Sunflower Development In The Texas High Plains: Environmental Effects

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FOREWORD

Sunflower (*Helianthus annuus* L.) is an important oilseed crop in the United States. Most of it is grown in North and South Dakota and Minnesota, but it is adaptable to many other U.S. regions. In the southern Great Plains, previous studies have shown that growth, yield, and quality factors of sunflower were significantly affected by planting date. This study was conducted at Bushland, Texas, on a Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll) to determine the effects of environmental factors associated with different planting dates on sunflower growth, yield, quality, and total water use. By understanding the relationships among environmental and sunflower response factors, producers should be able to better manage the crop with respect to irrigation, tillage, and residue management practices.

Sunflower was planted from late March to late July in 1980 and 1981. Development, yield, and quality factors were determined for each planting and were related to environmental factors by simple and multiple regression analyses. Environmental factors considered were planting date (day of year), soil temperature, air temperature, solar radiation, daylength, and summation of daylight for the different sunflower development periods (planting to emergence, emergence to budding, budding to anthesis, and anthesis to physiological maturity).

Time of planting significantly affected plant height; head diameter and weight; seed yield, total oil concentration, weight/seed, and test weight; linoleic and oleic acid concentration of oil; and total water use; but these factors also were related significantly to other environmental factors. Yields were higher for sunflower planted from early April to early June than for those planted earlier or later. Values for most other sunflower variables either increased or decreased progressively from the first to the last planting. Early planted sunflower developed slower and used more water than later planted sunflower and, consequently, resulted in lower water use efficiency than sunflower planted from April to early June. Sunflower planted after early June also resulted in lower water use efficiencies because of lower yields. In addition, later plantings resulted in lower oil concentrations and, consequently, in lower total oil production.

To use water efficiently and to obtain favorable yields of seed having a high oil concentration, results of this study suggest that sunflower in the Texas High Plains should be planted from about mid April to early June.

KEYWORDS: planting date/seedling emergence/budding/anthesis/physiological maturity/yield/oil concentration/linoleic acid/oleic acid/water use/water use efficiency/degree days/temperature/daylength/solar radiation/*Helianthus annuus*/irrigation.

INTRODUCTION

Sunflower (Helianthus annuus L.) has emerged as an important oilseed crop in the United States in recent years. Although most of the crop is grown in North and South Dakota and Minnesota, it has a wide range of adaptation. In the southern Great Plains, which includes the Texas High Plains and surrounding areas where low temperatures limit the growing season, sunflower has been planted from late March until early August. Yields, however, declined sharply for sunflower planted after about 21 June, and sunflower planted on 15 May or later had significantly lower seed oil concentrations and significantly higher linoleic acid and lower oleic acid concentrations of oil than sunflower planted before that date (Unger, 1980).

Where soil water did not limit yield, temperature was frequently mentioned as a factor influencing sunflower seed yield, seed oil concentration, and fatty acid (oleic and linoleic) concentration of the oil. Yields generally were highest when seed developed during periods of moderate temperature (Anderson et al., 1978; Johnson and Jellum, 1972; Murphy, 1978; Unger, 1980). Yields were lower when development occurred during periods of excessive temperatures (Bhattacharya et al., 1975; Downes, 1974; Keefer et al., 1976) or relatively low temperatures (Anderson et al., 1978; Johnson and Jellum, 1972; Keefer et al., 1976; Murphy, 1978; Unger, 1980). Other factors influencing seed yield were low temperatures during vegetative growth stages (Anderson et al., 1978), solar radiation (Anderson et al., 1978; Keefer et al., 1976), and daylength (Keefer et al., 1976).

Reported effects of temperature on seed oil concentration have been variable. Oil concentrations greater at high than at low temperatures were reported by Johnson and Jellum (1972), Jones (1984), Robinson (1970), Unger (1980), and Unger and Thompson (1982), whereas Downes (1974) and Harris et al. (1978) reported opposite results. Canvin (1965) showed that oil concentration was not affected by temperature, and Anderson et al. (1978) found no correlation between oil concentration and planting time, which implies that temperature had no effect. Anderson et al. (1978) suggested, however, that oil concentration is controlled by a complex set of factors including temperature during seed development.

Positive and negative correlations of oleic and linoleic acid concentrations, respectively, with temperature during seed development have been reported frequently (Anderson et al., 1978; Grindley, 1952; Harris et al., 1978; Johnson and Jellum, 1972; Jones, 1984; Keefer et al., 1976; Unger, 1980). However, Unger and Thompson (1982), using multiple regression techniques, established that oleic and linoleic concentrations of oil were significantly related to solar radiation and daylength but not to temperature during seed development. Radiation and daylength could have been factors in the different linoleic and oleic acid concentrations reported by Filipescu and Stoenescu (1978) for sunflower grown at a wide range of latitudes, although they considered temperature the major factor. Early planted sunflower generally yielded more seed with higher oil concentration than later planted sunflower in the southern Great Plains (Jones, 1984; Unger, 1980). However, oil from later planted sunflower had a higher linoleic acid concentration, which is higher in polyunsaturates and, hence, preferred for salad oils and margarines (Robertson et al., 1979).

To obtain favorable yields and concentrations of linoleic acid, a compromise planting date seems desirable. Selection of planting date should be based on a thorough understanding of the environmental factors that influence sunflower development, yield, and quality factors. Such understanding could also lead to improved management of this crop with respect to irrigation, tillage, and residue management practices. This study examines the influence of various environmental factors that are affected by planting date on sunflower development, yield, quality, and total water use. Use of different planting dates caused the various periods or growth stages (germination, emergence, budding, flowering, and seed development) to occur during periods of widely different temperature (soil and air), radiation, and daylength.

MATERIALS AND METHODS

The field study was conducted on Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll) in 1980 and 1981 at Bushland, Texas, which is at 35°11' N lat. and 102°5' W long. Elevation is 1180 m, and average dates of last and first frost are 18 April and 28 October.

'Hybrid 894' sunflower was planted on dates shown in Table 1 at a rate to obtain about 64,000 plants/ha. Seed was planted on 1-m spaced ridges in level plots surrounded by dikes to prevent runoff of irrigation water. Average plant-available soil water to a 1.2-m depth, measured with neutron scattering equipment, was maintained at or above the 50 percent level by irrigation as necessary. Water content to a 3.0-m depth also was measured with neutron equipment at planting and at harvest to determine changes during the growing season. Total water use was determined from net soil water extraction, precipitation, and irrigation water applied. The soil contained adequate fertilizer (> 112 kg N/ha) to a 1.2-m depth for good growth, or received anhydrous ammonia to raise it to that level, and adequate amounts of P and K. Separate but adjacent plots were used in different years. Plots were 25 m long and 8 m wide. Each planting was replicated four times.

Before planting, trifluralin (α,α,α-trifluoro-2,6-dinitro-*N*,*N*-dipropyl-*p*-toluidine) was applied at a rate of 0.11 g/m^2 for weed control. When sunflower moth (*Homoeosoma electellum* Hulst) populations warranted control, methyl parathion (*O*,*O*-dimethyl *O*-[*p*-nitrophenyl] phosphorothioate) was applied at 0.06 g/m^2. Stem weevils (*Cylindrocopturus adspersus* LeConte) were controlled with a 0.11-g/m^2 application of carbofuran (2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate).

Soil temperatures at a 5-cm depth were monitored with four thermocouples connected in parallel and recorded hourly with a strip chart recorder. Measurements were made in plots of two replications from planting until anthesis. Hourly air temperatures 2 m above the soil surface were monitored with unshielded thermocouples connected to the recorder. Solar radiation (total) was monitored at a weather station about 1 km from the plot area. Daylengths were obtained from Johnson and Davis (1980).

Time in days from planting to 50 percent emergence, budding, anthesis, and physiological maturity was determined for all plants. These growth stages corresponded to the VE, R1, R5.5, and R9 stages identified by

Schneiter and Miller (1981). On the day when most plants of a given planting reached the start of anthesis (R5 stage), about 30 randomly selected plants were marked with plastic ribbon. After 7 days and, subsequently, at 7-day intervals until physiological maturity, three randomly selected heads were sampled from each replication to determine head diameter and fresh weight. The heads were then partitioned into three ring-shaped zones, each corresponding to the outer, middle, or inner one-third of the radius. Seed was obtained from each zone and dried at 100°C before determining percentage of dry matter, weight per seed (based on 100 seeds), total oil concentration by the nuclear magnetic resonance technique (Granlund and Zimmerman, 1975), and oleic and linoleic acid concentrations of oil by the refractive index method (Goss, 1978).

Plant heights were determined after anthesis. After physiological maturity, head samples were obtained from a 6-m^2 area of each plot. These samples were oven dried at 50°C, then threshed to determine seed yield, weight per seed, and test weight. Subsamples dried at 100°C were used to determine oil concentration and oleic and linoleic concentrations of the oil by methods mentioned above.

Based on days from planting (P) to emergence (E), budding (B), anthesis (A), and physiological maturity (PM), the growing season was divided into the following periods: P-E, P-B, E-B, P-A, E-A, B-A, P-PM, E-PM, B-PM, and A-PM. For each period until A, soil temperature (ST) data were summarized for the following:

STmax -- average of daily maximums
STmin -- average of daily minimums
STavg -- average of STmax and STmin
STmean -- average of hourly ST÷24 for each day of period
ΣSDD > 0 -- summation of daily STmean > 0°C (DD = degree days)
ΣSDD > 5 -- summation of daily STmean > 5°C
ΣSDD > 7.5 -- summation of daily STmean > 7.5°C
ΣSDD > 10 -- summation of daily STmean > 10°C
ΣSDD > 12.5 -- summation of daily STmean > 12.5°C
ΣSDD > 30 -- summation of daily STmean > 30°C
ΣSDD 5-30 -- summation of daily STmean from 5 to 30°C
ΣSDD 7.5-30 -- summation of daily STmean from 7.5 to 30°C
ΣSDD 10-30 -- summation of daily STmean from 10 to 30°C
ΣSDD 12.5-30 -- summation of daily STmean from 12.5 to 30°C

For each period until PM, air temperature (AT) data were summarized for the following:

ATmax -- average of daily maximums
ATmin -- average of daily minimums
ATavg -- average of ATmax and ATmin
ΣADD > 0 -- summation of ATavg > 0°C (DD = degree days)
ΣADD > 5 -- summation of ATavg > 5°C
ΣADD > 7.5 -- summation of ATavg > 7.5°C
ΣADD > 10 -- summation of ATavg > 10°C
ΣADD > 12.5 -- summation of ATavg > 12.5°C
ΣADD > 30 -- summation of ATavg > 30°C
ΣADD 5-30 -- summation of ATavg from 5 to 30°C

ΣADD 7.5-30 -- summation of ATavg from 7.5 to 30°C
ΣADD 10-30 -- summation of ATavg from 10 to 30°C
ΣADD 12.5-30 -- summation of ATavg from 12.5 to 30°C

For the periods until PM, values were obtained also for ΣDLi (summation of daylight), DLe (average daylength for period), and ΣSR (summation of solar radiation). For the soil temperature variables (STmax, STmin, STavg, and STmean), STavg usually resulted in higher simple correlations (Statistical Analysis System [SAS], 1982) with sunflower development, yield, quality, and water use variables than STmax, STmin, or STmean. Consequently, STavg was used in subsequent multiple regression analyses (MRAs) using SAS (1982) procedures. Likewise, ATmin resulted in higher correlations than ATmax or ATavg, and it also was used in subsequent MRAs.

The STavg, ATmin, ΣDLi, DLe, ΣSR, and DY (day-of-year) variables were used to establish relationships with development, yield, quality, and water use variables for sunflower. Pearson correlation coefficients were determined for independent variables (environmental factors) to be used in a MRA. When the coefficient for a pair of variables equaled or exceeded 0.70, those variables were not included in the same MRA. Although some variables for some development periods that overlapped (for example, P-B and E-B) were not highly related to each other by simple correlation, they likewise were not included in the same MRA. For MRA, the SAS stepwise model-selection method was used to determine which independent variables had a significant effect ($P = 0.05$ for retention in model) on the dependent variable. In the tables for MRAs, data are given only for the relationships that involved two or more variables. The sunflower development, yield, quality, and water-use data were analyzed also by the analysis of variance technique, and the LSD test was used to determine which differences due to planting date were significant.

RESULTS AND DISCUSSION

Duration of Growth Stages

The influence of planting time (DY) on length of sunflower growth stages is shown in Figure 1. Planting time had a major effect on the length of the P-E, E-B, and A-PM periods and relatively minor effect on the B-A period. Results for 1980 and 1981 were similar, except that the P-E period was shorter in 1981 for the first three plantings. Length of the P-E period steadily decreased for the first three or four plantings, then remained variable between 4 and 7 days for the later plantings. Length of most periods was highly correlated with all environmental factors (EFs) considered (Table 2). Results of MRAs involving EFs not significantly related to each other are given in Table 3.

Based on the simple correlations (Table 2), length of the various development periods was most closely related to ΣDLi. Other high coefficients ($P > 0.001$) resulted from most other EFs, at least for some periods. The physical significance of the ΣDLi (time from sunrise to sunset) with respect to sunflower development is questionable. This variable probably resulted in the highest ranking because of its exact nature. Other variables, except DY and DLe, had random variability and, therefore, failed

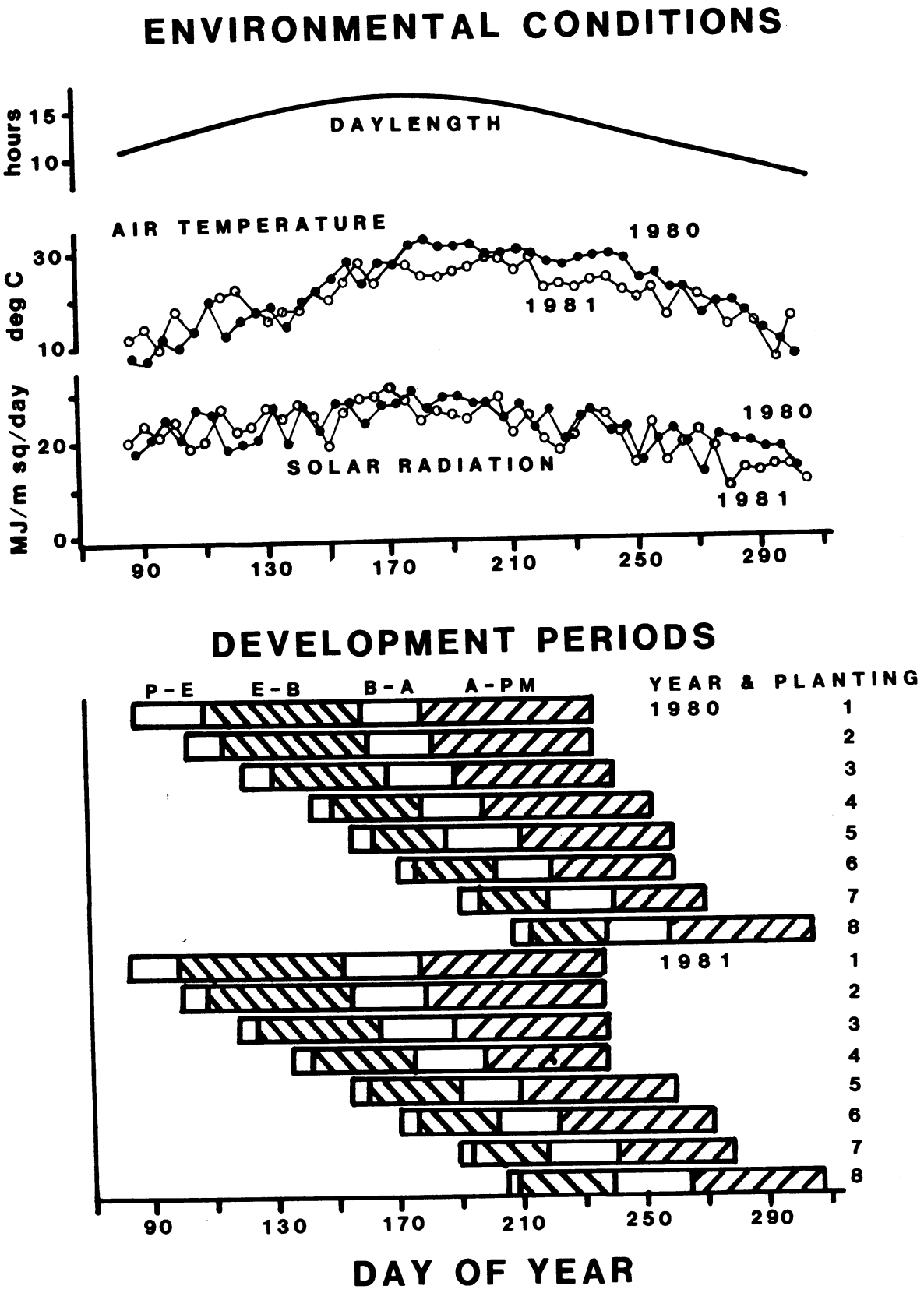

FIG. 1. Environmental conditions (daylength, 5-day average air temperatures, and 5-day average solar radiation) and lengths of the development periods of sunflower planted at different times at Bushland, Texas, in 1980 and 1981.

to achieve rankings as high as the above variables. The STavg, ATmin, and ΣSR variables, however, are highly correlated with ΣDLi, DLe, and DY and have a major influence on the rate of sunflower development. This is indicated by the high correlations between these variables and length of the periods (Table 2) and the highly significant R^2 values (P = 0.01) for MRAs involving variables other than ΣDLi, DLe, and DY (Table 3). However, a direct effect of ΣDLi may have occurred also because increasing periods of daylight may have provided favorable conditions for photosynthesis for a longer time each day.

Plant and Head Measurements

Average plant heights and head diameters and weights are given in Table 1. Simple correlations between various EFs, and plant height, head diameter, and head weight are included in Table 4. Based on simple correlations, plant height was related most closely to DLe during the B-A period (r = 0.568, P = 0.05) (Table 4). Other significant (P = 0.05) relationships involving plant heights, but with lower r values, resulted from ATmin, DLe, and ΣSR. The relatively low correlations between plant height and the EFs were not entirely unexpected because previous research (Unger, 1982, 1983) showed that the availability of adequate water from emergence to anthesis greatly influenced plant height when other factors were equal. In this study, soil water was maintained at adequate levels for good growth throughout the season.

Head diameter at PM was related significantly to numerous variables by simple correlation (Table 4), and to STavg, DY and ATmin, ATmin, and DLe variables by MRA (Table 5). The highest R^2 value (0.723, P = 0.01) resulted from the MRA involving ATmin during E-B and B-A periods. Correlations between head diameter and most ATmin variables were higher than those between head diameter and STavg variables because soil temperature data were not available after anthesis. Poor correlations with soil temperature variables, however, still may have occurred because the soil was almost fully shaded by the time of anthesis and temperature differences at later growth stages would have been minimal.

Head weight at PM was related significantly to numerous variables by simple correlation (Table 4). The highest R^2 value (0.802, P = 0.01) resulting from a MRA involved DY and ΣDLi as EFs for the B-A period (Table 5). The R^2 values for other MRAs ranged from 0.672 for DLe for the P-B and B-PM periods to 0.769 for ATmin for the E-B and B-A periods. As for head diameter, head weight generally was related more closely to ATmin than to STavg variables. A high simple correlation (0.771) between head weight and head diameter was not unexpected.

The close relationship between head diameter and ATmin during the E-B and B-A periods indicates that favorable plant growth conditions during vegetative growth stages (emergence to anthesis) are conducive to plants with large diameter heads. Several other combinations of ATmin variables for growth stages resulted in almost equally high R^2 values. For head weight, favorable conditions for vegetative development still were important, but also important were ATmin, ΣDLi, DLe, and ΣSR variables extending to PM, which included the period of seed development and, therefore, increases in head weight.

Yield

For yields (Table 1), the highest simple correlation (0.835, P = 0.001) with an EF resulted from DLe for the B-A period (Table 4). Other EFs also resulted in significant correlations.

Planting date (DY) in combination with ΣSR for the P-E period and various DLe and ΣSR variables were related significantly to yield as indicated by R^2 values associated with MRAs (Table 5). The highest R^2 value (0.821) resulted from DLe variables for E-B, B-A, and A-PM periods; the lowest (0.710) for DY and ΣSR for the P-E period.

Seed yields from the first planting averaged significantly lower than those from second and third plantings; were similar to those from fourth, fifth, and sixth planting; and were higher than those from the last two plantings (Table 1). Except for the increase after the first planting, the general decline with subsequent plantings was similar to the trends for the southern Great Plains reported by Unger (1980). In this study, planting date (DY variable) accounted for 53 percent of the variation in yield (r = -0.728, Table 4). No STavg variables accounted for more than 46 percent of the variation in yield. This level resulted from STavg during the E-B period.

For ΣDLi, the variable for the A-PM period accounted for 68 percent of the yield variation (r = 0.824, Table 4). The DLe variables for the E-B, B-A, and A-PM periods accounted for 82 percent of the yield variation (Table 5). The DY and ΣSR for the P-E period accounted for 71 percent of the yield variation; the ΣSR alone for the P-E and A-PM periods accounted for 82 percent of the variation (Table 5). The generally closer relationships between yields and DY, DLe, and ΣSR variables than between yields and STavg and ATmin are attributed to the more exact nature of the former variables. The latter variables were related closely to the former variables, however, and undoubtedly had a major effect on seed yields.

Seed yield was related significantly to variables covering all development periods. However, yield generally was related (simple correlations and MRAs) most closely to variables that extended to PM, which indicates that favorable early growth must occur to produce a plant capable of high yields. These results substantiate earlier findings that showed the importance of adequate water (irrigation) during early growth and seed filling stages to high yields of sunflower in the southern Great Plains (Unger, 1982, 1983).

Oil Characteristics

Except for some minor variation, oil concentration in seed generally declined from the first to the last planting. Also, there were consistent increases in linoleic and decreases and oleic acid concentrations of the oil from the first to the last planting (Table 1), as previously reported for the southern Great Plains (Unger, 1980).

Numerous EFs were correlated significantly with oil concentration in seed (Table 4), with almost identical high simple correlations (ranging from 0.892 to 0.900) occurring between oil concentration and length of and ΣDLi for the B-PM or A-PM period.

As indicated by R^2 values for MRAs involving oil concentration and various EFs, oil concentration was related most closely to ΣDLi for the P-E and A-PM periods, with $R^2 = 0.906$ (Table 5). A close relationship ($P > 0.01$) resulted also from ΣSR for the P-E and B-PM periods. Lower, but significant, R^2 values resulted from MRAs involving DLe, ΣDLi, and a combination of DY and ΣSR variables. When used in a MRA, variables for the B-A, B-PM, or A-PM period generally resulted in the highest ranking with respect to their influence on the relationships. This was expected because oil is produced during these latter developmental stages.

The highest simple correlations involving linoleic and oleic acid concentrations of the oil resulted from the DY variable. These correlations (0.947 for both acids) were positive for linoleic and negative for oleic acid. Progressively later planting dates (higher DY values) result in seed development and maturation during periods of progressively lower air temperatures, which has resulted in increasing concentrations of linoleic acid and decreasing concentrations of oleic acid in sunflower oil (Canvin, 1965; Harris et al., 1978; Johnson and Jellum, 1972; Keefer et al., 1976; Unger, 1980).

The MRA relationships between linoleic or oleic acid concentration of oil and the EFs were similar, except that the coefficients for the two acids were opposite in sign (Table 5). The signs were opposite because of the inverse relationships between linoleic and oleic acid concentrations, which, in turn, are negatively or positively related to DY, STavg, ATmin, ΣDLi, DLe, or ΣSR (Table 4).

The R^2 values for all MRAs involving linoleic or oleic acid concentrations and various EFs were significant at $P = 0.01$. The R^2 values ranged from 0.759 for the relationships involving STavg for the P-B and B-A periods to 0.966 for linoleic and 0.967 for oleic acid for the relationship involving DY and ATmin for the P-PM period. For the P-PM period, ATmin had a ranking of two and had much less influence on the relationship than DY, which alone accounted for almost 90 percent of the variability in acid concentrations (Table 4). The close relationship with DY was not unexpected because DY influences the prevailing temperature during the period of oil formation.

Seed Weight and Seed Test Weight

There were significant ($P = 0.05$) simple correlations between seed weight (mg/seed) or seed test weight (g/l) and most EFs evaluated (Table 4). The highest simple correlation coefficient for seed weight was 0.806, which involved ATmin for the B-PM period. For test weight, it was 0.896, which involved length of the E-PM period.

The highest R^2 value ($R^2 = 0.828$) for seed weight was obtained for the MRA involving ATmin for the E-B and B-A periods (Table 5). Some other ATmin variables or ATmin in combination with DY also resulted in high R^2 values. For seed test weight, R^2 values were 0.792 for ATmin for the P-B, B-A, and A-PM periods and 0.635 for DLe for the P-B and B-A periods. These were significant at $P = 0.01$ (Table 5).

Seed weight was related most closely to ATmin for the E-B and B-A periods; this was also the case for head diameter, indicating the importance

of large heads for obtaining heavy seeds. The coefficient for the simple correlation between head diameter and seed weight was 0.814 (Table 4). Seed weight, however, depends also on well-developed seed, of which seed test weight is an indicator. For the simple correlation between seed weight and seed test weight, the coefficient was 0.578 ($P = 0.05$). Simple correlations also showed that test weight was related ($r > 0.800$, $P > 0.001$) closely to length and ΣSR of periods extending to PM. These conditions provided adequate time of favorable conditions for the development of high test weight seed.

Water Use

Total water use during the growing season (net soil water depletion, precipitation, and irrigation) was related significantly ($P = 0.05$) by simple correlation to most factors considered (Table 4). The highest correlation coefficient (0.855) was for the relationship between water use and ΣSR for the A-PM period.

The R^2 values obtained for MRAs involving water use and various EFs were 0.711 for ATmin for the P-E and B-A periods and 0.660 for DY in combination with AT-min for the B-A period (Table 5).

Total water use was correlated negatively with DY for planting. Early plantings (low DY values) resulted in slower plant development (Fig. 1) and, consequently, longer growing seasons that resulted in greater total water use, even though part of the growing season for early planted sunflower occurred during a time of year (April-May) when potential evapotranspiration (ET) is lower than for later planted sunflower that develop during periods of higher ET. The longer growing season overshadowed the effects of higher potential ET, thus the greater total water use for early planted sunflower. The effect of the extended growing season on total water use is substantiated further by the positive coefficients for the simple correlations with length of the different periods. Most coefficients were significant at $P = 0.05$ (Table 4).

Relationships Among Sunflower Factors and Water Use

Simple correlations between sunflower and water use factors are presented in Table 6. Most factors were related significantly to each other at the $P = 0.05$ level, with many related to each other at the $P = 0.001$ level. Those having a simple correlation < 0.700 were included in MRAs. For the MRAs, only those variables were included that were judged to have an effect on the dependent variable being considered.

Plant height was judged to be affected by no sunflower variable but was related to water use (Table 6). Head diameter was related significantly ($r = 0.689$, $P = 0.01$) to plant height. Head weight was not related significantly to plant height, but there was a high simple correlation ($r = 0.771$, $P = 0.001$) between head diameter and head weight (Table 6).

Simple correlation indicated that plant height was related significantly to yield (Table 6). The relationship was positive, indicating that good plant growth is important for favorable yields. Yields averaged high for those plantings with the tallest plants (Table 1).

In addition to the simple correlations (Table 6), MRAs indicated that linoleic and oleic acid concentrations were related significantly to head diameter and seed test weight, with $R^2 = 0.655$ ($P = 0.01$). Seed weight was related to yield, oil concentration, and test weight, with $R^2 = 0.655$ ($P = 0.01$).

Relationships Among Sunflower Factors and Development Periods

Simple correlations between sunflower or water use factors and planting dates or length of development factors are included in Table 4. Plant height was not related significantly ($P = 0.05$) to length of any period. Head diameter was related significantly only to DY and length of the P-E, P-B, P-PM, and A-PM periods, whereas other factors generally were related significantly to all except length of the B-A period. Other exceptions were length of the P-E, P-B, and P-A periods for yield; P-E and B-A periods for oil concentration; and E-A and B-PM periods for seed weight.

Planting date (DY) and length of period variables related to sunflower and water use variables at $r < 0.700$ by simple correlation were used to establish relationships by MRAs. The analyses resulted in R^2 values of 0.560 for a combination of DY and length of the B-A period and 0.543 for length of the B-A and A-PM periods for head diameter, and 0.777 for length of the E-B and B-A periods for head weight. No other analysis involving two or more variables was statistically significant.

Degree Day Relationships

Summations of degree days (ΣDD) of ATavg above various base temperatures were determined for the various sunflower development periods. The ΣDDs and their coefficients of variability (CV) are shown in Table 7. Temperatures over 30°C had little effect on the results and were, therefore, excluded from further consideration.

Quadratic equations based on the CVs were determined, then solved to determine the air temperature at which the CVs were minimum (Arnold, 1959). The minimums, restricted to 0.0 to 12.5°C, ranged from 0.0 to 7.7°C and are included in Table 7. Use of ΣDD involving STmean resulted in only slight differences from those obtained with ATavg, and the summations are not shown. Using STmean, the temperatures at minimum CV were 1.4, 7.3, 8.8, 5.8, 8.4, and 0.0 for the P-E, P-B, E-B, P-A, E-A, and B-A periods, respectively (the only periods for which soil temperatures were determined).

The ΣDD (Table 7) for some periods was very similar to results for sunflower in Australia. Keefer et al. (1976) used a 0°C base temperature and found that flowering (anthesis) occurred at ΣDD = 1331 compared to 1324 in this study. Goyne et al. (1977) found that 50 percent flowering occurred at ΣDD = 1352, but they used -1.3°C as a base. Using 1°C as a base, Doyle (1975) found that ΣDD ranged from 1245 for an early cultivar to 1380 for a mid-season cultivar. Results from Minnesota (Robinson, 1971) indicated generally lower ΣDDs than those for this study. For six cultivars planted on six dates, the average ΣDD from planting to maturity was 1295 at a base temperature of 7.2°C compared with 1787 at a base of 7.5°C for this study. The slight difference in base temperature does not account for the difference in ΣDD for the two studies. Differences in length of photoperiod (daylength)

may result in different ΣDD (Arnold, 1959). Photoperiod at Rosemount, Minnesota, at 45° N lat. is longer than at Bushland, Texas, at 35° N lat. and thus may have resulted in faster development (lower ΣDD) of sunflower in Minnesota.

The results of this study suggest that different base temperatures for different periods, instead of a common base temperature, would result in improved prediction of the ΣDD required for different periods. Arnold (1959) also indicated this possibility. This could be accomplished through use of computers.

To further evaluate the base temperature effects, simple correlations between the sunflower development, yield, and quality factors and ΣDD above various ATavg base temperatures were determined for all development periods (Table 8). Numerous correlation coefficients (r values) were significant at P = 0.05 or above. In general, the coefficients involving ΣDD were at least as high as those obtained for simple correlations involving STavg, ΣDLi, ΣSR, and ATmin (Table 4).

Although the coefficients for the ΣDD variables varied only slightly for some sunflower variables, the ΣDD > 0 resulted in the highest coefficient for head weight, yield, oil concentration, linoleic and oleic acid concentration, and seed test weight. For plant height, ΣDD > 10 resulted in the highest coefficient while for head diameter and seed weight, ΣDD > 12.5 resulted in the highest correlation. These results further suggest that different base temperatures possibly should be used to obtain the best prediction of sunflower development during different periods. Use of the 0°C base temperature, however, may have limited physiological meaning, especially because such low temperature was encountered only a few times for the first two plantings and sunflower development at such temperature undoubtedly did not occur. Consequently, use of a 5°C base temperature seems more logical because the CV was minimum near this temperature for several growth periods (Table 7) and coefficients involving this base were significant at P = 0.05 or above and not greatly different from coefficients involving other base temperatures (Table 8).

Head and Seed Development

Results of the head and seed samplings at 7-day intervals, starting 7 days after anthesis, are in Table 9. Although seed samples were obtained at three head positions (outer, middle, and inner one-third of head radius) for determining seed dry matter, weight, oil concentration, and oleic and linoleic acid concentration of the oil, only average values for the entire head are presented in the table. At early samplings for seed from a given planting, dry matter concentration, seed weight, total oil, and linoleic acid concentration were highest and oleic acid concentration was lowest at the outer head position. At later samplings, the differences usually became slight or the trends even reversed, especially for total oil concentrations. These trends were similar to those reported by Unger and Thompson (1982). The differences required for statistical significance (LSD, P = 0.05) and the levels of significance for F-values obtained from analyses of variance are in Table 10.

Relationships among changes in values for successive samplings for head and seed factors and DY (sampling day), week (after first sampling), and average ATmax, ATmin, ATavg, SR, and DLe variables for the sampling interval were established by simple correlation and MRAs. As for previous MRAs, only those EFs not related to each other by high (> 0.700) simple correlation were used in a common MRA.

The simple correlations between changes in head, seed, and oil variables and the EFs are presented in Table 11. Head diameter was not related significantly to any EF by simple correlation, and head weight was related only to DY. Seed dry matter from different head areas usually was not related significantly to any EF, but average seed dry matter was related significantly to all EFs except DY and ATmax. In contrast, weight of seeds from different head areas was related significantly to all EFs except week of sampling and DLe. Average seed weight was related to all EFs except ATmax and ATavg. Most oil concentration and oleic and linoleic acid concentration variables were not related significantly to the EFs. Exceptions were the sampling day (DY) effect on oil concentration of seed from the mid (B) and inner (C) sections of the head, week of sampling effect on average oil concentration, and week of sampling, SR, and DLe effects on average oleic acid concentration.

The generally low simple correlations between changes in head and seed factors for successive samplings and the EFs indicate that the changes, in most cases, are not greatly affected by a single environmental factor, but by a combination of environmental factors. This was substantiated by MRAs involving various combinations of the EFs (Table 12).

The highest R^2 values were obtained for relationships involving average seed dry matter concentration as the dependent variable. For these relationships, DLe resulted in the highest ranking when other EFs were involved. When other EFs were excluded, the R^2 value remained high. The close relationship between changes in dry matter concentration and DLe is attributed to the rapid initial dry matter accumulation (changes between early samplings) when average DLe was longer than between later samplings when changes in dry matter accumulation diminished. The DLe factor by itself may have had little physical influence on dry matter changes for seed from plants of a given planting. For the entire season, however, DLe undoubtedly had at least an indirect influence on dry matter changes through its influence on other variables (AT and SR). These (AT and SR) were less constant than the DLe variable and, therefore, were not related as closely to dry matter as was the DLe variable.

Other relatively high R^2 values (> 0.500) were obtained for MRAs involving average seed weight, oil concentration, and average oleic acid concentration of oil as the dependent variables. For these relationships, DLe and week of sampling usually resulted in rankings of one or two. Week of sampling, as for DLe, was more constant than the AT and SR variables and, therefore, resulted in a generally high ranking. This is further substantiated by the generally high simple correlations presented in Table 11.

CONCLUSIONS

Irrigated sunflower was grown at Bushland, Texas, in 1980 and 1981. The sunflower was planted at about two and one-half intervals from late March to late July. The following are conclusions based on the results of the study:

1. Sunflower planted in late March or early April developed slower and used more water than later planted sunflower.

2. Seed yields were higher for sunflower planted from early April to early June than for those planted earlier or later.

3. Water use efficiency for seed production was highest for sunflower planted from April to early June. Sunflower planted after early June had low water use efficiency because of lower yields.

4. Late plantings resulted in lower total oil concentrations and, because of lower seed yields, also in lower total oil production.

5. Linoleic acid concentrations of oil increased and oleic acid concentrations decreased from the first to the last planting.

6. To use water efficiently and to obtain favorable yields of seed having a high oil concentration, sunflower in the Texas High Plains should be planted between mid April and early June.

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TABLE 1. Sunflower growth, yield, quality, water use, and water use efficiency factors† as affected by planting date in 1980 and 1981 at Bushland, Texas

Plant.	Day of year		Date		Pl Ht	Hd Di	Hd Wt	Sd Yd	Oil	LA	OA	Sd Wt	Tt Wt	W Use	WUE
no.	1980	1981	1980	1981	(m)	(mm)	(g)	(Mg/ha)	(g/kg)	(g/kg)	(g/kg)	(mg)	(g/l)	(mm)	(kg/ha mm^{-1})
1	84	82	24 Mar.	23 Mar.	1.57	188	450	1.69	452	477	407	43.9	324	959	1.76
2	101	99	10 Apr.	9 Apr.	1.51	177	414	2.02	464	493	390	45.2	327	951	2.12
3	119	117	28 Apr.	27 Apr.	1.60	186	367	2.20	453	525	369	44.2	313	837	2.63
4	141	134	20 May	14 May	1.68	179	208	1.81	438	543	342	40.5	289	861	2.10
5	154	153	2 June	2 June	1.70	173	173	1.99	434	587	298	38.1	282	876	2.72
6	169	169	17 June	18 June	1.43	178	197	1.44	418	622	264	35.0	261	793	1.82
7	189	188	7 July	7 July	1.24	125	81	0.44	339	670	217	27.4	237	506	0.87
8	206	204	24 July	23 July	1.46	141	122	0.68	398	715	172	28.9	289	525	1.30
LSD (0.05 level)					0.10	7	46	0.34	20	13	13	27.0	11	57	0.04

† Pl ht = plant height, Hd Di = head diameter, Hd wt = head fresh weight, Sd Yd = seed yield, oil = total oil concentration, LA = linoleic acid concentration, OA = oleic acid concentration, Sd Wt = seed weight, Tt Wt = seed test weight, W Use = total water use, and WUE = water use efficiency.

TABLE 2. Coefficients for simple correlations between lengths in days of sunflower development periods and determined environmental factors†

Development period‡	DY	STavg	ATmin	ΣDLi	DLe	ΣSR
P-E	-0.738	-0.776	-0.794	0.998	-0.788	0.974
P-B	-0.893	-0.897	-0.942	0.998	-0.638	0.985
E-B	-0.897	-0.907	-0.951	0.998	-0.522	0.979
P-A	-0.888	-0.903	-0.947	0.994	-0.220	0.961
E-A	-0.863	-0.897	-0.939	0.992	0.040	0.943
B-A	-0.203	-0.596	-0.586	0.929	0.012	0.686
P-PM	-0.895		-0.473	0.988	0.404	0.948
E-PM	-0.872		-0.293	0.985	0.479	0.934
B-PM	-0.704		0.182	0.956	0.490	0.857
A-PM	-0.728		0.341	0.969	0.538	0.888

Level of significance	Value to be significant
0.05	0.482
0.01	0.606
0.001	0.724

† DY = day of year, STavg = average soil temperature (°C), ATmin = minimum air temperature (°C), ΣDLi = summation of daylight (hours), DLe = daylength (hours), and ΣSR = summation of solar radiation (MWm^{-2}).

‡ P = planting, E = emergence, B = budding, A = anthesis, and PM = physiological maturity (PM).

TABLE 3. Relationships based on multiple regression analyses between length in days of the sunflower development periods (dependent variables) and various environmental factors† during the development periods

Development period‡	Intercept	Equation coefficients§ DY	STavg	ΣDLi	DLe	ΣSR	ATmin	R^2¶
B-A	5.484	0.012(3)		0.061(1)			-0.226(2)	0.970**
B-A	6.847	0.013(2)	-0.242(3)	0.061(1)				0.961**
B-A	22.360		-0.099(3)	0.065(1)	-1.297(2)			0.991**
B-A	22.699					59.453(1)	-0.552(2)	0.779**
A-PM	12.540			0.068(1)			-0.483(2)	0.986**
B-PM	123.393	-0.222(1)					-1.262(2)	0.631*
B-PM	22.202			0.063(1)			-0.713(2)	0.976**
B-PM	46.466					111.711(1)	-1.535(2)	0.947**
E-PM	207.706	-0.399(1)					-2.830(2)	0.906**
E-PM	96.015			0.072(1)	-6.965(2)			0.999**
E-PM	69.547					109.809(1)	-2.424(2)	0.979**
P-PM	225.914	-0.443(1)					-3.104(2)	0.924**
P-PM	102.093			0.073(1)	-7.472(2)			0.999**
P-PM	174.320				-10.175(2)	134.285(1)	-1.334(3)	0.995**

† DY = day of year, STavg = average soil temperature (°C), ATmin = minimum air temperature (°C), ΣDLi = summation of daylight (hours), DLe = daylength (hours), and ΣSR = summation of solar radiation (MWm^{-2}).

‡ P = planting, E = emergence, B = budding, A = anthesis, and PM = physiological maturity.

§ Numbers in parentheses after coefficients indicate ranking of variable (1 is highest).

¶ R^2 = coefficient of determination. Significance levels are * (0.05) and ** (0.01).

TABLE 4. Simple correlations between sunflower growth, yield, quality, and water use factors† and various environmental factors for sunflower

Environmental factors‡	Yield (Mg/ha)	Oil (g/kg)	LA (g/kg)	OA (g/kg)	Sd Wt (mg)	Tt Wt (g/l)	Pl Ht (m)	Hd Di (mm)	Hd Wt (g)	W Use (mm)
DY----------	-0.728	-0.674	0.947	-0.947	-0.709	-0.747	-0.448	-0.620	-0.830	-0.728
Length-----P-E	0.237	0.271	-0.668	0.670	0.544	0.561	0.296	0.535	0.804	0.532
--P-B	0.452	0.525	-0.773	0.773	0.563	0.765	0.286	0.488	0.847	0.559
--E-B	0.517	0.602	-0.762	0.761	0.528	0.800	0.259	0.428	0.801	0.529
--P-A	0.447	0.551	-0.755	0.755	0.526	0.785	0.251	0.419	0.795	0.542
--E-A	0.492	0.616	-0.716	0.716	0.466	0.802	0.208	0.328	0.711	0.492
--B-A	0.089	0.308	-0.090	0.090	-0.085	0.331	-0.142	-0.305	-0.103	0.036
--P-PM	0.595	0.725	-0.780	0.779	0.576	0.876	0.335	0.512	0.774	0.657
--E-PM	0.648	0.794	-0.753	0.752	0.543	0.896	0.321	0.468	0.710	0.642
--B-PM	0.702	0.899	-0.622	0.620	0.473	0.867	0.337	0.434	0.482	0.671
--A-PM	0.747	0.899	-0.668	0.666	0.553	0.866	0.422	0.580	0.579	0.736
STavg------P-E	-0.571	-0.672	0.806	-0.806	-0.524	-0.780	-0.320	-0.476	-0.752	-0.703
--P-B	-0.608	-0.697	0.700	-0.700	-0.422	-0.805	-0.302	-0.433	-0.719	-0.581
--E-B	-0.625	-0.704	0.639	-0.638	-0.367	-0.789	-0.273	-0.391	-0.666	-0.512
--P-A	-0.504	-0.642	0.585	-0.585	-0.286	-0.771	-0.241	-0.304	-0.629	-0.498
--E-A	-0.494	-0.639	0.486	-0.485	-0.186	-0.740	-0.193	-0.213	-0.531	-0.407
--B-A	0.045	-0.205	-0.209	0.209	0.454	-0.231	0.075	0.380	0.162	0.105
ATmin------P-E	-0.579	-0.638	0.856	-0.856	-0.609	-0.802	-0.416	-0.525	-0.814	-0.711
--P-B	-0.583	-0.634	0.769	-0.769	-0.525	-0.814	-0.331	-0.478	-0.799	-0.570
--E-B	-0.587	-0.635	0.712	-0.712	-0.467	-0.797	-0.278	-0.425	-0.747	-0.492
--P-A	-0.417	-0.537	0.608	-0.608	-0.329	-0.751	-0.180	-0.298	-0.698	-0.417
--E-A	-0.379	-0.508	0.506	-0.505	-0.220	-0.702	-0.086	-0.191	-0.604	-0.299
--B-A	0.290	0.024	-0.323	0.323	0.577	-0.076	0.426	0.550	0.181	0.405
--P-PM	0.108	-0.213	-0.124	0.125	0.306	-0.429	0.217	0.207	-0.144	0.172
--E-PM	0.227	-0.093	-0.354	0.355	0.491	-0.243	0.348	0.382	0.100	0.375
--B-PM	0.575	0.278	-0.811	0.812	0.806	0.258	0.531	0.685	0.615	0.703
--A-PM	0.623	0.347	-0.866	0.867	0.798	0.330	0.518	0.668	0.663	0.729
ΣDLi-------P-E	0.233	0.252	-0.666	0.668	0.555	0.540	0.312	0.552	0.803	0.540
--P-B	0.484	0.537	-0.796	0.796	0.585	0.765	0.319	0.520	0.863	0.586
--E-B	0.551	0.613	-0.789	0.789	0.552	0.800	0.298	0.467	0.822	0.560
--P-A	0.520	0.590	-0.808	0.809	0.573	0.792	0.304	0.471	0.817	0.595
--E-A	0.573	0.655	-0.782	0.782	0.524	0.806	0.272	0.396	0.743	0.557
--B-A	0.385	0.500	-0.382	0.382	0.163	0.446	0.041	-0.066	0.084	0.279
--P-PM	0.673	0.745	-0.854	0.854	0.639	0.862	0.392	0.570	0.806	0.711
--E-PM	0.724	0.803	-0.841	0.840	0.617	0.876	0.385	0.539	0.756	0.704

TABLE 4. (Cont'd.)

Environmental factors	Yield (Mg/ha)	Oil (g/kg)	LA (g/kg)	OA (g/kg)	Sd Wt (mg)	Tt Wt (g/l)	Pl Ht (m)	Hd Di (mm)	Hd Wt (g)	W Use (mm)
DLe--------P-E	-0.390	-0.524	0.718	-0.718	-0.516	-0.799	-0.175	-0.361	-0.779	-0.449
--P-B	0.153	-0.146	0.145	-0.145	-0.052	-0.516	0.242	0.146	-0.345	0.069
--E-B	0.278	-0.042	-0.025	0.026	0.070	-0.415	0.317	0.234	-0.228	0.201
--P-A	0.579	0.237	-0.388	0.389	0.356	-0.128	0.447	0.430	0.046	0.425
--E-A	0.694	0.383	-0.604	0.605	0.503	0.096	0.530	0.572	0.295	0.618
--B-A	0.835	0.598	-0.898	0.899	0.723	0.473	0.568	0.688	0.642	0.759
--P-PM	0.777	0.478	-0.823	0.823	0.662	0.329	0.542	0.619	0.550	0.656
--E-PM	0.778	0.510	-0.860	0.861	0.668	0.391	0.531	0.634	0.621	0.697
--B-PM	0.786	0.576	-0.939	0.939	0.729	0.526	0.534	0.651	0.711	0.714
--A-PM	0.780	0.581	-0.939	0.939	0.726	0.542	0.520	0.650	0.731	0.722
ΣSR--------P-E	0.179	0.158	-0.612	0.614	0.502	0.428	0.315	0.540	0.751	0.486
--P-B	0.536	0.546	-0.840	0.840	0.618	0.733	0.373	0.559	0.865	0.619
--E-B	0.636	0.659	-0.852	0.852	0.604	0.791	0.360	0.510	0.826	0.613
--P-A	0.622	0.635	-0.891	0.891	0.649	0.772	0.387	0.538	0.818	0.659
--E-A	0.698	0.719	-0.881	0.881	0.624	0.797	0.367	0.476	0.747	0.641
--B-A	0.668	0.680	-0.730	0.730	0.513	0.611	0.290	0.276	0.375	0.544
--P-PM	0.731	0.735	-0.929	0.929	0.728	0.824	0.460	0.645	0.834	0.769
--E-PM	0.782	0.790	-0.927	0.927	0.722	0.843	0.457	0.623	0.798	0.771
--B-PM	0.829	0.829	-0.922	0.921	0.755	0.828	0.493	0.659	0.734	0.825
--A-PM	0.818	0.812	-0.914	0.913	0.777	0.834	0.521	0.736	0.798	0.855

Level of significance	Value to be significant
0.05	0.482
0.01	0.606
0.001	0.724

†Yield = seed yield, Oil = total oil concentration, LA = linoleic acid concentration, OA = oleic acid concentration, Sd Wt = seed weight, Tt Wt = seed test weight, Pl Ht = plant height, Hd Di = head diameter, Hd Wt = head fresh weight, and W Use = total water use.

‡DY = day of year for planting, length of periods (P = planting, E = emergence, B = budding, A = anthesis, and PM = physiological maturity), STavg = soil temperature average, ATmin = air temperature minimum, ΣDLi = summation of daylight, DLe = daylength, and ΣSR = summation of solar radiation.

TABLE 5. Relationships based on multiple regression analyses for sunflower (dependent) variables and various environmental conditions during the sunflower development periods† and day of year.

Environmental factors‡	Intercept	Equation coefficients§ DY	P-E	P-B	E-B	P-A	E-A	B-A	P-PM	E-PM	B-PM	A-PM	R^2¶
		Head diameter (mm)											
STavg	53.613		-2.411(1)					7.048(2)					0.472*
STavg	51.946			-4.135(1)				8.939(2)					0.540**
STavg	56.994				-4.666(1)			9.334(2)					0.521**
DY & ATmin	117.181	-0.394(1)						5.923(2)					0.647**
ATmin	75.630		-2.382(2)					6.773(1)					0.619**
ATmin	75.732			-4.008(2)				8.386(1)					0.720**
ATmin	76.079				-4.626(2)			9.029(1)					0.723**
DLe	-291.651		-35.548(1)		67.560(2)								0.499*
		Head weight (g)											
STavg	28.756			-30.653(1)				39.478(2)					0.744**
STavg	64.500				-34.069(1)			41.952(2)					0.690**
ATmin	298.574			-21.879(1)							16.640(2)		0.764**
ATmin	214.971				-33.683(1)			30.961(2)					0.769**
ATmin	329.975					-23.208(1)						17.839(2)	0.724**
ATmin	322.471						-24.550(2)					20.439(1)	0.692**
DY & ΣDLi	1255.439	-3.707(1)						-1.552(2)					0.802**
ΣDLi	-223.757		1.403(1)							0.220(2)			0.740**
DLe	551.843		-241.847(1)		216.211(2)								0.732**
DLe	917.564			-176.032(2)								136.579(1)	0.688**
DLe	900.608						-258.507(2)					225.245(1)	0.714**
DLe	639.740			-182.902(2)							161.551(1)		0.672**

		Seed yield (Mg/ha)											
DLe	-10.230					-1.089(3)			3.862(1)			-2.046(2)	0.821**
DY & ΣSR	4.897	-0.017(1)	-13.984(2)										0.710**
ΣSR	-0.482		-11.513(2)									9.174(1)	0.815**
		Total oil concentration (g/kg)											
ΣDLi	209.294		-0.322(2)									0.393(1)	0.906**
DLe	262.081					-127.893(3)			301.790(1)			-171.567(2)	0.623**
DY & ΣSR	646.656	-1.170(1)	-935.535(2)										0.617**
ΣSR	249.910		-624.894(2)								475.284(1)		0.785**
		Linoleic acid concentration of oil (g/kg)											
DY & STavg	506.971	1.951(1)							-8.809(2)				0.939**
STavg	737.104		11.284(1)						-17.148(2)				0.803**
STavg	750.363			17.090(1)					-24.005(2)				0.759**
STavg	730.962					18.831(1)			-25.242(2)				0.694**
DY & ATmin	432.738	2.030(1)								-9.213(2)			0.966**
ATmin	687.774		7.714(1)								-12.329		0.916**
ATmin	658.202			8.506(2)								-12.728(1)	0.917**
ATmin	659.942					9.007(2)						-13.625(1)	0.911**
ATmin	674.068						9.220(2)					-14.848(1)	0.895**
ATmin	671.100							10.076(2)				-15.842(1)	0.887**
DY & DLe	867.329	1.867(1)					-39.910(2)						0.926**
DLe	1157.481					104.490(2)			-146.299(1)				0.941**
DLe	1184.727			92.438(2)					-135.803(1)				0.937**
ΣSR	951.600				-645.059(1)				-1236.857(2)				0.809**

TABLE 5. (Cont'd.)

Environmental factors†	Intercept	DY	P-E	P-B	E-B	P-A	E-A	B-A	P-PM	E-PM	B-PM	A-PM	R^2¶
		Equation coefficients§											
		Oleic acid concentration of oil (g/kg)											
DY & STavg	376.637	-1.921(1)						8.677(2)					0.939**
STavg	150.010		-11.116(1)					16.892(2)					0.805**
STavg	136.931			-16.827(1)				23.639(2)					0.760**
STavg	156.004				-18.532(1)			24.849(2)					0.694**
DY & ATmin	449.430	-2.000(1)							9.098(2)				0.967**
ATmin	197.952		-7.587(1)								12.174(2)		0.918**
ATmin	227.079			-8.362(2)								12.561(1)	0.918**
ATmin	225.277				-8.849(2)							13.445(1)	0.913**
ATmin	211.694					-9.073(2)						14.643(1)	0.897**
ATmin	214.561						-9.913(2)					15.622(1)	0.889**
DY & DLe	20.087	-1.838(1)				39.424(2)							0.926**
DLe	-268.138				-102.570(2)			144.042(1)					0.941**
DLe	-293.782			-90.829(2)				133.750(1)					0.937**
ΣSR	-61.015			635.952(1)				1215.609(2)					0.810**
		Seed weight (mg/seed)											
DY & STavg	12.472	-0.149(1)						1.970(2)					0.708**
STavg	-6.054			-1.334(2)				3.156(1)					0.625**
STavg	-4.500				-1.482(2)			3.263(1)					0.593**
DY & ATmin	23.160	-0.142(1)						1.936(2)					0.788**
ATmin	4.578					-1.890(2)		3.483(1)					0.817**
ATmin	7.769			-1.364(2)				2.782(1)					0.826**
ATmin	7.881				-1.573(2)			3.001(1)					0.828**
		Seed test weight (g/l)											
ATmin	347.413			-9.060(1)				8.814(3)				-4.995(2)	0.792**
DLe	706.995			-62.137(2)				32.461(1)					0.635**

		Water use (mm)			
DY & ATmin	732.926	-3.495(1)		30.762(2)	0.660**
ATmin	384.969		-23.120(1)	38.647(2)	0.711**

† P = planting, E = emergence, B = budding, A = anthesis, and PM = physiological maturity.

‡ DY = day of year, STavg = average soil temperature (°C), ATmin = minimum air temperature (°C), ΣDLi = summation of daylight (hours), DLe = daylength (hours), and ΣSR = summation of solar radiation (MWm^{-2}).

§ Numbers in parentheses indicate ranking of variable (1 is highest).

¶ R^2 = coefficient of determination. Significance levels are * (0.05) and ** (0.01).

TABLE 6. Simple correlations between sunflower growth, yield, quality, and water use factors†

	Yield (Mg/ha)	Oil (g/kg)	LA (g/kg)	OA (g/kg)	Sd Wt (mg)	Tt Wt (g/l)	Pl Ht (m)	Hd Di (mm)	Hd Wt (g)	W (
Yield	1.000	0.821	-0.738	0.736	0.638	0.627	0.654	0.706	0.549	0.
Oil conc.	0.821	1.000	-0.622	0.620	0.443	0.835	0.425	0.463	0.442	0.
Linoleic acid conc.	-0.738	-0.622	1.000	-0.999	-0.853	-0.677	-0.536	-0.686	-0.804	-0.
Oleic acid conc.	0.736	0.620	-0.999	1.000	0.853	0.675	0.536	0.686	0.804	0.
Seed weight	0.638	0.443	-0.853	0.853	1.000	0.578	0.592	0.814	0.780	0.
Seed test weight	0.627	0.835	-0.677	0.675	0.578	1.000	0.431	0.486	0.711	0.
Plant height	0.654	0.425	-0.536	0.536	0.592	0.431	1.000	0.689	0.481	0.
Head diameter	0.706	0.463	-0.686	0.686	0.814	0.486	0.689	1.000	0.771	0.
Head weight	0.549	0.442	-0.804	0.804	0.780	0.711	0.481	0.771	1.000	0.
Water use	0.722	0.734	-0.769	0.769	0.726	0.702	0.532	0.703	0.660	1.

Level of significance	Value to be significant
0.05	0.482
0.01	0.606
0.001	0.724

†Yield = seed yield, Oil = total oil concentration, LA = linoleic acid concentration, OA = oleic acid concentration, Sd Wt = seed weight, Tt Wt = seed test weight, Pl Ht plant height, Hd Di = head diameter, Hd Wt = head fresh weight, and W Use = total water use.

TABLE 7. Summations of degree days (ΣDD) above various base air temperatures (°C) for the sunflower development period with coefficients of variability (CV) and air temperature (°C) at minimum CV

Development period†	Factor	> 0.0	> 5.0	> 7.5	> 10.0	> 12.5	Temp. at min. CV
P-E	ΣDD	156.2	115.3	94.2	79.7	59.4	0.0
	CV	0.21	0.23	0.32	0.39	0.56	
P-B	ΣDD	919.3	717.8	602.1	499.2	392.6	6.7
	CV	0.12	0.08	0.08	0.12	0.23	
E-B	ΣDD	763.1	602.5	507.9	418.9	339.5	7.7
	CV	0.13	0.10	0.08	0.10	0.16	
P-A	ΣDD	1480.3	1178.5	1000.9	842.9	685.0	4.5
	CV	0.10	0.07	0.09	0.11	0.15	
E-A	ΣDD	1324.1	1063.2	906.7	764.4	625.6	6.1
	CV	0.10	0.09	0.09	0.11	0.15	
B-A	ΣDD	561.0	460.7	398.8	344.8	283.5	0.0
	CV	0.12	0.13	0.16	0.18	0.24	
P-PM	ΣDD	2625.5	2095.6	1786.5	1511.3	1241.7	0.0
	CV	0.18	0.16	0.19	0.21	0.23	
E-PM	ΣDD	2469.3	1980.3	1692.3	1431.6	1182.3	0.0
	CV	0.19	0.18	0.21	0.23	0.25	
B-PM	ΣDD	1707.4	1377.9	1184.4	1012.1	842.8	0.0
	CV	0.23	0.23	0.28	0.31	0.35	
A-PM	ΣDD	1145.1	917.2	785.6	667.3	556.7	0.0
	CV	0.29	0.31	0.37	0.41	0.44	

† P = planting, E = emergence, B = budding, A = anthesis, and PM = physiological maturity.

TABLE 8. Coefficients for simple correlations between sunflower growth, yield, and quality factors† and summation of degree days (DD) above various base temperatures in degrees C

Base and period‡		Pl Ht (m)	Hd Di (mm)	Hd Wt (g)	Yield (Mg/ha)	Oil (g/kg)	LA (g/kg)	OA (g/kg)	Sd Wt (mg)	Tt Wt (g/l)
ΣDD > 0	P-E	-0.001	0.362	0.346	-0.149	-0.280	-0.216	0.217	0.391	-0.078
	P-B	0.356	0.546	0.826	0.436	0.450	-0.809	0.809	0.675	0.643
	E-B	0.393	0.481	0.796	0.532	0.591	-0.821	0.820	0.615	0.736
	P-A	0.474	0.610	0.765	0.620	0.610	-0.932	0.932	0.847	0.724
	E-A	0.503	0.557	0.725	0.694	0.716	-0.934	0.934	0.800	0.787
	B-A	0.404	0.382	0.259	0.573	0.532	-0.624	0.623	0.659	0.461
	P-PM	0.557	0.743	0.808	0.750	0.693	-0.961	0.961	0.879	0.752
	E-PM	0.567	0.730	0.797	0.775	0.726	-0.963	0.962	0.867	0.772
	B-PM	0.576	0.748	0.747	0.788	0.714	-0.939	0.939	0.878	0.729
	A-PM	0.573	0.773	0.798	0.780	0.704	-0.940	0.940	0.863	0.738
ΣDD > 5	P-E	-0.284	-0.085	-0.330	-0.475	-0.635	0.412	-0.412	-0.063	-0.613
	P-B	0.206	0.149	0.290	-0.039	0.040	-0.220	0.220	0.323	0.204
	E-B	0.318	0.175	0.415	0.177	0.322	-0.388	0.387	0.325	0.463
	P-A	0.417	0.307	0.293	0.287	0.341	-0.461	0.460	0.621	0.424
	E-A	0.477	0.315	0.373	0.409	0.507	-0.556	0.555	0.605	0.579
	B-A	0.413	0.307	0.158	0.449	0.454	-0.464	0.463	0.601	0.425
	P-PM	0.593	0.711	0.745	0.692	0.644	-0.891	0.890	0.886	0.722
	E-PM	0.598	0.697	0.749	0.708	0.674	-0.897	0.897	0.866	0.748
	B-PM	0.594	0.729	0.741	0.741	0.677	-0.908	0.908	0.886	0.732
	A-PM	0.583	0.757	0.802	0.740	0.667	-0.925	0.925	0.872	0.735
ΣDD > 7.5	P-E	-0.308	-0.167	-0.472	-0.439	-0.627	0.499	-0.499	-0.171	-0.703
	P-B	0.205	0.203	0.047	-0.022	-0.163	-0.147	0.147	0.316	-0.234
	E-B	0.461	0.354	0.405	0.300	0.280	-0.537	0.537	0.485	0.256
	P-A	0.465	0.480	0.256	0.432	0.279	-0.563	0.563	0.718	0.180
	E-A	0.590	0.555	0.434	0.604	0.513	-0.760	0.760	0.802	0.438
	B-A	0.480	0.502	0.311	0.599	0.494	-0.654	0.654	0.743	0.410
	P-PM	0.595	0.763	0.733	0.726	0.593	-0.928	0.928	0.915	0.611
	E-PM	0.604	0.756	0.752	0.743	0.630	-0.945	0.945	0.904	0.653
	B-PM	0.587	0.761	0.751	0.754	0.636	-0.940	0.940	0.903	0.664
	A-PM	0.576	0.774	0.805	0.744	0.630	-0.948	0.948	0.885	0.681
ΣDD > 10	P-E	-0.421	-0.272	-0.539	-0.429	-0.522	0.467	-0.467	-0.216	-0.643
	P-B	0.019	-0.076	-0.382	-0.281	-0.431	0.288	-0.288	-0.045	-0.592
	E-B	0.311	0.069	-0.157	-0.068	-0.201	0.069	-0.069	0.082	-0.345
	P-A	0.355	0.318	-0.030	0.229	0.040	-0.263	0.262	0.489	-0.128
	E-A	0.560	0.464	0.185	0.426	0.257	-0.478	0.478	0.637	0.121
	B-A	0.500	0.538	0.325	0.599	0.472	-0.655	0.655	0.761	0.385
	P-PM	0.600	0.758	0.688	0.693	0.531	-0.893	0.893	0.912	0.535
	E-PM	0.624	0.762	0.720	0.714	0.566	-0.912	0.912	0.907	0.582
	B-PM	0.590	0.763	0.751	0.737	0.604	-0.936	0.936	0.911	0.638
	A-PM	0.577	0.771	0.806	0.726	0.599	-0.946	0.947	0.892	0.660

Table 8. (Cont'd.)

Base and period		Pl Ht (m)	Hd Di (mm)	Hd Wt (g)	Yield (Mg/ha)	Oil (g/kg)	LA (g/kg)	OA (g/kg)	Sd Wt (mg)	Tt Wt (g/l)
ΣDD > 12.5	P-B	-0.035	-0.141	-0.510	-0.399	-0.574	0.497	-0.497	-0.203	-0.717
	E-B	0.107	-0.121	-0.429	-0.261	-0.359	0.298	-0.298	-0.115	-0.555
	P-A	0.296	0.138	-0.191	0.054	-0.137	-0.073	0.072	0.325	-0.277
	E-A	0.470	0.266	0.004	0.245	0.084	-0.318	0.318	0.497	-0.032
	B-A	0.497	0.383	0.245	0.524	0.386	-0.602	0.601	0.715	0.339
	P-PM	0.600	0.743	0.632	0.639	0.450	-0.837	0.837	0.899	0.448
	E-PM	0.619	0.749	0.678	0.672	0.509	-0.879	0.879	0.905	0.520
	B-PM	0.596	0.766	0.751	0.714	0.570	-0.927	0.927	0.920	0.615
	A-PM	0.565	0.797	0.810	0.712	0.577	-0.933	0.933	0.897	0.634

Level of significance	Value to be significant
0.05	0.482
0.01	0.606
0.001	0.724

†Pl Ht = plant height, Hd Di = head diameter, Hd Wt = head fresh weight, Yield = seed yield, Oil = total oil concentration, LA = linoleic acid concentration, OA = oleic acid concentration, Sd Wt = seed weight, and Tt Wt = seed test weight.

‡P = planting, E = emergence, B = budding, A = anthesis, and PM = phyiological maturity.

TABLE 9. Sunflower head, seed, and oil factors as influenced by time of sampling and planting date (values for seed and oil factors are averages for samples from three head areas)

Factor	Sampling†	Planting‡ 1	2	3	4	5	6	7	8
Head diameter (mm)	1	214	199	190	196	190	189	146	139
	2	204	184	192	182	185	187	146	133
	3	198	176	199	184	171	166	129	129
	4	200	188	180	178	179	176	106	130
	5	180	184	174	179	175	192	106	125
Head weight (g)	1	445	378	358	424	385	367	259	230
	2	461	380	439	387	422	416	264	239
	3	481	390	516	399	331	304	122	225
	4	527	468	439	342	283	251	34	164
	5	450	441	384	278	198	185	34	97
Dry matter conc. (g/kg)	1	158	153	164	177	165	146	160	158
	2	273	286	281	312	265	239	239	227
	3	401	437	424	453	418	421	407	360
	4	539	542	572	563	564	552	585	486
	5	664	681	659	778	775	650	585	613
Seed weight (mg)	1	11	11	12	14	13	10	9	8
	2	22	21	23	23	22	18	14	14
	3	31	29	32	31	27	24	17	20
	4	39	39	39	38	33	30	19	24
	5	42	43	42	42	36	32	19	24
Oil conc. (g/kg)	1	37	51	49	59	75	36	43	48
	2	199	226	236	273	282	219	234	178
	3	370	413	389	398	405	413	265	341
	4	427	460	459	449	423	418	364	389
	5	467	478	467	445	428	403	364	366
Oleic acid conc. (g/kg)	3	554	508	504	436	344	351	257	284
	4	478	465	422	347	276	238	209	195
	5	426	436	360	326	269	236	211	163
Linoleic acid conc. (g/kg)	3	337	373	377	446	540	532	629	602
	4	404	418	460	537	609	647	676	692
	5	456	446	523	558	615	673	674	724

† Numbers correspond to weeks after 50 percent anthesis.

‡ Plantings in 1980 and 1981 were 1 = 24 and 23 March, 2 = 10 and 9 April, 3 = 28 and 27 April, 4 = 20 and 14 May, 5 = 2 and 2 June, 6 = 17 and 18 June, 7 = 7 and 7 July, and 8 = 24 and 23 July.

TABLE 10. Differences required for statistical significance (LSD, P = 0.05) and levels of significance for F-values obtained from analyses of variance

Factor	Planting (P)	Sampling (S)	Head area (A)	P x S	P x A	S x A	P x S x A
Head diameter (mm)	11.0**	4.0**	NA	NS	NA	NA	NA
Head weight (g)	45.0**	25:0**	NA	70.0**	NA	NA	NA
Dry matter conc. (g/kg)	18.1**	10.4**	3.0**	29.1**	8.5**	7.0**	19.6**
Seed weight (mg)	2.4**	1.4**	0.04**	3.7**	1.1**	0.9**	5.0**
Total oil conc. (g/kg)	8.0**	6.3**	4.9**	25.4**	12.0**	7.0**	NS
Oleic acid conc. (g/kg)	89.6**	55.0**	49.4**	37.7**	13.9**	9.4**	NS
Linoleic acid conc. (g/kg)	90.0**	55.1**	49.4**	38.0**	14.0**	9.4**	NS

Significance levels are * (0.05), ** (0.01), and NS (not significant).

NA = not applicable.

TABLE 11. Simple correlations between changes in sunflower head, seed, and oil variables and various environmental factors†

Sunflower factors		DY	W	ATmax	ATmin	ATavg	SR	DLe
Head diameter (mm)		0.144	-0.048	-0.086	-0.176	-0.069	-0.150	-0.154
Head weight (g)		-0.326	-0.229	0.223	0.139	0.237	0.128	-0.145
Dry matter conc. (g/kg)-----	A‡	-0.092	-0.032	0.157	0.119	0.130	0.206	0.018
	--B	-0.146	0.126	0.190	0.214	0.145	0.304	0.143
	--C	-0.040	0.157	0.169	0.135	0.116	0.214	0.092
	--Avg.	-0.082	0.951	-0.224	0.272	-0.359	0.644	0.997
Seed weight (mg)----------	A	-0.443	-0.147	0.268	0.282	0.252	0.317	0.057
	--B	-0.531	-0.090	0.338	0.377	0.330	0.360	0.064
	--C	-0.515	-0.008	0.349	0.372	0.330	0.407	0.073
	--Avg.	-0.412	0.603	0.062	0.430	-0.041	0.704	0.746
Oil conc. (g/kg)----------	A	-0.319	-0.299	0.182	0.190	0.194	0.148	-0.024
	--B	-0.350	-0.275	0.200	0.214	0.206	0.186	-0.002
	--C	-0.361	-0.265	0.231	0.220	0.238	0.191	-0.035
	--Avg.	-0.294	-0.486	0.223	0.115	0.258	0.020	-0.233
Oleic acid conc.(g/kg)------	A	0.074	0.016	0.083	-0.039	0.052	0.023	-0.066
	--B	0.137	0.225	-0.090	-0.043	-0.127	0.086	0.138
	--C	0.208	0.086	-0.128	-0.166	-0.143	-0.015	0.002
	--Avg.	0.069	0.539	-0.175	0.061	-0.264	0.379	0.464
Linoleic acid conc. (g/kg)--	A	-0.063	-0.014	-0.075	0.038	-0.049	-0.017	0.066
	--B	-0.137	-0.225	0.090	0.043	0.127	-0.086	-0.138
	--C	-0.209	-0.085	0.126	0.166	0.142	0.015	-0.001
	--Avg.	-0.123	-0.265	0.098	0.039	0.147	-0.150	-0.179

Level of signif.	Value to be signif.	Value to be signif. (oil factors)
0.05	0.250	0.349
0.01	0.325	0.449
0.001	0.408	0.554

†DY = day of year, Week = week of sampling, ATmax = maximum air temperature (degrees C), ATmin = minimum air temperature (degrees C), ATavg = average air temperature (degrees C), SR = summation of solar radiation (MW/m squared), and DLe = daylength (hours).

‡Letters (A, B, C) refer to outer (A), mid (B), and inner (C) one-third portion (radius) of the head.

Table 12. Relationships based on multiple regression analyses among changes in sunflower factors (dependent variables) and average environmental factors† for the sampling interval

Dependent variables‡	Intercept	Equation coefficients§ DY	Week	ATmin	ATavg	SR	DLe	R^2¶
Head diam. (mm)	-3.766		2.713(2)				-0.482(1)	0.122*
Head wt. (g)	185.610	-0.824(1)	-3.941(2)					0.159**
	-118.679					18.765(2)	-1.112(1)	0.109*
DM conc. (g/kg) -- A	-0.180	0.001(3)	-0.005(2)			0.025(1)		0.144*
-- B	0.018	0.001(2)				0.010(1)		0.101*
-- C	0.047		0.011(2)			0.012(3)	-0.002(1)	0.127*
-- avg.	-0.668	0.001(2)				0.022(3)	0.024(1)	0.996**
-- avg.	-0.158			-0.002(2)			0.025(1)	0.996**
-- avg.	-0.145				-0.002(2)		0.025(1)	0.995**
Seed wt. (mg) -- A	16.678	-0.036(3)	-1.822(1)				0.283(2)	0.473**
-- B	18.344	-0.048(3)	-0.884(1)				0.137(2)	0.387**
-- C	-2.826					1.496(1)	-0.046(2)	0.232**
-- avg.	15.418	-0.043(3)	-0.985(2)				0.292(1)	0.723**
-- avg.	0.757			0.229(2)			0.133(1)	0.606**
-- avg.	0.098					1.281(2)	0.098(1)	0.638**
Oil conc. (g/kg) -- A	123.031		-60.362(1)				9.151(2)	0.782**
-- B	126.740		-56.756(1)				8.677(2)	0.761**
-- C	120.115		-45.258(1)				6.814(2)	0.549**
-- avg.	133.215		-53.153(1)				7.392(2)	0.769**
OA conc. (g/kg) -- A	-166.555		33.340(2)			11.905(3)	-5.448(1)	0.443**
-- B	-113.950		36.234(1)				-5.199(2)	0.428**
-- C	-112.548		35.164(1)				-5.199(2)	0.379**
-- avg.	-114.275		33.727(1)				-4.434(2)	0.544**

(Continued on next page)

Table 12. (Cont'd.)

Dependent variables†		Intercept	Equation coefficients§ DY	Week	ATmin	ATavg	SR	DLe	R^2¶
LA conc. (g/kg)	-- A	175.663		-35.007(2)			-13.511(3)	5.767(1)	0.422**
	-- B	114.933		-37.246(1)				5.352(2)	0.412**
	-- C	113.690		-36.262(1)				5.370(2)	0.362**
	-- avg.	110.194		-34.819(1)				4.963(2)	0.413**

† DY = day of year, Week = week of sampling, ATmin = air temperature minimum (°C), ATavg = air temperature average (°C), SR = solar radiation (MWm^{-2}), and Dle = daylength (hours).

‡ The letters A, B, and C after the variables indicate the outer, mid, and inner one-third sections of the head, based on the radius of the head. Abbreviations used are DM (dry matter), OA (oleic acid), and LA (linoleic acid). Results are shown only for relationships that were statistically significant.

¶ R^2 = coefficient of determination. Levels of significance are * (0.05) and ** (0.01).

§ Numbers in parentheses indicate ranking of the variables.