2440a | 52.5b-d | 3.5 | 118a-c | 114a-c | 32.3 |
| UC-1 | 1380ab | 52.3b-e | 3.8 | 79c | 32.7 | 1750a | 54.6a | 4.1 | 102f | 30.5 | 2720ab | 54.5a | 4.0 | 112d-e | 112bc | 29.8 |
| S-317 | 1240ab | 51.9c | 3.1 | 91ab | 35.4 | 1450a | 52.1ab | 3.4 | 113bc | 33.7 | 2350ab | 53.5ab | 3.3 | 120ab | 117a | 34.3 |
| S-541 | 1560a | 52.4b-e | 3.4 | 95a | 37.0 | 1200a | 51.7b | 3.7 | 116b | 34.2 | 2240ab | 51.8cd | 3.6 | 121ab | 115ab | 35.2 |
| S112 | 1200b | 49.7e | 3.2 | 75c | 34.9 | 1670a | 52.3b | 3.9 | 105ef | 33.2 | 2220ab | 51.9cd | 3.6 | 113c-e | 110c | 32.5 |
| Calwest 74 | 1400ab | 50.3d-e | 3.9 | 89ab | 35.6 | 1520 | 50.3b | 4.3 | 112bc | 32.5 | 2130ab | 49.5e | 4.1 | 116b-d | 112bc | 32.0 |
| Gila | 1440ab | 53.2a-b | 3.5 | 75c | 29.5 | 1700a | 54.4a | 3.9 | 107d-f | 30.7 | 2100ab | 54.3a | 3.8 | 107e | 110c | 29.1 |
| Carmex 353 | 1430ab | 51.1c-d | 3.2 | 90ab | 34.2 | 1220a | 50.1b | 3.7 | 114bc | 31.6 | 1910ab | 52.3d | 3.5 | 120ab | 116ab | 32.5 |
| Sidwill | 1420ab | 54.2a | 3.5 | 93ab | 28.5 | 1620a | 54.4a | 3.9 | 121a | 27.5 | 1910ab | 53.3a-c | 3.5 | 125a | 118a | 25.8 |
| S-742 | 1100b | 49.2e | 2.9 | 78c | 34.6 | 1240a | 46.9c | 3.2 | 109c-e | 33.2 | 1870b | 48.5e | 3.2 | 116b-d | 117a | 33.5 |
| Means | 1350 | 51.6 | 3.4 | 85 | 33.7 | 1480 | 51.7 | 3.8 | 111 | 31.8 | 2160 | 52.1 | 3.6 | 117 | 114 | 31.7 |
| S.E. | 32.9 | 0.13 | — | 0.75 | — | 50.4 | 0.24 | — | 0.62 | — | 51.7 | 0.16 | — | 0.59 | 0.44 | — |
| C.V. | 15.4 | 1.6 | — | 5.6 | — | 25.9 | 3.1 | — | 3.0 | — | 15.2 | 1.9 | — | 3.2 | 2.5 | — |
| D.F. | 39 | 39 | — | 39 | — | 39 | 39 | — | 39 | — | 39 | 39 | — | 39 | 39 | — |

Note: Means within a column marked by an asterisk (*) not followed by the same letter differ at the 5% level of probability by Duncan's new multiple range test

[1]Data not statistically analyzed. Data taken on the four-replication bulk samples.

[2]Days from planting.

ently subirrigated from a small creek nearby. The trial at Pullman was on a typical Palouse slope. The block effect was non-significant at St. John, but it was significant at Pullman due to a yield gradient with increasing yield from the top to bottom of the slope. In 1980, the trial at St. John was on a slope which produced an increasing yield gradient from bottom to top of the slope. The incidence of *Rhizopus* (head rot) and *Sclerotinia* (white mold) increased considerably toward the bottom of the slope, and apparently reduced yields of these replications accordingly.

The May 18 eruption of Mt. St. Helens and subsequent ash fall probably influenced the 1980 results as well. Only a small amount of ash fell at Pullman, but from 2 to 3 cm of ash (compacted after rain) accumulated both at St. John and Lind. The ash layer partially "sealed" in soil moisture, thereby giving more efficient soil water use. At Lind, where water was especially limiting, the ash-effect probably enhanced yields (table 4). At St. John, particularly at the foot of the slope, there may have been enough water to increase the incidence of disease, and hence decrease yields (table 4). In General, the incidence of diseases and insects was minimal for all dryland experiments with the exception of St. John in 1980.

It was difficult to make selections on the basis of yield potential, because ranking of cultivars varied with year and location. The results did suggest some differences in adaptation among cultivars over the wide range of environments involved in the study. The entire range in yield, however, was not wide in any single year at any one location, which indicated that a number of the cultivars were about eqally suited for commercial production in a given locality. S-208, S-317, S-541 and UC-1 yielded consistently well, while Partial Hull yielded relatively lower.

Test weights were not affected a great deal by the different regimes (tables 3 and 4). Overall test weight range for the three locations over the 2 years was

46.9 to 57.0 kg/hl. Likewise, 100-seed weight varied little in 1980, with a range for the means of 3.4 to 3.8 g (table 4).

Plant height development of safflower was probably the growth factor influenced most consistently by moisture regime. The increase in plant heights from Lind to Pullman was directly related to the moisture gradient, with the exception noted above for the subirrigated plots at St. John in 1979 (tables 3 and 4). Plant height means at Lind were 69% and 73% of the means at Pullman in 1979 and 1980, respectively. In spite of occasional tall plant development, lodging was negligible throughout the studies.

Although there was a range in maturities for the cultivars grown, it seemed to have little effect on yield (tables 3 and 4). Data taken at Pullman in 1980 indicated a range in heading dates from 110 to 118 days after planting. The highest yield was for cultivar S208, which matured at 114 days.

In 1979 the oil percentage for safflower from all dryland locations averaged 40% or more. The relatively cool, moist conditions of 1980, however, seemed to limit the synthesis and accumulation of oil. Mean oil contents in 1980 were about 25% below average results for 1979 (tables 3 and 4). Low oil percentage could be a problem for the Washington dryland producer, as price premium or discounts are frequently given for safflower seed above or below a certain percentage oil. Hence, the selection of cultivars for high oil percentage may prove of importance. In 1979 some oil percentages were in the mid-30s while other cultivars had oil contents above 48% (table 3). Most consistent dryland cultivars from the standpoint of total oil production (yield x oil conent) were Calwest 74, S-541, S-208, and S-112 (table 5).

Safflower yields reported herein are generally as good or better than yields reported in other dryland safflower-growing areas (2), which suggests a degree of adaptability of these cultivars to dryland eastern Washington. A high yield of 2,960 kg/ha was reported by

Table 5. Oil yield of safflower cultivars at Prosser, Lind, St. John, and Pullman, 1979-1980.

| | Irrigated experiments | | Dryland experiments | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Prosser | | Lind | | St. John | | Pullman | |
| Cultivar | 1979 | 1980 | 1979 | 1980 | 1979 | 1980 | 1979 | 1980 |
| | kg/ha | | | | | | | |
| S-112 | 1210 | 1680 | 410 | 420 | 1320 | 560 | 570 | 720 |
| S-208 | 1130 | 1750 | 450 | 460 | 1230 | 430 | 620 | 790 |
| S-317 | 1370 | 1650 | 390 | 440 | 1600 | 490 | 710 | 810 |
| S-400 | 1380 | 1510 | 330 | — | 1360 | — | 490 | — |
| S-541 | 1520 | 1660 | 480 | 580 | 1510 | 410 | 540 | 790 |
| S-742 | 1060 | 1550 | — | 380 | — | 410 | — | 630 |
| UC14-5 | 950 | 1150 | 390 | — | 1080 | — | 530 | — |
| Gila | 970 | 1780 | 350 | 420 | 1140 | 520 | 510 | 610 |
| Partial Hull | 980 | 1320 | 260 | — | 1290 | — | 500 | — |
| Sidwill | 840 | 1150 | 210 | 400 | 1000 | 440 | 470 | 490 |
| Carmex 353 | 1020 | 1790 | 450 | 490 | 1140 | 390 | 580 | 620 |
| Calwest 74 | 1400 | 1830 | 400 | 500 | 1360 | 490 | 620 | 680 |
| UC-1 | — | 130 | 400 | 450 | 1140 | 540 | 700 | 720 |
| Mean | 1152 | 1555 | 377 | 454 | 1264 | 468 | 570 | 686 |

Note: Data not statistically analyzed. Data computed on the four-replication bulk samples for oil analysis.

McCormick and Thomsen (10) for one New Zealand cultivar in 1976, with 50% lower yields reported in 1977. In India, where 50% of the world's safflower crop is grown, the average commercial yield is less than 300 kg/ha (5). Experimental yields of up to 1,920 kg/ha have been reported in India with careful management (13). In the well-established safflower growing area of northeastern Montana and northwestern North Dakota, Bergman et al. (1979) reported yields ranging from 1,103-2,100 kg/ha, and experimental yields in northern Idaho ranging from 687-3,900 kg/ha (1). Mean commercial yield estimates for 1978 for the leading safflower-producing countries outside India were 1,900 kg/ha for the United States, 1,415 kg/ha for Mexico, 817 kg/ha for Australia, and 391 kg/ha for Ethiopia (5).

## Conclusions

Within the eastern Washington production area sampled in this study, Lind is probably a marginal site for the dryland production of safflower. Spring crops in general do not compete well economically with winter wheat, the major crop of the area, because of the low annual precipitation. The yields of 1979 (table 3) were more indicative of the average response anticipated for this low rainfall area than the high yields obtained in 1980, the "wetter" of the 2 years (table 4). In the intermediate-to-high rainfall area from St. John to Pullman, safflower appears to be reasonably well adapted. Yields obtained here are comparable to yields from other safflower producing areas.

The yields of irrigated safflower were generally higher than on dryland sites, but of course the production costs would also be much higher on irrigated land. Oil yields of irrigated safflower were also higher than for dryland production (table 5). Under irrigation at Prosser, safflower produced an average of 1,150 and 1,550 kg/ha oil in 1979 and 1980, respectively. On dryland sites, average oil yields from safflower varied from very low (337 kg/ha) at Lind in 1979 to 626 kg/ha at Pullman in 1980. An average oil yield of 1,260 kg/ha (table 5) for safflower grown in 1979 at St. John was due to the aforementioned subirrigation at this site. It appears oil yield was influenced more by seed yield than by oil percentage.

Insect and disease problems seemed to be minor at all locations during both years except at St. John in 1980. Frost at Prosser in late October did not cause a reduction in yield, even for the most slowly maturing cultivars. Shattering was not a problem, even when safflower seeds which had reached physiological maturity in late September were not harvested until October.

Safflower has an advantage as an alternate rotational crop for central and eastern Washington, where the predominant crop group is small grains (cereals) because conventional small grain equipment can be utilized in its production. Most likely, growers would readily accept safflower production if a market were available with a suitable price. Based on an economic study in eastern Washington and northern Idaho, it appears that safflower has the potential to be produced as economically as barley and dry peas, the common alternate crops to winter wheat (15) in this region.

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## Unit Equivalents

| Metric | U.S. |
|---|---|
| 1 kilogram (kg) | 2.205 pounds (lb) |
| hectare (ha) | 2.471 acres (a) |
| 1 kilogram/ha | 0.892 pounds/acre (lb/a) |
| 1 centimeter (cm) | 0.394 inches (in) |
| 1 metric ton (MT) | 1.102 tons (ton) |
| 1 meter (m) | 1.094 yard (yd) |
| 1 metric ton/hectare (1 MT/ha) | 0.446 ton/acre (ton/a) |
| 1 gram (g) | 0.035 ounce (oz) |
| 1 kilogram/hectoliter (kg/hl) | 0.776 pounds/bushel (lb/bu) |
| °Celsius (C) | 5/9 (°F-32) |
| 9/5°C+32 | °Farenheit (F) |


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Work was conducted under project number 0481.


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