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A. N. Hang and D. W. Evans

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ABSTRACT

Increasing competition for water supplies and rising costs of applying water make efficient irrigation increasingly important. Yield and water use of sunflower (*Helianthus annuus* L.) and safflower (*Carthanus tinctorius* L.) were evaluated on silt loam soil. Deficit irrigation treatments using the line source method were initiated near the time of canopy closure and continued until maturity. Moisture stress on sunflower and safflower caused shortened plant height, early blooming, early maturity, and decreased seed yield. In 1980 sunflower yields ranged from 2.41 to 4.50 Mg ha^{-1} for 2.5 to 35.0 cm irrigation. In 1981 sunflower yields ranged from 1.56 to 3.37 Mg ha^{-1} for 2.5 to 45.0 cm irrigation. Safflower yields in 1981 ranged from 1.84 to 5.15 Mg ha^{-1} for the same irrigation rates. In 1981, sunflower and safflower received the same total amount of water to produce maximum seed yield. Increased irrigation water results in increased yield for both sunflower and safflower; however, yield per unit applied water decreases with increased irrigation rates so that at some point, the expected increase in yield would not cover the cost of additional water application. Increased irrigation increased oil concentration of sunflower except for cv. 894 in 1980. Oil concentration of safflower did not respond to increased irrigation rates. It was concluded that limiting irrigation on sunflower and safflower to $\leq$ 30 cm permits utilization of residual soil water on silt loam soil with consequent savings in irrigation water supplies and costs of application. Soil moisture is then recharged by winter rainfall.

Additional index words: Deficit sprinkler irrigation, *Helianthus annuus*, *Carthanus tinctorius*, Canopy closure, Line source method, Total water use, Residual soil water.

ALTHOUGH sunflower (*Helianthus annus* L.) and safflower (*Carthanus tinctorius* L.) are considered drought-tolerant crops, inadequate soil water will decrease seed yield (12,15). The optimum irrigation for these crops has not yet been determined for eastern Washington.

Water stress has been shown to decrease sunflower seed yield (14,16,17), test weight (17,18), and oil concentration (2,16,17). Yield losses may result from stress at any stage of growth (16), though stress at flowering to late flowering appears to be most deleterious (18). Seed yields are usually highest when sunflower is irrigated to avoid water stress, but yield increases may not be proportional to water use (18).

Water stress also decreases safflower yield, and the amount of water required for a satisfactory crop varies with environments (4,6,12). Seed weight has been increased by irrigation (6), while seed oil concentration has been variously increased or unaffected (1,6,11).

Most of the above research on safflower and sunflower has involved intermittent irrigation at various stages of growth and with variable periods between irrigations.

The objective of this study was to compare the effect of regularly scheduled adequate and deficit sprinkler irrigation on sunflower and safflower growth, seed yield, oil concentration, test weight, and water use efficiency.

MATERIALS AND METHODS

Field studies were conducted during the 1980 and 1981 cropping seasons on two sites at the Irrigated Agriculture Research and Extension Center, near Prosser, WA. The soil at both sites was a Warden silt loam (coarse, silty, mixed, mesic Xerollic Camborthid).

Fertilizer was broadcast and worked in during seed bed preparation at rates of 205 kg N, 56 kg P, and 135 kg K ha^{-1}. Dyfonate[3] (*O*-ethyl-S-phenylethylphosphonodithioate) and Treflan (*a,a,a*-trifluoro-2,6-dinitro-*N,N*-dipropyl-*p*-toluidine) were preplant incorporated into the top 10 cm of soil

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[2] Assistant agronomist and agronomist, respectively. Washington State Univ. Irrigated Agric. Res. and Ext. Center, Prosser, WA 99350.

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to control soil insects and weeds at rates of 4.92 and 0.64 kg a.i. ha^{-1}, respectively. Two cultivars of sunflower ('Saturn' and '894')[3] in 1980 and one (894) in 1981 were seeded on 9 May and 29 April, respectively, in 56 cm rows. After emergence, plants were thinned to 28 cm apart resulting in a population of 63 320 plants ha^{-1}.'S-208'[3] safflower was planted on 30 Apr. 1981 in 23 cm rows at the rate of 0.028 Mg ha^{-1}.

Experimental fields were uniformly sprinkler-irrigated and allowed to drain before seeding. After emergence a line source was installed (8) lengthwise through the center of each experimental field (45 m by 65 m) paralleling the crop rows and the prevailing wind direction. Irrigation treatments were started on 30 June 1980 and 24 June 1981. Water applied in subsequent irrigations was monitored with two sets of catchcans installed across the field perpendicular to the line source. Pairs of cans were placed 1.7 m on either side of the line source and then at every 2.2 m to the extent of the sprinklers patterns, which gave seven cans on either side of the pipeline in both years. Can heights were maintained slightly above the canopy and water in the cans was measured immediately following irrigations. Evaporation was prevented by placing kerosene in the cans. The first irrigation after planting was about the time of canopy closure (30 June 1980 and 24 June 1981). Subsequently, fields were irrigated at weekly intervals during early morning hours to minimize wind interference. Each irrigation was planned to deliver an amount of water equivalent to the previous week's standard U.S. Weather Bureau water pan evaporation (E_p) to the second sampling site from the line source. To prevent water runoff, only 0.95 E_p was applied (K_c=0.95; K_c= crop factor used to estimate water use) (9). Irrigation was terminated on 26 Aug. 1980 and 13 Aug. 1981. During the treatment periods only 0.02 and 0.43 cm rainfall were recorded in 1980 and 1981, respectively.

Sunflower and safflower cultivars were seeded in rows parallel to the line source pipeline and extending outward from the pipeline to beyond the range of the sprinkler heads (45 m). Blocks were separated one direction by the centerline and in the other by two 1.5 m alleys running normal to the pipeline leaving six blocks of equal size. Each block was subdivided into seven sampling areas at increasing distance from the line source and centered on the catchcan spacings. Cultivar blocks were seeded as main plots in a split plot arrangement within species; species were seeded separately in 1981 because of plant height differences. There were three blocks each of 894 and Saturn sunflower in 1980, eight blocks of 894 sunflower, and four blocks of S-208 safflower in 1981.

From before seeding until harvest, soil water distribution was measured with a neutron meter at weekly intervals. Readings were taken at a depth of 23 cm and at every 15 cm thereafter to bedrock or to 150 cm (2,3). Probe access holes were located in the same rows as the catchcans. Soil water depletion was taken as the difference between the initial and the final water content measurements. Water applied was taken as the sum of rainfall (trace) and irrigation water. Because of frequent irrigation in the amount of only 0.95 E_p and water retention capacity of silt loam soil, water runoff was negligible. Total water used by sunflower was computed as the sum of rainfall, irrigation water, and soil water depletion from planting to harvest. Water applied and water used were then plotted, and the amount of water applied or water used at any particular distance from the line source was computed by interpolating from the two nearest catchcan and neutron probe measurements.

Due to heavy bird infestations, sunflower heads were bagged with plastic window screening following anthesis each year. Twenty representative heads were bagged in the center two rows of each sampling site in 1980 and 40 heads per site in 1981. These heads were hand harvested, threshed, and area yields calculated based on harvest stand counts. Safflower yields were based on 8 m by 1.1 m (4 row) combined strips. Seeds were dried at 40 °C before cleaning and weighing for yield and test weight determination. Subsamples were hand cleaned, redried at 54 °C, and analyzed for oil concentration using NMR (Nuclear Magnetic Resonance) spectrometry.

Representative values for water applied were tabulated as averages of readings from two locations of the same side of the line source. Data were computed and regression analyses were used to test the effect of irrigation on yield, test weight, and oil concentration for all sites. Head diameter was measured in 1981 sunflower and safflower plots. Plant height was measured only in safflower plots. Water use efficiency was also computed to compare the rate of seed yield increase per unit of water applied.

RESULTS

Water Applied and Water Used

The amounts of water applied from seeding to maturity are given in Table 1. Maxima of 34.5 and 45.8 cm of water were applied in 1980 and 1981, respectively. Differences in water application between the two years reflect differences in evaporative demand (Table 2). The amount of water applied to safflower in 1981 was very similar to that applied to sunflower in the same year.

In 1980, sunflower used 53.1 cm of water including 18.6 cm of soil water at the highest irrigation rate (sampling site 7, Table 1). Soil water use increased as the

Table 1. Water applied† and water used† at various deficit irrigation sampling sites using the line source sprinkler system for sunflower and safflower, 1980 and 1981, Prosser, WA.

Sampling site‡	Sunflower 1980 Water Applied	Sunflower 1980 Water Used	Sunflower 1981 Water Applied	Sunflower 1981 Water Used	Safflower 1981 Water applied
	cm				
1	0.1	27.8	0.4	30.1	0.4
2	1.0	28.3	4.1	33.7	4.2
3	4.7	32.0	12.1	40.7	12.4
4	11.6	37.4	19.0	47.7	19.1
5	18.9	42.8	24.9	53.0	24.6
6	26.9	46.4	34.7	60.7	34.6
7	34.5	53.1	44.8	69.4	44.9

† The amount of water applied and water used was the average of four sites (two in each side of the line source) equidistant from the line source. The water used for safflower was not measured. These values were not used to compute the yield and other responses of crops to water stress. Rainfall was recorded at 0.05 and 0.43 cm in 1980 and 1981, respectively.

‡ Sampling sites were located 1.7 m either side of the line source and every 2.2 m to the limit of the sprinkler pattern.

Table 2. Monthly evaporation measurements from a class A pan from seeding to maturity, of sunflower and safflower, 1980 and 1981, Prosser, WA.

Year	April	May	June	July	Aug.	Sept.	Total
	cm						
1980	--	11.9‡	18.1	23.5	19.2	--	72.7
1981	0.5†	18.2	21.8	25.4	22.1	2.3¶	90.3

† 30 April. ‡ 10 through 31 May. ¶ 1 through 4 September.

[3] Mention of product or cultivar names is for the benefit of the reader and does not imply endorsement by Washington State Univ.

amount of irrigation decreased until the plants were extracting about an additional 9 cm of soil water in the driest plots (sampling sites 1 to 3). In 1981, sunflower used a maximum of 69.4 cm of water including 24.6 cm of soil water (sampling site 7). Soil water use again increased with decreasing irrigation until plants were extracting 4 to 5 cm additional soil water (sampling sites 1 to 4). Sunflower extracted similar maxima of 27.7 and 29.7 cm of soil water from the measured 150-cm soil profile in 1980 and 1981, respectively.

Sunflower

Sunflower plants were observed to be shortest at the edges of the field where irrigation water was minimal and tallest near the line source. Stressed plants also produced flower buds and reached maturity earlier. Head size increased with the increase in irrigation water up to about 25 cm of water applied (Fig. 1). It then leveled off as the amount of water applied increased up to 45.8. These findings agreed with Yegappan and Paton (19).

Seed yield of both sunflower cultivars increased with applied water in 1980, particularly at the low irrigation

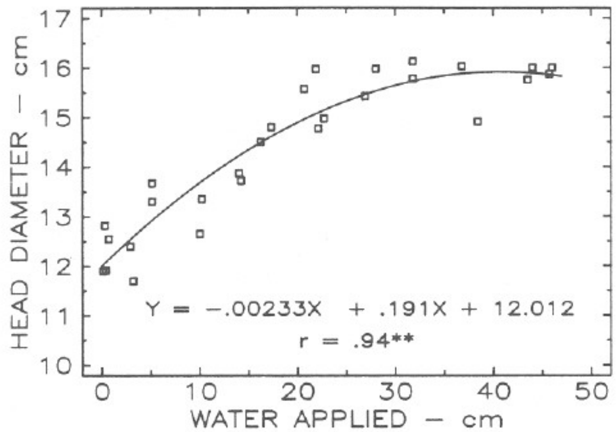

Fig. 1. Relationship of head size of 894 sunflower to various amounts of water applied, 1981 (significant at P=0.01; SE = 0.26; n = 4).**

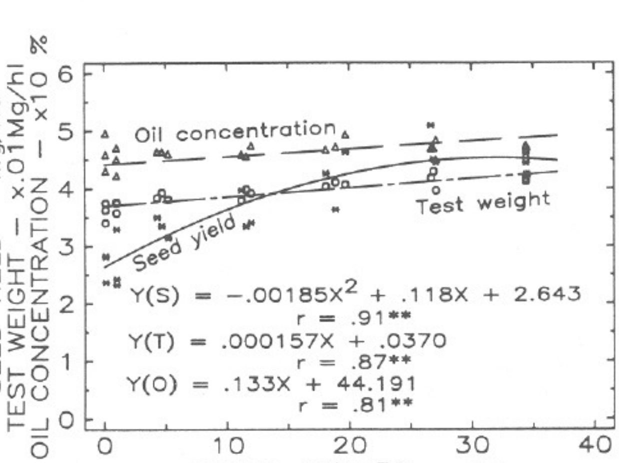

Fig. 2. Relationship of seed yield, test weight, and oil concentration of Saturn sunflower to various amounts of water applied, 1980 (significant at P = 0.01; SE = 0.20, 0.019 and 0.73 for seed yield, test weight and oil concentration, respectively; n = 3).**

rate of 5 to 10 cm water when compared with no irrigation (Fig. 2 and 3). The rate of increase in seed yield vs. water applied was higher for Saturn, but both cultivars produced maximum yield with about 20 cm of applied water and 43 cm of total water use. Yields decreased slightly with > 25 cm of irrigation (e.g., cv. 894) (Fig. 2 and 3).

In 1981, seed yield of 894 again increased with irrigation, but the maximum seed yield of 3.5 Mg ha^{-1} was obtained with about 27.5 cm of water applied or 55 cm of total water use (Fig. 4). The 27.5-cm figure was 7.5 cm higher than in 1980 and roughly equal to half of the 17.5 cm greater evaporation in 1981 than in 1980 (Table 2). Sunflower generally yielded less in 1981 than in 1980, indicating that factors other than irrigation water had influenced the seed yield.

In both years, seed yield per cm water applied was highest for cv. Saturn at the lowest irrigation rate (5 cm of water applied). In 1980, this rate of return on water applied decreased sharply when the amount of water applied was doubled and then gradually decreased as the irrigation water increased. Sunflower cv. 894 was less responsive to water applied. Its water use efficiency was about 0.584 Mg cm^{-1}; however, the rate of return in water applied also decreased as for cv. Saturn (Fig. 7). In 1981 water use efficiency of sunflower was lower than in 1980. This may be explained by the higher soil moisture when the treatments were started (Table 1).

Test weight is defined to be the dry weight per unit volume of grain (Mg hl^{-1}). It was consistent among cultivars and years. In 1980, test weight of Saturn and 894 increased with water applied. It was linearly correlated with the amount of water applied (Fig. 2 and 3). In 1981 test weight of 894 was significantly increased and curvilinearly correlated with irrigation up to 45 cm water applied (Fig. 4). Lower test weight associated with low irrigation water was also reported by Yegappan and Paton (19).

Both sunflower cultivars in this experiment produced high seed oil concentration (Fig. 2,3, and 4). Oil concentration of Saturn seed increased from 44 to 48% as irrigation water increased from 0 to 34.5 cm (Fig.

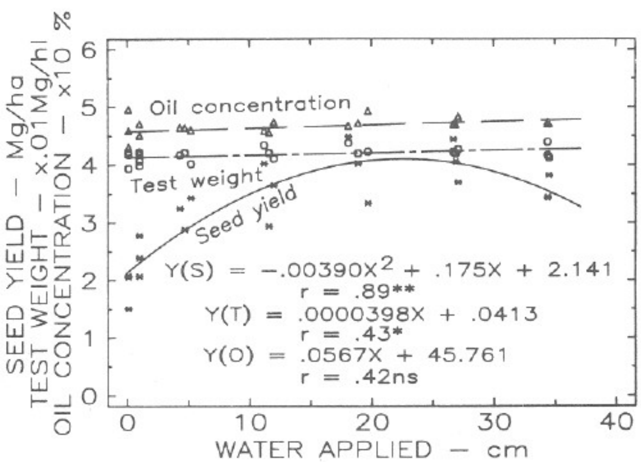

Fig. 3. Relationship of seed yield, test weight, and oil concentration of 894 sunflower to various amounts of water applied, 1980 (, * significant at P=0.01 and 0.05, respectively; ns = not significant; SE = 0.23, 0.019 and 0.90 for seed yield, test weight and oil concentration, respectively; n = 3).**

2). Oil concentration of 894 did not respond significantly to irrigation in the 1980 experiment (Fig. 3), but in 1981 it increased significantly with increasing water over the entire irrigation range (Fig. 4). Talha and Osman (17) and Alessi et al. (2) also concluded that sunflower oil concentration was reduced by moisture stress.

Safflower

Safflower plants responded to irrigation in much the same way as sunflower. Water deficit produced the same visual stress symptoms—e.g., reduced plant size, change in leaf color, and shortened leaf life—on safflower as it did on sunflower. Similar effects have been reported with other grain crops (5,7,10,13).

Leaves of stressed safflower plants turned yellow early in the growing season, while leaves of plants receiving full irrigation were green and normal. Plant height increased with increasing irrigation up to 30 cm of water applied and then decreased (Fig. 5). Similar effects of water stress on plant height have also been found on winter wheat (*Triticum aestivum* L.) (7,10) and on spring wheat (5,7). In this experiment, stress also reduced the head size of safflower, and stressed plants bloomed and matured earlier than nonstressed plants. Plant height and head diameter of safflower were linearly correlated with the amount of irrigation water.

In 1981 seed yield of S-208 increased with water applied up to 40 cm (Fig. 6). The greatest response was obtained over the 0 to 25 cm range; seed yield increased only slightly with irrigation above 25 cm. Regression alalysis showed that safflower seed yield was curvilinearly correlated with water applied (r = 0.95, significant at P = 0.01). As for sunflower, environmental factors other than irrigation and soil water apparently contributed to the high seed yield of cv. S-208 in 1981. Seed yield per unit water applied decreased sharply between 5 and 10 cm irrigation. This rate of return on water applied then gradually decreased with increasing irrigation (Fig. 7).

In this experiment, irrigation level had no effect on oil concentration or test weight of safflower cultivar S-208 (Fig. 6). This agrees with the results of Abel (1),

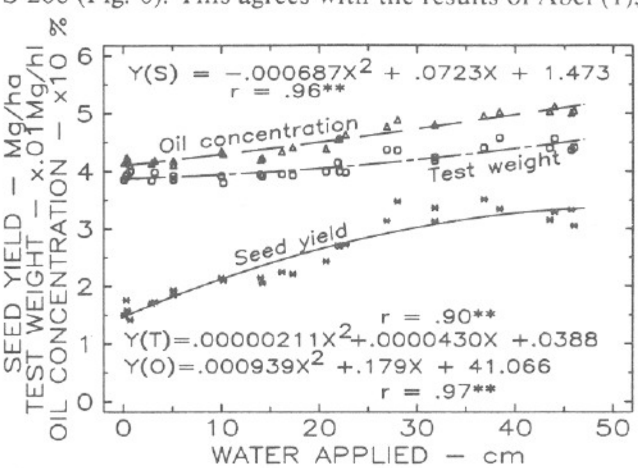

Fig. 4. Relationship of seed yield, test weight, and oil concentration of 894 sunflower to various amounts of water applied, 1981 (significant at P=0.01; SE = 0.10, 0.017 and 0.45 for seed yield, test weight and oil concentration, respectively; n = 4).**

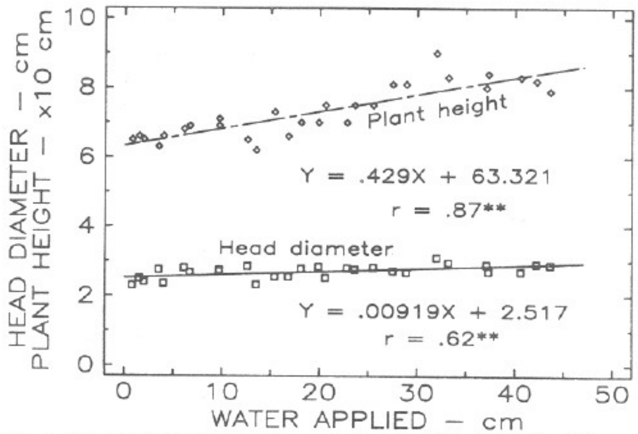

Fig. 5. Relationship of head size and plant height of S-208 safflower to various amounts of water applied, 1981 (significant at P=0.01; SE =0.08 and 1.94 for head size and plant height, respectively; n = 4).**

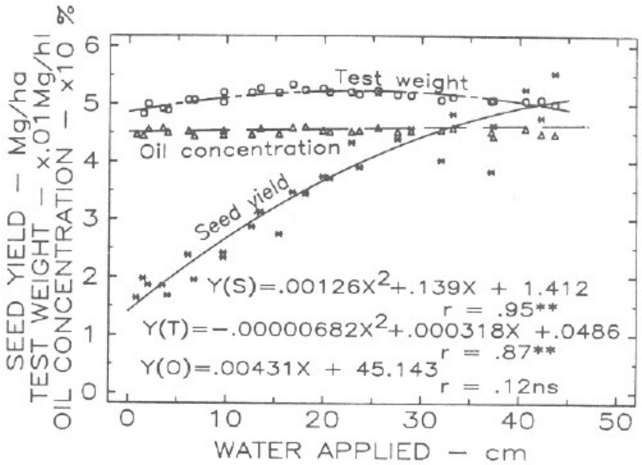

Fig. 6. Relationship of seed yield, test weight, and oil concentration of S-208 safflower to various amounts of water applied, 1981 (significant at P=0.01; ns = not significant; SE = 0.25, 0.0011, and 0.25 for seed yield, test weight and soil concentration, respectively; n = 4).**

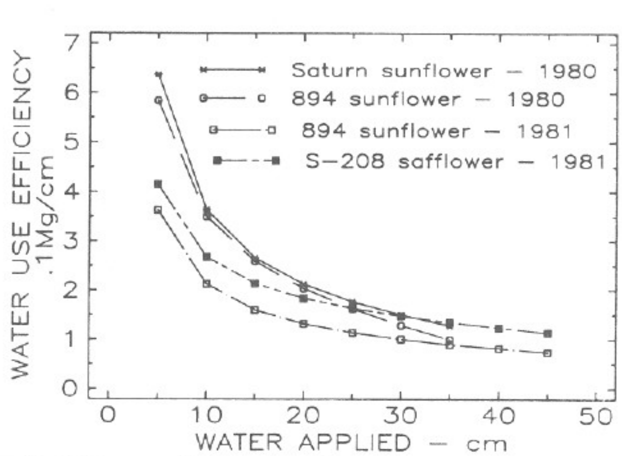

Fig. 7. Water use efficiency of sunflower and safflower grown on loam soil at various amounts of water applied, 1980 and 1981 [values were seed yields produced per centimeter of water applied; SE = 0.046, 0.037, 0.028, and 0.027 for Saturn sunflower, 894 sunflower (1980), 894 sunflower and S-208 safflower (1981), respectively; n = 2].

who concluded that oil percentage of safflower seed was not improved by various irrigation regimes in Arizona; however, test weight of safflower was curvilinearly correlated with amount of applied water (r = 0.87) and the maximum test weight was reached at 20 cm irrigation (Fig. 6).

DISCUSSION

In all years, irrigation level had a positive effect on sunflower and safflower seed yield but a variable effect on oil concentration. In 1980, 894 sunflower produced a higher seed yield than in 1981, but maximum oil concentration was slightly less. In 1980 oil yields (seed yield × oil concentration) of 894 sunflower ranged from 0.98 to 1.92 Mg ha^{-1} for 2.5 to 25 cm irrigation water, while Saturn sunflower produced 1.17 to 2.23 Mg ha^{-1} for the same range of water applied. In 1981 seed yield of 894 sunflower was low and its oil yields ranged from 0.65 to 1.67 Mg ha^{-1} for 2.5 to 40 cm of water applied. In comparison to sunflower, S-208 safflower yielded 0.70 to 2.30 Mg of oil ha^{-1} for the same amount of water applied.

The water used by safflower and sunflower in this experiment was higher than that reported by Alessi et al. (2,3). In a mid-May planting at Mandan, ND, an annual average of 30 cm of water or less were used over a 3-yr period. Seed yields were very low at Mandan in comparison to the data reported in this study. Unger (17) reported that maximum water use by his sunflower was 58 cm with a seed yield of only 2.49 Mg ha^{-1}. Seed yield and oil concentration of sunflower and safflower in this study were higher than those reported by any authors in the main producing areas of these crops.

Irrigation treatments terminated at physiological maturity of the crop rather than harvest maturity, which occurs at a latter date. Physiological maturity represents the end-point of the influence of soil water on the weight of seed. An estimated date for physiological maturity is required for optimum timing of the final irrigation to supply the crop needs at this stage and to avoid excessive irrigation.

Other considerations involved in the decision to terminate irrigation include the development of the estimation of the quantity of irrigation, root system and leaf canopy of the crop, and estimation of the quantity of irrigation (K_c) (9). These factors may explain the differences between years and among cultivars of both crops at this location and other locations worldwide.

Water use efficiency was computed based on seed yield per unit of water applied. Calculations showed that the more water was applied to the crop the lower the rate of return on applied water became. This efficiency decreased sharply, as the amount of water applied increased from 5 to 10 and to 15 cm, and then it gradually decreased as the amount of water applied increased. Saturn sunflower was more tolerant to drought than sunflower cv. 894. With the same amount of water applied, safflower responded to water more than sunflower.

In this study on both sunflower and safflower grown on loam soil, data showed that irrigation beyond 30 cm did not increase seed yield and oil concentration significantly.

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