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# IRRIGATION EFFECT ON SUNFLOWER GROWTH, DEVELOPMENT, AND WATER USE

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## ABSTRACT

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Sunflower (*Helianthus annuus* L.) production in the U.S.A. has greatly increased in recent years. Some are irrigated in the southern Great Plains, but because of declining water supplies, limited irrigation is often used. To better manage available water for sunflower production, a knowledge of sunflower response to applied water is needed. The objective of this study was to determine the effect of irrigations at readily identifiable growth stages on sunflower growth, development, dry matter (DM) accumulation, total water use, and water use-plant development relationships. Sunflower irrigated at budding were 19 cm taller than those irrigated only at flowering or late flowering. Irrigation at budding also favored leaf and stem DM production. Irrigation at flowering or late flowering was important for head and especially seed development, which resulted in seed being a larger part of total DM at the final sampling. Highest seed and total DM yields were obtained with the full irrigation treatment, but they were not always significantly higher than those resulting from fewer well-timed irrigations, namely those at flowering or late flowering. Irrigation treatments affected the rate of oil accumulation in seed, and had a relatively small but significant effect on final oil percent. Linoleic and oleic acid concentrations of oil were little affected by irrigation treatments.

## INTRODUCTION

Sunflower (*Helianthus annuus* L.) production in the U.S.A. has greatly increased since the introduction of hybrids in the early 1970's. Most sun-

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flower is grown without irrigation, but some are irrigated in subhumid and semiarid regions where precipitation is limited, as in the southern Great Plains. Seed yields are often doubled with adequate irrigation and plant nutrients (Robinson, 1971). With limited irrigation which does not fully replace soil water lost by evapotranspiration, yields are generally lower than with full irrigation, but water use efficiency (WUE) can be higher with limited irrigation (Gimenez Ortiz et al., 1975; Unger, 1978). The available information shows that seed yield response to water is usually greatest when sunflower is irrigated at late bud or flowering stages (Robinson, 1973; Unger, 1978; Stegman and Lemert, 1980). High seed yield of a crop is usually the goal, and favorable plant development is considered essential for achieving high yields. Through a better understanding of sunflower growth and development as affected by water availability at different growth stages, improved management practices can be developed to obtain greater responses when sunflower is not fully irrigated. The objective of this study was to determine the effect of irrigations at readily identifiable growth stages on sunflower growth, development, dry matter accumulation, total water use with time, and water use-plant growth relationships.

## METHODS AND MATERIALS

The study was conducted in 1978, 1979, and 1980 on Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll) at Bushland, which is in northern Texas (U.S.A.) at 35° 11′ N Lat. and 102° 5′ W Long. at an elevation of 1 180 m above mean sea level. Precipitation averages 470 mm annually, with about one-half received from May to August, the major growing season for sunflower in northern Texas.

Sunflower was rotated with fallow in a 2-year rotation. During fallow, the plot area was uniformly disked or sweep plowed to control weeds. Before planting sunflower, beds and furrows were formed with a disk bedder, and trifluralin ($\alpha,\alpha,\alpha$-trifluoro-2,6-dinitro-*N*,*N*-dipropyl-*p*-toluidine) was applied at a 1.1-kg/ha ai (active ingredient) rate and incorporated with a rolling cultivator. In 1979, a rolling cultivator was also used for additional weed control during the growing season. No fertilizer was applied because analyses revealed that the soil to a 1.2-m depth contained at least 112 kg/ha of N as nitrates. Crops on Pullman clay loam at Bushland have not responded to added P or K (Mathers et al., 1975).

The plot area was uniformly irrigated before planting sunflower to ensure uniform germination and seedling emergence. This irrigation of about 75 mm each year was designated the emergence (E) irrigation. The treatments, based on time of irrigation in relation to sunflower growth stage, were:
E, emergence only;
E+B, emergence and budding;
E+F, emergence and flowering;
E+LF, emergence and late flowering;

E+B+F, emergence, budding, and flowering;
E+B+LF, emergence, budding, and late flowering;
E+F+LF, emergence, flowering, and late flowering;
E+A, emergence and adequate irrigation; and
E+FI, emergence and full irrigation.

Budding (B) irrigations were applied when buds were 2 to 3 cm in diameter. Flowering (F) irrigations were applied when about 5% of the plants had ray flowers showing; the late flowering (LF) irrigations were applied 14 days after the F irrigation. Sunflower for the E+A treatment was irrigated when afternoon wilt was observed. Beginning at about 30 days after emergence, sunflower for the E+FI treatment was irrigated at about 10-day intervals, unless more than about 20 mm of rain occurred. When such rains occurred, irrigations were delayed with the delay time depending on the amount of rainfall. The goal for the E+FI treatment was to avoid plant wilting.

Treatments were replicated three times in 1978 and four times in 1979 and 1980. The experiment had a randomized block, split plot design. Plots were 70 m long and 6 m (six 1-m bed-furrows) wide, and were on furrow-irrigated land that had a uniform slope of about 0.3%. At each irrigation, the five center furrows of each plot were irrigated through gated pipe until the lower end of the field was fully wetted across the surface. Water application amounts were determined, and tailwater runoff was measured from four furrows for two replications of each treatment by use of H-flumes and water stage recorders. Rainfall was measured near the plot area.

On 10 May 1978, 9 May 1979, and 14 May 1980, 'Hybrid 894' sunflower was planted with unit planters in single rows per bed at a rate to obtain about 64 000 plants per ha. Because of extra seed drop, some thinning was needed to obtain a plant spacing of about 0.15 m in the row.

After planting, access tubes for measuring soil water content by the neutron attenuation method were installed to the 2.7-m depth. Water contents were measured at the midpoint of 0.3-m depth increments at planting, near the start of the different growth stages, and at harvest.

In 1979 and 1980, carbofuran (2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate) was applied to the sunflower during the bud stage at a 1.1-kg/ha ai rate to control stem weevils (*Cylindrocopturus adspersus* LeConte). In 1978 and 1979, methyl parathion [*O*,*O*-dimethyl *O*-(*p*-nitrophenyl) phosphorothioate] was applied twice during the flowering stage at a 0.6 kg/ha ai rate to control sunflower moths (*Homoeosoma electellum* Hulst.). Moths caused no problems in 1980.

Plant heights were measured periodically during the growing season. Beginning at 35, 30, and 27 days after planting in 1978, 1979, and 1980, respectively, plants were cut at ground level from 1-m sections of the center two rows per plot at weekly intervals. The plants were counted and total fresh weight was determined for all plants. Then a subsample of two representative plants was partitioned into leaves, stems, and, at later samplings, buds or heads. The green leaves were counted. The materials were dried in a forced-air oven at 50° C. Total dry matter yields were calculated from total sample weights and subsample fresh and dry weights. Yields of individual plant parts were calculated from subsample dry weights of the different parts. When seed had sufficiently developed, it was removed from the head for determining the number of seeds per head, seed dry matter, seed oil percent, and linoleic and oleic oil concentration of the oil. Oil percent was determined by the nuclear magnetic resonance (NMR) method (Granlund and Zimmerman, 1975) and oleic and linoleic concentrations of the oil were estimated by the refractive index method (Goss, 1978).

Data were analyzed by analysis of variance, and relationships between plant development factors and water use were established by multiple linear regression using the step-down procedure (Ezekiel and Fox, 1959; Steel and Torrie, 1980). Differences among means were established through use of the Duncan multiple range test or the Protected LSD (least significant difference) test (Steel and Torrie, 1980).

## RESULTS AND DISCUSSION

### *Rainfall, irrigation, and soil water depletion*

Growing season rainfall was near the long-term average (235 mm for May through August) for Bushland in 1979, but only 76 and 59% of average, respectively, in 1978 and 1980 (Table I). In all years, however, rainfall was near or above average in late May and early June, and it continued near average until the end of June in 1978.

Some runoff occurred from all plots as a result of the May and June rains in 1978 and 1979. In 1978, however, no rain fell near the end of Period 1 (planting to budding) and sunflower on the E+A and E+FI treatment plots was irrigated once during this period. No irrigations were needed during Period 1 in 1979. Little rain fell during the latter half of Period 1 in 1980; therefore, sunflower on E+A and E+FI treatment plots was irrigated once and twice, respectively, during Period 1 in 1980.

Because of favorable rainfall in 1979, sunflower on E+A and E+FI treatment plots were irrigated only two and four times, respectively, as compared with four and five times, respectively, in 1978. In 1980, sunflower on E+A and E+FI plots received five and six irrigations, respectively. Total water use by sunflower with the E+A and E+FI treatments, however, was similar in 1980 because the extra irrigation with the E+FI treatment caused more runoff and less depletion of soil water. In all cases, soil water depletion generally decreased with increases in growing season irrigation.

### *Plant height*

Irrigation timing resulted in significant differences in plant height during

TABLE I

Growth period and seasonal water use by sunflower irrigated at different growth stages, Bushland, TX, 1978–80

| Year and growth period[a] | Length of growth period (days) | Total rain (mm) | Water use[b] (mm) Irrigation treatment[c] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | E | E+B | E+F | E+LF | E+B+F | E+B+LF | E+F+LF | E+A | E+FI |
| 1978 | | | | | | | | | | | |
| 1 | 46 | 130 | 81 | 84 | 91 | 74 | 85 | 86 | 79 | 80[e] | 115[e] |
| 2 | 15 | 19 | 138 | 176[e] | 41 | 106 | 113[e] | 195[e] | 41 | 140[e] | 97[e] |
| 3 | 14 | 3 | 35 | 55 | 198[e] | 33 | 231[e] | 34 | 176[e] | 158[e] | 226[f] |
| 4 | 30 | 26 | 54 | 38 | 58 | 208[e] | 76 | 126[e] | 148[e] | 191[e] | 141[e] |
| GS[d] total | | 178 | 308 | 353 | 388 | 421 | 505 | 441 | 444 | 569 | 579 |
| 1979 | | | | | | | | | | | |
| 1 | 51 | 138 | 25 | 16 | 35 | 55 | 32 | 35 | 19 | 29 | 24 |
| 2 | 19 | 19 | 82 | 160[e] | 87 | 93 | 146[e] | 145[e] | 91 | 156[e] | 166[e] |
| 3 | 14 | 60 | 84 | 79 | 113[e] | 68 | 96[e] | 87 | 109[e] | 100[e] | 97[f] |
| 4 | 21 | 26 | 55 | 64 | 70 | 93[e] | 128 | 112[e] | 149[e] | 113 | 229[e] |
| GS total | | 243 | 246 | 319 | 305 | 309 | 402 | 379 | 368 | 398 | 516 |
| 1980 | | | | | | | | | | | |
| 1 | 49 | 106 | 125 | 131 | 125 | 129 | 124 | 141 | 124 | 191[e] | 244[f] |
| 2 | 14 | 0 | 119 | 171[e] | 121 | 118 | 163[e] | 174[e] | 122 | 193[e] | 106[e] |
| 3 | 11 | 0 | 50 | 55 | 115[e] | 51 | 140[e] | 51 | 116[e] | 134[f] | 79[e] |
| 4 | 30 | 33 | 6 | 6 | 23 | 106[e] | 80 | 113[e] | 73[e] | 143[e] | 226[f] |
| GS total | | 139 | 300 | 363 | 382 | 404 | 507 | 479 | 435 | 661 | 655 |
| GS average (1978–80) | | 173 | 285 f[g] | 345 ef | 358 de | 378 cde | 471 b | 433 bc | 416 bcd | 543 a | 583 a |

[a] Growth periods were: 1, plant to bud; 2, bud to flower; 3, flower to late flower; 4, late flower to maturity.

[b] Water use based on rainfall infiltration, irrigation water infiltration, and soil water content change.

[c] The irrigations represented by the letters were: E, emergence; B, budding, F, flowering; LF, late flowering; A, adequate and FI, full irrigation.

[d] GS, growing season.

[e] One irrigation during the period.

[f] Two irrigations during the period.

[g] Means followed by the same letter or letters are not significantly different at the 5% level (Duncan Multiple Range Test).

TABLE II

Plant heights of sunflower irrigated at different growth stages, Bushland, TX, 1978–80

| Year and date | Height (cm) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Irrigation treatment[a] | | | | | | | | | Average | |
| | E | E+B | E+F | E+LF | E+B+F | D+B+LF | E+F+LF | E+A | E+FI | Sampling date | Year |
| 1978 | | | | | | | | | | | |
| 14 June | 29 | 31 | 31 | 33 | 31 | 30 | 28 | 29 | 30 | 30 e[b] | |
| 23 June | 61 | 64 | 62 | 67 | 64 | 62 | 62 | 65 | 66 | 64 d | |
| 28 June | 88 | 97 | 89 | 92 | 93 | 101 | 87 | 100 | 99 | 94 c | |
| 5 July | 112 | 121 | 113 | 115 | 123 | 131 | 115 | 123 | 139 | 121 b | |
| 19 July | 117 | 134 | 125 | 122 | 140 | 146 | 127 | 146 | 150 | 134 a | |
| Average | 81 d[b] | 89 bc | 84 d | 86 cd | 90 bc | 94 ab | 84 d | 93 ab | 97 a | | 89 a[b] |
| | [Protected LSD (0.05) for treatment by sampling date = 5.2] | | | | | | | | | | |
| 1979 | | | | | | | | | | | |
| 8 June | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 d | |
| 27 June | 49 | 50 | 50 | 50 | 49 | 48 | 46 | 52 | 53 | 50 c | |
| 12 July | 110 | 131 | 115 | 110 | 133 | 130 | 110 | 131 | 132 | 122 b | |
| 9 Aug. | 129 | 149 | 127 | 129 | 150 | 148 | 125 | 148 | 149 | 139 a | |
| Average | 74 b | 85 a | 75 b | 75 b | 85 a | 84 a | 73 b | 84 a | 86 a | | 80 a |
| | [Protected LSD (0.05) for treatment by sampling date = 7.0] | | | | | | | | | | |
| 1980 | | | | | | | | | | | |
| 10 June | 8 | 9 | 9 | 9 | 7 | 8 | 9 | 8 | 8 | 8 d | |
| 25 June | 40 | 45 | 39 | 41 | 38 | 39 | 41 | 46 | 40 | 41 c | |
| 9 July | 84 | 100 | 87 | 87 | 91 | 98 | 85 | 104 | 105 | 93 b | |
| 31 July | 100 | 107 | 102 | 101 | 115 | 117 | 104 | 124 | 134 | 111 a | |
| Average | 58 b | 65 ab | 59 b | 60 b | 63 ab | 66 ab | 60 b | 71 a | 72 a | | 64 b |
| | [Protected LSD (0.05) for treatment by sampling date = 6.9] | | | | | | | | | | |
| Average final height 1978–80 | 115 db | 130 c | 118 d | 117 d | 135 bc | 137 b | 119 d | 139 ab | 144 a | | |

[a]The irrigations represented by the letters were: E, emergence, B, budding, F, flowering, LF, late flowering, A, adequate and FI, full irrigation.

[b]Means for treatments (annual and average final), sampling dates within years, or average for years followed by the same letter or letters are not significantly different at the 5% level (Duncan Multiple Range Test).

the growing season, which were detected after the budding irrigation, and in average final plant heights, which were measured after the sunflower had fully flowered (Table II). Budding irrigations were applied on 26 June, 3 July, and 3 July in 1978, 1979, and 1980, respectively. Irrigation near or at the budding stage (Treatments E+B, E+B+F, E+B+LF, E+A, and E+FI) resulted in 19-cm taller plants than irrigations at later stages (Treatments E+F, E+LF, and E+F+LF). Final heights resulting from the E, E+F, E+LF, and E+F+LF treatments were not significantly different, but seed yields with E+F, E+LF, and E+F+LF treatments were significantly greater than with the E treatment (Unger, 1982). Because early-season water stress resulted in short plants, but did not reduce seed yields, irrigation timing greatly influenced water use efficiency (Unger, 1982). Controlling plant heights by withholding irrigation until flowering may also reduce the potential for plant lodging and associated harvesting problems and seed losses.

*Leaves per plant*

The number of green leaves per plant (leaves that were at least partially green) was maximum at 45 to 55 days after planting each year (data not shown). Although the analysis of variance indicated significant differences due to irrigation treatments, there were no consistent trends. Water stress affects the number of leaves per plant when it occurs before 20 days after planting (Marc and Palmer, 1976). In this study, irrigation treatments were imposed after 20 days; therefore, no major differences in leaf numbers were expected, except for leaf abscission with continued water stress or plant maturation. Although the trends for number of leaves were similar, the photosynthetic activity may have been different because all partially green leaves were counted. However, observations revealed that leaves of the more fully irrigated sunflower had a higher percentage of green tissue than those receiving less water. Also, leaves of the more fully irrigated sunflower were larger.

Although the leaf number trends were similar for the irrigation treatments, the trends differed among years. In 1980, the number of leaves increased more rapidly initially and, in general, decreased more rapidly later in the season. The earlier plant development and leaf drying in 1980 were attributed to above average temperatures during June, July, and August (Laboratory climatic data, 1980). With some treatments, limited rainfall also contributed to early leaf drying.

*Dry matter accumulation*

Average dry matter (DM) accumulation in leaves, stems, buds or heads, and seed is illustrated in Fig. 1. Leaves were separated from stems at the early sampling dates with heads (buds) becoming separable by 55 days and seed by 75 days after planting.

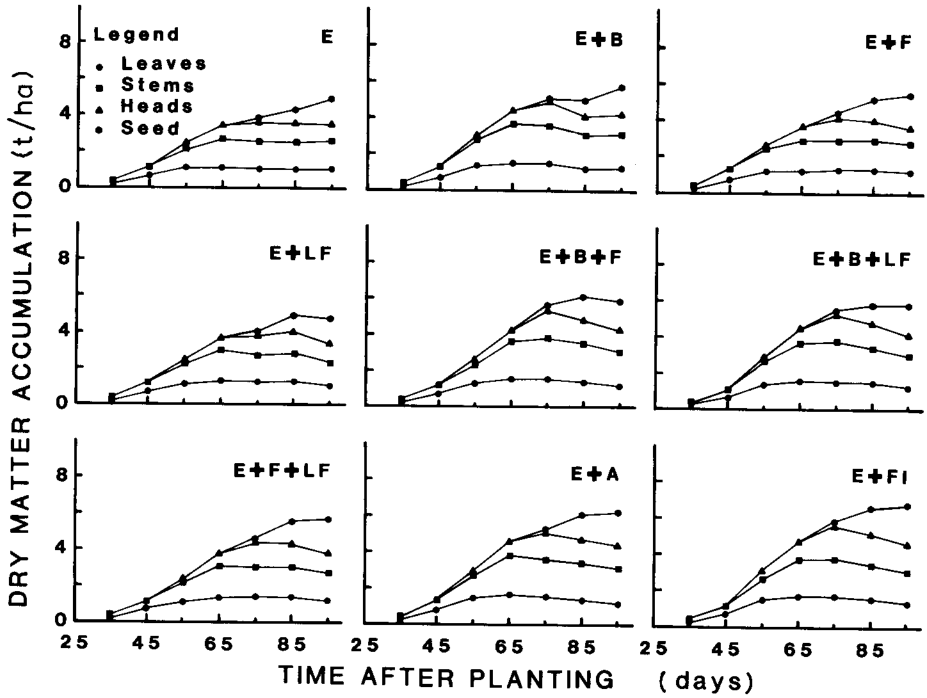


Fig. 1. Effect of time and frequency of irrigation on sunflower leaf, stem, head, and seed dry matter accumulation, Bushland, TX.

Irrigation treatments significantly affected DM accumulation in leaves, stems, buds, or heads, and seed, and by the entire plant. The irrigation by time interaction also significantly affected DM, except for seed DM in 1978 and 1979 and head DM in 1980.

Leaf DM accumulation was maximum at about 65 days after planting (Fig. 1), which was 10 to 20 days after the maximum for green leaves per plant and indicates continued leaf growth during this interval. Leaf DM values later declined somewhat in most cases because of leaf senescence and loss, and possibly because of translocation of photosynthate and nitrogenous compounds to seed.

Sunflower irrigated before or at budding accumulated significantly more DM in leaves than those not irrigated or those initially irrigated at later growth stages. Average maximum leaf DM yields ranged from 1.12 to 1.68 t/ha for the E and E+FI treatments, respectively. At the final sampling, leaf DM values ranged from 1.07 t/ha for the E and E+LF treatments to 1.28 t/ha for the E+FI treatment. Leaves contain a major part of plant TDM during the growing season, but many leaves are lost before harvest (later than sampling for this study); therefore, leaf loss would substantially decrease the phytomass harvestable for purposes other than for seed.

Maximum stem DM weight, which occurred at or slightly after maximum leaf DM, occurred at about the same time for all treatments and remained near or at the maximum for the remainder of the season. Stems, which represent the major harvestable phytomass other than seed, accounted for 27 (E+LF) to 34% (E+B) of plant TDM at the last sampling. Average stem DM yields at the final sampling ranged from 1.30 to 2.23 t/ha for the E+LF and E+FI treatments, respectively.

Head DM accumulation usually reached a maximum at the last sampling date before seed became separable from the heads. At that sampling, heads contained florets and rudimentary seed that added to the head weight, but which were lost or removed with the seed at later samplings. At the final sampling, head DM yields ranged from 0.71 to 1.21 t/ha for the E and E+A treatments, respectively. Head DM at that sampling ranged from 14 to 21% of plant TDM for the E and E+LF treatments, respectively.

Seed DM increased for successive samplings. At the last sampling, seed DM ranged from 1.42 to 2.67 t/ha for the E+B and E+FI treatments, respectively, and represented 27 and 40% of plant TDM. Seed DM as a percent of TDM for all treatments averaged 25 in 1978, 39 in 1979, and 37 in 1980. Higher average values in 1979 than in 1978 resulted from more and better distribution of rainfall in 1979 (Table I). Higher values in 1980 than in 1978 were also related to rainfall distribution. In 1978, early season rainfall favored early season plant development, and limited rainfall at later stages resulted in poor seed filling. Hence, the low seed DM values as a percent of plant TDM. In 1980, negligible rainfall after mid-June resulted in both limited plant growth and seed filling, which in turn resulted in more favorable seed DM percentages.

Plant TDM, the composite of the various plant parts, is illustrated by the upper curves in Fig. 1. Average TDM yields ranged from 4.75 t/ha for the E+LF treatment to 6.75 t/ha for the E+FI treatment, a range of 2.00 t/ha. Compared with the E treatment, TDM yields increased an average of 0.37 t/ha with one growing season irrigation (E+B, E+F, and E+LF treatments) and 0.83 with two growing season irrigations (E+B+F, E+B+LF, and E+F+LF treatments). For the E+A and E+FI treatments, the increase averaged 1.55 t/ha.

Based on average values for all treatments, sunflower TDM at the last determination was comprised of about 21% leaves, 31% stems, 17% heads, and 31% seed. Average values for years usually differed more from the above than average values for individual treatments.

*Seed development*

The E and E+B treatments resulted in significantly fewer seeds/head than the remaining treatments, and some differences among other treatments were also significant (Table III). Floral initiation in sunflower occurs before about 30 days after planting (Marc and Palmer, 1976), which was before the irrigation treatments were imposed in this study. Therefore, differences in seed numbers due to treatments were not expected. The number of seeds formed probably was similar for all treatments, but because of incomplete

TABLE III

Seed development factors of sunflower irrigated at different growth stages, Bushland, TX, 1978—80

| Sampling (days after planting) | Irrigation treatment[a] | | | | | | | | | Average |
|---|---|---|---|---|---|---|---|---|---|---|
| | E | E+B | E+F | E+LF | E+B+F | E+B+LF | E+F+LF | E+A | E+FI | |
| *No. seeds per head* | | | | | | | | | | |
| 76—88 | 590 | 730 | 800 | 720 | 950 | 790 | 750 | 780 | 890 | 780 c[b] |
| 83—95 | 740 | 800 | 1 040 | 1 020 | 1 040 | 1 030 | 1 140 | 1 150 | 1 280 | 1 030 b |
| 92—102 | 1 000 | 880 | 1 160 | 1 130 | 1 090 | 1 110 | 1 210 | 1 180 | 1 310 | 1 120 a |
| Average | 780 c[b] | 800 c | 1 000 b | 960 b | 1 030 ab | 980 b | 1 030 ab | 1 040 ab | 1 160 a | |
| *Total oil* (%) | | | | | | | | | | |
| 76—88 | 22.0 | 24.8 | 23.8 | 25.6 | 23.8 | 21.4 | 21.7 | 22.4 | 19.8 | 22.8 c |
| 83—95 | 37.0 | 39.6 | 35.5 | 39.8 | 37.7 | 38.4 | 37.0 | 37.5 | 37.4 | 37.8 b |
| 92—102 | 43.6 | 42.3 | 44.5 | 46.7 | 42.6 | 43.6 | 45.0 | 47.9 | 47.4 | 44.8 a |
| Average | 34.2 b | 35.6 ab | 34.6 b | 37.4 a | 34.7 b | 34.5 b | 34.6 b | 35.9 ab | 34.9 b | |
| | [Protected LSD (0.05) for treatment by sampling = 3.0][c] | | | | | | | | | |
| *Linoleic acid concentration* (% of oil) | | | | | | | | | | |
| 76—88 | 29.7 | 30.6 | 27.3 | 30.0 | 28.7 | 27.5 | 27.7 | 31.4 | 29.6 | 29.2 c |
| 83—95 | 47.9 | 47.3 | 45.4 | 45.4 | 44.9 | 47.0 | 44.3 | 46.3 | 45.4 | 46.0 b |
| 92—102 | 56.0 | 54.1 | 53.6 | 53.7 | 55.2 | 55.2 | 55.8 | 54.6 | 53.1 | 54.6 a |
| Average | 44.5 a | 44.0 a | 42.1 a | 43.0 a | 42.9 a | 43.2 a | 42.6 a | 44.1 a | 42.7 a | |
| *Oleic acid concentration* (% of oil) | | | | | | | | | | |
| 76—88 | 58.4 | 57.5 | 60.6 | 58.1 | 59.4 | 60.6 | 63.7 | 56.6 | 58.5 | 59.3 a |
| 83—95 | 40.3 | 41.0 | 42.9 | 43.0 | 43.4 | 41.3 | 44.0 | 42.0 | 42.9 | 42.3 b |
| 92—102 | 32.3 | 34.3 | 33.8 | 34.7 | 33.2 | 33.2 | 32.7 | 33.8 | 35.2 | 33.7 c |
| Average | 43.7 a | 44.3 a | 45.8 a | 45.3 a | 45.3 a | 45.0 a | 46.8 a | 44.1 a | 45.5 a | |

[a]The irrigations represented by the letters were: E, emergence; B, budding; F, flowering; LF, late flowering; A, adequate and FI, full irrigation.

[b]Averages for treatments or days after planting for a given factor followed by the same letter or letters are not significantly different at the 5% level (Duncan Multiple Range Test).

[c]LSD values are shown only when the $F$-test indicated that the interaction was significant (Steel and Torrie, 1980).

filling, lighter seed was lost during the cleaning process and not counted. Losses due to immaturity also resulted in low seed numbers for the first and second samplings.

Averaged across treatments, seed oil percent significantly increased for successive samplings (Table III), indicating that oil percent increased as seed matured. Degree of maturity, therefore, was involved at the first sampling when the E+FI treatment resulted in a significantly lower oil percentage than some other treatments. The fully irrigated sunflower matured slightly slower than sunflower with the other treatments. Adequate irrigation resulted in intermediate oil percentages in mature seed in a previous study (Unger, 1978). In this study, the E+A and E+FI treatments resulted in similarly high average oil percentages at the last sampling. Next highest was for the E+LF treatment, which resulted in the highest average oil percentage in mature seed in the previous study (Unger, 1978).

Seed oil percentage is significantly related to mean air temperature during the seed development period (Unger and Thompson, 1982), but it is doubtful that air temperature differences were involved in this study because sunflower on all plots were sampled on the same day. A possible factor causing the variable results was water stress during the seed development stage (Davidescu et al., 1977). Because of slight differences in rate of development, a given rainstorm or irrigation occurred at slightly different growth stages, thus causing differences in oil percentages in the seed. Also, differential irrigation treatments caused differential water stress in plants, which caused different transpiration rates and possibly different effective plant temperatures.

Linoleic and oleic acid concentrations in oil increased and decreased, respectively, for successive samplings (Table III). As for oil percent, degree of maturity at sampling (Unger and Thompson, 1982), water stress at a given seed development stage, and mean temperature (Canvin, 1965; Keefer et al., 1976; Harris et al., 1978; Unger, 1980) probably affected linoleic and oleic acid concentration of the oil. Average linoleic and oleic concentrations of the oil were not significantly affected by irrigation treatments.

*Plant development-water use relationships*

Based on multiple linear regression analyses involving data for all years (not average data), plant height, stem DM, seed DM, TDM, and seed oil percent were significantly dependent on growing season rainfall. However, based on rankings of the standardized regression coefficients, rainfall contributed less to each factor than water use during different periods, and, thus, rainfall was dropped from subsequent analyses (data not shown).

Final plant height was most strongly correlated with water use from budding to flowering (Period 2); water use from flowering to late flowering (Period 3) gave the next closest relationship (Table IV). Leaf, stem, seed, and total DM were most closely related to water use from planting to budding

TABLE IV

Summary of multiple linear regression analyses associating sunflower plant development factors and water use during different periods; rankings are based on standardized partial regression coefficients[a] and levels of significance of the equation coefficients[b] are based on the *t*-test of the partial regression coefficients

| Dependent variable | Intercept | Equation coefficients[c] | | | | SE[d] | $R$[e] |
|---|---|---|---|---|---|---|---|
| | | Water use during[f] | | | | | |
| | | Period 1 | Period 2 | Period 3 | Period 4 | | |
| Plant height - - cm | 95 | —0.0615 (4)* | 0.1943 (1)** | 0.1017 (2)** | 0.0840 (3)** | 7.7 | 0.804** |
| Leaf DM (t/ha) | 1.74 | —0.0036 (1)** | — | — | 0.0026 (2)* | 0.299 | —0.653** |
| Stem DM (t/ha) | 2.12 | —0.0078 (1)** | — | — | 0.0038 (2)** | 0.349 | —0.820** |
| Seed DM (t/ha) | 2.47 | —0.0098 (1)** | — | — | 0.0052 (2)* | 0.729 | —0.660** |
| Total DM (t/ha) | 6.69 | —0.0229 (1)** | — | — | 0.0142 (2)** | 1.050 | —0.831** |
| No. seeds per head | 782 | 0.9783 (3)* | — | 1.0790 (2)* | 1.7165 (1)** | 113 | 0.798** |
| Linoleic acid (%) | 56.8 | —0.0249 (1)** | — | — | — | 2.2 | —0.533** |
| Oleic acid (%) | 31.5 | 0.0247 (1)** | — | — | — | 2.1 | 0.548** |

[a]Rankings are shown in parentheses immediately after partial regression coefficients. Rankings in order from 1 (highest) to 4 (lowest).
[b]Levels of significance are shown after rankings and are * (0.05) and ** (0.01).
[c]Results are shown only for the analyses for which the partial regression coefficients were significant, and for which the standard error of estimate was lowest and the coefficient of correlation was highest.
[d]Standard error of estimate.
[e]Coefficient of correlation. Level of significance was ** (0.01).
[f]Independent variables are water use (mm rainfall and irrigation infiltration and soil water depletion) during growth periods: Period 1, planting to budding; Period 2, budding to flowering; Period 3, flowering to late flowering; and Period 4, late flowering to physiological maturity.

(Period 1). However, the equation coefficients were negative, which was opposite the expected trend. The negative coefficients (lower DM production with greater water use) resulted from evaporation being a major part of water use (evapotranspiration) during Period 1. All plots were irrigated before planting, thus plant growth was little affected by rainfall that occurred during the early part of Period 1. The rain fell mainly on bare soil with much of it being lost by evaporation. Hence, as rainfall frequency increased, evaporation increased. The evaporation losses accounted for greater water use without causing increased plant growth. The irrigation for the E+A and E+FI treatments during this period also caused increased evaporation without causing major DM increases.

Water use during Period 2 was not significantly correlated with any factor, except plant height, and water use during Period 3 was correlated with only plant height and seed per head (2 rankings). Water use from late flowering to maturity (Period 4) resulted in significant regression coefficients with rankings of 3 for plant height; 2 for leaf, stem, seed, and total DM; and 1 for seed per head.

Seed oil percent was not significantly related to water use during any period. However, linoleic and oleic acid concentrations varied significantly with water use during Period 1. The relationship between Period 1 water use was negativve for linoleic acid and positive for oleic acid (Table IV). These trends are opposite those reported by Talha and Osman (1975) for sunflower in Egypt. In their study, early season water stress resulted in higher oleic and lower linoleic acid concentrations than later water stress. The reason for the different results is not apparent, but differences in climate, planting dates, and other management factors may have been involved.

The positive relationship between Period 2 water use and plant height was as expected, as was the relationship between Period 3 or 4 water use and seed per head. Not expected, as previously discussed, was the significant negative relationship between Period 1 water use and leaf, stem, seed, or total DM. Also not expected was the significant relationship between Period 3 or 4 water use and plant height. This, however, was relatively unimportant because of the 2 and 3 rankings, and the relatively low coefficients. The negative relationship between Period 1 water use and seed DM suggests that the preplant irrigation and early rainfall resulted in plants capable of seed yields greater than those actually obtained. Yields fell below their potential because of late season stress with some treatments.

## CONCLUSIONS

Irrigation of sunflower at the budding growth stage results in taller plants and higher leaf and stem DM production than irrigation at early to late flowering growth stages. However, tall plants and high leaf and stem DM yields are not essential for high seed yields. Seed yields were higher when the sunflower was irrigated at early to late flowering stages as compared with irrigation only at the budding stage. Full irrigation resulted in the highest seed yield and water use, but yield per unit of water used was lower for the full irrigation treatment than for some other treatments that resulted in lower yields and lower water use.

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