AN ABSTRACT OF THE THESIS OF

William Joseph Cox for the degree of Doctor of Philosophy

in Crop Science presented on August 5, 1982

Title: SUNFLOWER AND SOYBEAN ADAPTATION TO WESTERN OREGON

Redacted for privacy

Abstract approved: Gary D. Jolliff

Sunflower (Helianthus annus L.) and soybean (Glycine max [L]. Merr.) are potential oilseed crops in the Pacific Northwest. Soil water availability may limit their adaptation to this region. Line source sprinkler designs were established for both crops in 1980 and 1981 to evaluate their agronomic potential in western Oregon.

Carbon exchange rates (CER) and maximum crop growth rate (CGR) in the well-irrigated sunflower crop averaged 1.55 mg m^{-2} s^{-1} and 30 g m^{-2}, respectively, across years. Such high values were reflected in a crop yield (3280 kg ha^{-1}) which approached the yield potential of the crop. Also, the low vapor pressure deficits of the environment resulted in seasonal water use of only 30 cm. Consequently, water use efficiency (WUE) in the well-irrigated sunflower crop was excellent (109 kg ha^{-1} cm^{-1}).

The well-irrigated soybean crop also have high CER (1.00 mg m^{-2} s^{-1}) and maximum CGR (30 g m^{-2}). Crop yield, however, averaged only 2640 kg ha^{-1}. Cool night temperatures apparently inhibited seed set and/or seed growth rate in soybean. This contributed to lower WUE (97 kg ha^{-1} cm^{-1}) for the well-irrigated soybean crop in comparison

to that of the well-irrigated sunflower crop.

The dryland sunflower crop showed excellent tolerance to the dry summer conditions of western Oregon. Osmotic adjustment was observed in the dryland crop which allowed for the maintenance of turgor (0.2 MPa) and CER (0.85 mg m^{-2} s^{-1}) under high evaporative demand. Osmotic adjustment may have also contributed to excellent soil water extraction by dryland sunflower. Averaged across years, crop yield and WUE in dryland sunflower were 1565 kg ha^{-1} and 90.7 kg ha^{-1} cm^{-1}, respectively.

The dryland soybean crop showed poor tolerance to the dry summer conditions. Limited osmotic adjustment was observed in dryland soybean which may have resulted in the loss of turgor and CER under high evaporative demand. Seasonal water use (8.9 cm) of dryland soybean was only 50% of that in dryland sunflower. Crop yield and WUE, averaged across years, were 320 kg ha^{-1} and 34.6 kg ha^{-1} cm^{-1}, respectively, in the dryland soybean crop.

SUNFLOWER AND SOYBEAN ADAPTATION TO WESTERN OREGON

by

William Joseph Cox

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

Completed August, 1982

Commencement June, 1983

APPROVED:

Redacted for privacy

Professor of Crop Science
in charge of major

Redacted for privacy

Head of Department of Crop Science

Redacted for privacy

Dean of Graduate School

Date thesis is presented August 5, 1982

Typed by Lynn O'Hare and Heidi W. Pearson for William Joseph Cox

ACKNOWLEDGEMENTS

I wish to express my sincere thanks to Dr. Gary D. Jolliff for his concern and guidance during my graduate study at Oregon State University. I appreciate the opportunity that he has provided me to grow as a researcher, teacher, and individual.

A special thanks is extended to the members of my committee for their advice concerning my research efforts. I am especially grateful to Dr. Richard Cuenca for his help in the design of the experiment.

Acceptance and cooperation from Dr. Benno Warkentin and the Soil Science Department has been greatly appreciated. I am especially grateful to Dr. Larry Boersma for his interest in my research and professional career.

I wish to extend thanks to the New Crops Project for their companionship that has made my stay at Oregon State more enjoyable. Special appreciation goes to Jimmie Crane and Majid Seddigh for their help in my research efforts.

Special recognition goes to Lynn O'Hare and Heidi Pearson for their help in the preparation of this manuscript. Thank you, both, for your patience with the innumerable changes.

Finally, my deepest appreciation is extended to my wife and children. Thank you for your patience with me during my graduate career.

Part of this project was accomplished through findings provided by the Pacific Northwest Regional Commission. The statements, findings, conclusions, recommendations, and other data are solely those of the authors and do not necessarily reflect the view of the Pacific Northwest Regional Commission

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (cont.)

LIST OF TABLES

SUNFLOWER AND SOYBEAN ADAPTATION TO WESTERN OREGON

INTRODUCTION

The Willamette Valley of Oregon is an important agricultural region in the Pacific Northwest. The mild climate, long growing season, and suitable soils are conducive to a highly productive cropping system. Wheat, grass seed, and hay currently comprise a majority of the cropping acreage in the Willamette Valley. Recent soil-borne disease problems, associated with the continuous cropping of wheat, necessitates suitable crop rotation schemes. Also, the environmental concern with pollutants from the field-burning of grass seed crop residue places the grass seed industry in a somewhat tenuous position. In addition, the marketing of both crops has become increasingly difficult and often unprofitable. Interest in alternate crops for the Willamette Valley has resulted from these production and marketing problems.

Agricultural producers and processers have expressed interest in the establishment of an oilseed industry in the Pacific Northwest. A report by the Pacific Northwest Regional Commission suggested that the economic potential exists for the development of an oilseed industry in this region (Divine et al. 1977). The report also indicated that the industry would probably be initially based on sunflower and soybean production. The combined interest in alternate crops for the Willamette Valley as well as the establishment of an oilseed industry in the Pacific Northwest stimulated the current research on sunflower and soybean.

Major environmental factors influencing crop adaptation to any region include day length, solar radiation, temperature, precipitation, and relative humidity. The successful introduction of a crop species to a new region requires a positive interaction of the crop species with these environmental factors.

Prior to the initiation of this research, environmental factors of the Willamette Valley were evaluated to identify potential limiting factors to the successful introduction of sunflower and soybean to this region.

Day Length

The phenology of a crop is often dependent upon day length or photoperiod. The Willamette Valley is situated at the 45° N latitude which results in relatively long summer days and short summer nights. The maximum day length in the Willamette Valley is about 15.5 hours. This occurs on the summer solstice. During the remainder of the summer, day length gradually decreases to about 12 hours at the autumn equinox.

Sunflower is often classified as insensitive to photoperiod because it flowers through a wide range of day lengths (Robinson, 1978). Robinson (1971) reported that day length variation between the northern latitudes of 30° and 50° has little effect on flowering in sunflower. Consequently, day length does not influence sunflower adaptation to areas within the temperature zones of North American (Robinson, 1978).

Soybean is considered a short-day plant and cultivars differ in day length requirements (Shibles et al. 1975). Due to cultivar differences in photoperiodic response, plant breeders have adapted soybean cultivars to rather narrow latitudinal belts in the United States (Hicks, 1978). Based on this recognition of adaptation belts, soybean cultivars have been classified according to maturity groups. Maturity Group 0 comprises the cultivars that are normally associated with the 45° latitude. The maturity group system, however, may be misleading if the environment of production differs from the environment of cultivar development (Hicks, 1978). Soybean cultivars of Maturity Group 0 are thus adapted to the Willamette Valley day length. Other environmental factors, however, may limit their agronomic performance in this region.

Light

Summer days in the Willamette Valley are normally clear resulting in relatively high light intensities. During the summer months, daily solar radiation averages approximately 250 W m^{-2} (Appendix Table 1). This represents 65% of the maximum sunlight of this environment.

Photosynthetic rates in sunflower exhibit an asymptotic response to light intensities with maximum photosynthetic rates occurring at 350 W m^{-2} (English et al., 1979). At a light intensity of 250 W m^{-2}, photosynthetic rates in sunflower were reduced by only 10% from the maximum value (English et al., 1979). Relative growth rate (RGR) in sunflower is also positively correlated with irradiance (Blackman et al., 1955; Warren Wilson, 1967a; Hodgson 1967; Eze 1973; Rajan et al. 1973). Overall, irradiance levels in the Willamette Valley are favorable for excellent sunflower growth.

Photosynthetic light saturation in soybean occurs at 25% of full sunlight (Shibles et al., 1975); Hicks, 1978). As a result, light intensity is almost never a limiting factor for soybean photosynthesis

(Sinclair, 1980). Crop growth rate (CGR) in soybean is a function of intercepted irradiance (Shibles, 1975). As in sunflower, light levels in the Willamette Valley are favorable for soybean growth.

Temperature

Marine air moderates temperatures in the Willamette Valley. The spring is cool with average temperatures of 13° and 16°C during May and June, respectively (Appendix Table 1). During July and August, the maximum and minimum ambient temperatures average only 27° and 10°C, respectively (Appendix Table 1). Consequently, the Willamette Valley has a unique temperature regime for the growth of summer annuals.

Photosynthetic rates and RGR in sunflower exhibit a broad optimum temperature range (20-35°C) with maximum rates occurring at 27° and 28°C, respectively (English et al. 1979; Warren Wilson, 1967 Consequently, cool June temperatures in the Willamette Valley may delay early sunflower vegetative development. During the remainder of the growing season, however, temperatures are ideal for maximum sunflower photosynthesis and growth. Also, ambient temperature in the Willamette Valley during August and early September closely approximates the 21° to 24°C range for optimum seed development (Robinson, 1978). Generally, temperature factors in the Willamette Valley are excellent for sunflower growth and yield.

Cool temperatures during early vegetative development of soybean inhibit photosynthetic rates and RGR (Togari and Murata, 1975). Therefore, June temperatures in the Willamette Valley may also retard soybean development. Maximum leaf growth and photosynthesis in soybean occurs at about 30°C (Hicks, 1978). As a result, July and August temperatures are also favorable for soybean growth. Cool night temperatures, however, inhibit soybean pod set (Hume and Jackson, 1981) seed set (Summerfield and Wien 1980,) and seed growth rate (Egli and Wardlaw; 1980). The cool night temperatures of the Willamette Valley may therefore impair reproductive development of soybean.

Precipitation and Relative Humidity

Annual precipitation in the Willamette Valley averages over 100 cm (Appendix Table 1). Ninety percent of the precipitation occurs between October and May. This rainfall distribution pattern results in saturated soils during the winter months and soil water deficits in a cropping system during the summer months.

The daily minimum relative humidity during July and August averages 30% in the Willamette Valley (Appendix Table 1). The relative humidity of this environment in combination with the mild temperature results in relatively low vapor pressure deficits (VPD). As a result, the open pan evaporation during July and August averages only 6 mm day^{-1} (Appendix Table 1). The low evaporative demand of this environment may therefore moderate the effects of infrequent summer precipitation.

Maximum crop yield in irrigated sunflower has been achieved by maintaining soil water close to field capacity (Sionit et al., 1973; Prunty, 1981). As a result, sunflower yield is reduced under slight soil water deficits. Sunflower, however, can extract deeply stored soil water which enables the crop to partially satisfy its water requirement under prolonged dry conditions (Vijayalakshmi, 1975). Sunflower also has good water-use efficiency (WUE) under low VPD

(Rawson and Constable, 1980a). Consequently, the effective rooting depth in sunflower and the low VPD of the environment may allow for dryland crop production in this area.

Soybean is usually grown in rainfed cropping systems. Crop yield in soybean does not always respond to irrigation (Burch et al. 1978; Mason et al. 1980). Soybean often extracts soil water to a 150 cm depth, and in some cases, below the 200 cm level (Willatt and Taylor, 1978). This effective rooting depth in soybean probably accounts for the lack of yield response to irrigation in some environments. In the Willamette Valley, however, summer rainfall is so infrequent that a yield response to irrigation is probable.

Hypothesis and objectives

The lack of summer precipitation is expected to be the major environmental limitation to the successful crop introduction of sunflower and soybean to the Willamette Valley. The full soil water profile at planting time and the mild evaporative demand during the summer, however, may moderate the severity of soil water deficits during the growing season. Consequently, it was hypothesized that soil water deficits would limit sunflower and soybean crop yield in this environment. However, dryland culture or deficit irrigation practices may be agronomically feasible in both crops. In order to test this hypothesis, a line source sprinkler design was established in each crop. This design allows for the evaluation of crop responses under varying soil moisture regimes.

The objectives of the research were threefold:

1) the quantification of sunflower and soybean water requirements

in the Willamette Valley. This will provide information on the agronomic feasibility of sunflower and soybean production under irrigated and dryland culture in the Willamette Valley.

2) The quantification of sunflower and soybean growth and development under irrigated and dryland practices. With this information, cultural practices or genetic characteristics can be identified which could facilitate sunflower and soybean adaptation to the Willamette Valley.

3) The assessment of sunflower and soybean crop water status under irrigated and dryland culture. This should provide information on sunflower and soybean physiological responses to soil water deficits under the mild evaporative demand of the Willamette Valley.

MANUSCRIPT I

SUNFLOWER AND SOYBEAN ADAPTATION TO WESTERN OREGON I. CROP YIELD

ABSTRACT

Sunflower (Helianthus annus L.) and soybean (Glycine max [L.] Merr.) are potential oilseed crops in the Pacific Northwest. Soil water availability, however, may limit their agronomic feasibility. An evaluation of crop water requirements and water use efficiency (WUE) under irrigated and dryland conditions is essential in assessing their agronomic potential in western Oregon.

In 1980 and 1981, a line source sprinkler irrigation design was established for each crop on a fine silty mixed mesic Aquultic Argixeroll. Treatments consisted of 5 irrigation levels, and soil water was monitored to a 210 cm depth with a neutron moisture meter. The Water Balance Equation determined crop evapotranspiration (ET) and WUE was defined as crop yield ET^{-1}.

Crop yield and yield components in sunflower exhibited significant linear responses to ET. Crop yield in the well-irrigated sunflower treatment averaged 3280 kg ha^{-1} across years. Crop ET, however, averaged only 30 cm across years which resulted in WUE above 100 kg ha^{-1} cm^{-1}. The low vapor pressure deficits (VPD) of this environment account for the high WUE.

Crop yield, pods per plant and 1000 seed weight in soybean exhibited significant linear responses to ET. The well-irrigated soybean crop maximized dry matter production in this environment, but cool night temperatures may have inhibited seed set and/or seed growth. Consequently, crop yield in the well-irrigated soybean crop averaged only 2640 kg ha^{-1} across years.

The dryland sunflower crop yielded 2000 kg ha^{-1} in 1981. In contrast, crop yield in the 1981 dryland soybean treatment was only 539 kg ha^{-1}. Superior soil water extracting ability of sunflower accounted for this difference. A physically stronger root system or osmotic adjustment are possible reasons for more soil water depletion by dryland sunflower in the experiment.

The data from this experiment indicated that irrigated or dryland sunflower production is agronomically feasible in western Oregon. In order to establish the soybean crop in this area, cultivars that are tolerant to cool nights and/or drought conditions are necessary.

Additional Index Words: Evapotranspiration, Water use efficiency, Yield components, Line source sprinkler system, Environmental stress, Soil water extraction, Osmotic adjustment, *Helianthus annus* L., *Glycine max* (L.) Merr.

SUNFLOWER AND SOYBEAN ADAPTATION TO WESTERN OREGON

INTRODUCTION

Sunflower (Helianthus annus L.) and soybean (Glycine max [L.] Merr.) are potential oilseed crops in the Pacific Northwest (Divine et al., 1977). The lack of summer precipitation in this region, however, may limit the agronomic feasibility of both crops. Supplemental irrigation may enhance agronomic performance, but negate economic feasibility of both crops in this region (Holst et al., 1979). An evaluation of sunflower and soybean water requirements and water use efficiency (WUE) is essential in assessing their agronomic potential in western Oregon.

Maximum crop yield in irrigated sunflower has been achieved by maintaining soil water close to field capacity (Sionit et al., 1973; Prunty, 1981). Doorenboors and Kasaam (1979) estimate crop evapotranspiration (ET) of 60 to 100 cm under these conditions. Sunflower WUE (crop yield ET^{-1}) often averages 30 to 50 kg ha^{-1} cm^{-1} (Robinson, 1978; Doorenboors and Kasaam, 1979). WUE, however, can be increased with ET deficits (Robinson, 1978). The timing of the ET deficits may influence WUE. Soil water stress at anthesis induces large yield reductions (Talha and Osman, 1975; Sionit, 1977; Robinson, 1978; Doorenboors and Kasaam, 1979) which may result in low WUE. Crop water stress at the vegetative and seed filling stage elicits less yield reduction (Sionit, 1977; Doorenboors and Kasaam, 1979). Consequently, ET deficits at this period may increase WUE. Under dryland conditions, sunflower can extract deeply stored soil water enabling the crop to endure prolonged dry periods

(Vijayalakshmi et al, 1975). Sunflower WUE under dryland culture, however, varies with yearly climatic conditions (Unger, 1981).

For maximum soybean production, Doorenboors and Kasaam (1979) estimate crop ET of 45 to 70 cm with accompanying WUE of 40 to 70 kg ha^{-1} cm^{-1}. Pod filling is the most sensitive stage to soil water deficits (Shaw and Laing, 1966; Doss et al., 1974). Consequently, WUE may be low with water stress during this period. Yield component compensation buffers against yield reduction to water stress at flowering (Shaw and Laing, 1966; Momen et al., 1979). Consequently, ET deficits at this time may result in high WUE. Soybean often extracts soil water to a 150 cm depth (Reicosky and Deaton, 1979), and in some cases below the 200 cm depth (Willatt and Taylor, 1978). The effective rooting depth in soybean probably contributes to higher WUE in dryland over irrigated treatments in some studies (Burch et al., 1978; Mason et al., 1980).

Field experiments were conducted on sunflower and soybean in western Oregon. Existing sunflower and soybean cultivars have not been selected for this area so introduced cultivars had to be utilized. The purpose of the study was to assess the agronomic responses of sunflower and soybean under irrigated and dryland practices in western Oregon.

MATERIALS AND METHODS

Field experiments were established in 1980 and 1981 at the Oregon State University Hyslop Crop Science Field Laboratory. The sunflower cultivar '894' was planted during mid-May and early May in 1980 and 1981, respectively. Row spacing was 60 cm, and the plant population was thinned to 50,000 plants ha^{-1}. The crop received 137 kg ha^{-1} of nitrogen and 1.12 kg ha^{-1} of boron. Amiben was applied preemergence for weed control. In both years, the crop was hand harvested in mid-September and dried, threshed, and cleaned before yield determination.

Inoculated soybean was planted both years at 30 cm row spacing, and plant population was thinned to 240,000 plants ha^{-1}. In 1980, the cultivar 'Evans' was planted in mid-May, and the cultivar S09-90 was planted in early May of 1981. Both cultivars were selected according to the maturity group for this latitude (45°N). The crop received 56 kg ha^{-1} of nitrogen at planting and 84 kg ha^{-1} of nitrogen at early pod formation. Lasso and Lorox were applied pre-emergence for weed control. In both years, soybean was harvested in mid-October with a small plot combine.

Experimental Design

A line source sprinkler design (Hanks et al., 1976) was established for each crop in both seasons. In this design, water application is uniform parallel to the sprinkler line with a linear decrease of applied water away from the line (Fig. 1). The differential irrigation pattern creates a soil moisture gradient. In this experiment, 5 treatments or irrigation levels were chosen for both crops (Table 1).

Access tubes were installed in the center of each harvest plot in order to take soil water measurements with a neutron moisture meter. In the optimum treatments, soil water was measured at 2 to 3 day intervals. Irrigation was applied when the upper 30 cm soil depth was at 50% available water. The soil water status in the optimum treatments, thus, determined frequency and amount of applied water for the entire experiment. Catch cans were attached to the access tubes and situated at canopy height to measure applied water. To minimize wind problems and evaporation losses, irrigation was applied at night. Application rates were then measured on the following morning. Irrigation was terminated 15 days after anthesis in sunflower and at beginning maturity or the R_7 stage (Fehr and Caviness, 1977) in soybean.

The experimental design allows for the evaluation of a large number of irrigation treatments in a small area. The design, however, precludes randomization which results in no valid error term in the analysis of variance table for assessing irrigation effects (Hanks et al., 1980). Consequently, regression techniques was the statistical tool for analysis of this experiment.

Soil Characteristics

Experiments were conducted on fallowed Woodburn silt loam soil (fine silty mixed mesic Aquultic Argixeroll). In both years, winter rains replenished the soil profile to field capacity. Soil reaction was medium acid necessitating lime applications to maintain soil pH close to 6.5 in the upper 30 cm soil zone. Initial soil water content and bulk density measurements indicated minimal spatial variability in the experimental site.

Soil moisture release curves differed for the A(0-45 cm) and B(> 45 cm) horizons, but estimated available water was about the same at each depth layer throughout the profile. Laboratory measurements estimated field capacity (-0.033 MPa) to be 34 and 42% by volume for the A and B horizons, respectively. In situ field measurements by the neutron scattering technique were slightly lower than the estimated laboratory values. The lower limit of available water (-1.5 MPa) averaged 17 and 21% by volume for each respective layer. Consequently, 30 cm of available water was estimated for the upper 150 cm of the soil profile.

Land preparation in 1980 inadvertently compacted the soil, and bulk density values of 1.7 g cm^{-3} were recorded at the 15 cm soil depth. Fall chiseling and minimum spring tillage alleviated the problem somewhat. Bulk density in 1981 averaged 1.40 and 1.35 g cm^{-3} throughout the respective A and B horizons.

Measurements

A neutron moisture meter measured volumetric soil water in all treatments at 7 to 10-day intervals during both growing seasons. Measurements commenced at mid-June in both years. Readings were recorded at 15, 30, 45, 60, 75, 90, 120, 150, 180, and 210 cm soil depths. The neutron moisture meter was field-calibrated, and separate calibration equations were necessary at the 15 cm level, 30 cm level, and for the B horizon. The Water Balance Equation was used to determine crop ET rates in all plots (Hillel, 1980). Deep drainage losses were observed early in the season in all treatments, and later in the season for some of the over-irrigated treatments. These losses were accounted for in the equation.

Four sunflower and 8 soybean plants contiguous to the neutron access tubes were selected in each plot for yield component analysis. In sunflower, the 4 plants were hand-threshed and seed number and 1000 seed weight were determined. In soybean, the 8 plants were also hand-threshed and pods per plant, seeds per pod and 1000 seed weight were recorded.

In both crops, 12 by 2.8 m areas in each plot were harvested for grain yield. Crop yield was adjusted to 13% seed moisture in soybean and 9% seed moisture in sunflower. In this portion of the study, WUE was defined as the unit of grain yield produced per unit of ET.

<u>Weather Data</u>

A National Weather Bureau Station was located 100 meters from the experimental site. The ambient weather conditions during both growing seasons are presented in Fig. 2. In both years, June conditions were cooler, cloudier, and wetter than normal. During the remainder of both growing seasons, light intensities averaged 25 W m^{-2} less than normal whereas the other environmental factors closely approximated the 30-year average.

RESULTS

Crop yield and yield components in sunflower exhibited significant linear responses to ET across years (Fig. 3). In soybean, linear responses to ET were also observed for crop yield, pods per plant, and 1000 seed weight (Fig. 4). Seeds per pod in soybean, however, showed no correlation with ET. In both crops, the optimum treatments had the highest crop yield, ET and WUE (Tables 2 and 3). In all comparable treatments, yield, ET, and WUE in sunflower was superior to that of soybean (Tables 2 and 3).

Optimum Treatments

Crop yield in the optimum sunflower treatment averaged 3280 kg ha^{-1} across years (Table 2). Accompanying ET averaged 30 cm across years which resulted in an average WUE of 109 kg ha^{-1} cm^{-1} in the optimum sunflower treatment (Table 2). Both yield components were also significantly higher in the optimum sunflower treatment than the yield components of other treatments (Table 2).

Crop yield and ET in the optimum soybean treatment averaged 2640 kg and 27 cm, respectively, across years (Table 3). As a result, WUE averaged 97 kg ha^{-1} cm^{-1} in the optimum soybean treatment (Table 3). In this experiment, seeds per pod and 1000 seed weight appeared to be low in all soybean treatments. The 2-year averages for seeds per pod and 1000 seed weight in the optimum soybean treatment were 1.54 and 142.5 g, respectively (Table 3).

Dryland Treatments

Crop yield, ET, and WUE, averaged across years in the dryland sunflower treatment, were 1565 kg ha^{-1}, 16.9 cm, and 90.7 kg ha^{-1}

cm^{-1}, respectively (Table 2). There was a strong interaction between years, however, in the dryland sunflower treatment. In fact, crop yield was almost twice as high in the 1981 dryland sunflower crop in comparison to the yield in 1980 (Table 2). Also, all other agronomic characteristics were higher in the 1981 dryland sunflower crop in comparison to values of the 1980 treatment (Table 2).

Crop yield, ET, and WUE, averaged across years in the dryland soybean treatment, were 320 kg, 8.9 cm, and 35 kg ha^{-1} cm^{-1}, respectively (Table 3). As in dryland sunflower, values for most agronomic characteristics in dryland soybean were higher in 1981 than values in 1980 (Table 3). All agronomic traits, however, remained low in the 1981 dryland soybean treatment.

Crop ET in the dryland sunflower treatment was twice as high as ET in the dryland soybean treatment. This was reflected in the soil water depletion patterns for both dryland crops (Fig. 5). In both years, the dryland sunflower crop depleted more soil water than that of soybean at each soil depth (Fig. 5). The more efficient soil water extraction by the dryland sunflower crop was particularly emphasized in the deeper portion of the soil profile (Fig. 5).

DISCUSSION

The significant linear responses of crop yield to ET in sunflower and soybean agree with data on other crop species (Hanks and Hill, 1980). The significant correlation between yield components and ET indicates that adjustment among yield components did not occur. Consequently, the reduction in seed number or pod number due to ET deficits was not compensated by an increase in 1000 seed weight in either crop. Momen et al. (1979) stated that the soybean crop is very flexible with respect to yield components and moisture stress. In this experiment, soil water deficits were evenly imposed throughout the season and not at critical growth stages. Consequently, both crops were responding to a soil moisture gradient and not moisture stress periods. This probably accounts for the lack of yield component compensation by both crops in this experiment.

Crop yield in the optimum sunflower treatments approached the yield potential of the crop (Robinson, 1978). Provided soil moisture is adequate, summer environmental conditions in western Oregon are conducive to the maximum expression of crop growth and yield. July and August are clear months, resulting in favorable light intensities for photosynthetic rates in sunflower (English et al., 1979; Rawson and Constable, 1980). Maximum ambient temperature during these months averages 27°C which is the optimum temperature for sunflower photosynthesis (English et al., 1979), and almost equals the 28°C optimum for net assimilation rates (Warren Wilson, 1967). The mean ambient temperature in August and early September is 19°C which approximates the 21° to 24°C range for good seed production (Robinson, 1978). As a result, the agronomic potential for irrigated sunflower in western Oregon is excellent.

Crop ET in the optimum sunflower treatments were substantially lower than the estimated values of Doorenboors and Kasaam (1979). The modified marine climate of this environment accounts for the discrepancy. The sea breeze moderates air temperature and vapor pressure deficits (VPD) which results in a relatively mild evaporative demand (W.P. Lowry, personal communication). As a result, potential evapotranspiration (PET), as computed by the FAO Penman method (Doorenboors and Kasaam, 1979) averaged only 4.5 mm day^{-1} in July and August of both years. Furthermore, the use of this same method with appropriate crop coefficients predicted only 32 cm of ET for a well-irrigated sunflower crop for both years. ET rates in this experiment agree favorably with this estimate.

High crop yield and low ET resulted in excellent sunflower WUE. In fact, sunflower WUE in this experiment was twice as high as typical WUE values. Sunflower WUE is inversely related to VPD (Rawson and Constable, 1980). In western Oregon, the slow warming of the air results in average VPD at noon of only 1 to 2 KPa (Fig. 2). The relatively low VPD of this environment is thus conducive to high sunflower WUE. The high WUE of sunflower in this experiment suggests that the yield-ET model is very site specific (Hanks and Hill, 1980). The use of the data for modeling purposes is probably restricted to the coastal valleys of the Pacific Northwest.

The optimum irrigated soybean treatment produced more than 1300 kg ha^{-1} of dry matter in both years (Cox and Jolliff, 1982a). Crop yield, however, was relatively low. Night temperatures in western Oregon are cool. In both years of this experiment, minimum night temperatures were consistently below 10°C (Fig. 2). The cool nights of this environment apparently limited the reproductive development of soybean(M. Seddigh and G.D. Jolliff. The Effects of low night temperature on field grown soybean. Agronomy Abstracts, 1982). In the determinate cultivar, 'Ransom', Thomas and Raper (1976) reported maximum vegetative dry weight and minimum pod dry weight with a day/night temperature range similar to this environment. The data from this experiment suggest a similar response for the Maturity Group 0 cultivars tested in this experiment. Pod development is sensitive to cool temperatures (Hume and Jackson, 1981), but pod number was not limiting in either year of this study. In contrast, seeds per pod and 1000 seed weight appear to restrict the yield expression of soybean in this environment. The exact mechanism for the limited expression of these agronomic characteristics is not clear. Cool night temperatures may affect pollen viability and reduce seed set (Summerfield and Wien, 1980). Egli and Wardlaw (1980) demonstrated that cool temperatures also reduce the seed growth rate and ultimately seed weight in soybean. They suggest that the temperature effect is directly on the seed, and not on the crop's ability to provide assimilates to the seed. Regardless of the mechanism, soybean appears to be sink limited in this environment.

The apparent sink limitation of soybean in this environment reduced the WUE of the crop. Based on dry matter production and ET rates, the optimum soybean and sunflower treatments had similar WUE (Cox and Jolliff, 1982a). Based on crop yield and ET rates, however, WUE in soybean was substantially lower than sunflower WUE.

Precipitation was less than 2 cm during July and August of both years (Fig. 2). This period coincided with the most sensitive sunflower growth stages to soil water deficits. Crop yield in the dryland sunflower crop, however, was relatively high in both years. As mentioned previously, PET during July and August averaged 4.5 mm day^{-1} (FAO Penman). Apparently, the dryland sunflower crop extracted enough soil water from the deeper portion of the profile to adequately satisfy this water requirement. Consequently, the effective rooting depth in sunflower and the mild evaporative demand of the environment allowed the crop to tolerate drought conditions in western Oregon.

An examination of the soil water extraction patterns in dryland sunflower emphasizes the importance of rooting depth for dryland crop production. Although weather conditions were similar in both years, the 1980 dryland sunflower crop depleted less soil water than that of the 1981 dryland sunflower crop. The soil physical conditions probably accounted for this difference. Severe soil compaction in the upper 15 cm soil zone (bulk density values of 1.7 g cm^{-3}) apparently inhibited root development and water uptake in 1980. As a result, leaf area development and photosynthetic rates were lower in the 1980 crop compared to that of the 1981 dryland crop (Cox and Jolliff, 1982a; Cox and Jolliff, 1982b). The lower leaf area and photosynthetic rates resulted in less seeds plant^{-1}, 1000 seed weight, and crop yield in the 1980 dryland crop.

Dryland soybean production in western Oregon is agronomically unfeasible due to poor soil water extraction in this environment. Although soil compaction was reduced in 1981, dryland soybean extracted only a small portion of the available water from the B horizon. In this experiment, the soil water extraction pattern of soybean contradicts other studies in which the crop readily extracted soil water to 150 to 200 cm depths (Reicosky and Deaton, 1979; Mason et al., 1980). Soil physical conditions may explain this discrepancy. Reicosky and Deaton conducted their study on a sandy loam soil, and in the Iowa study, Mason et al. reported bulk densities of about 1.25 g cm^{-3} throughout the soil profile. Both conditions favor root development. In the 1981 experiment, bulk density values (1.40 g cm^{-3} in the A horizon) indicate some soil compaction. The combination of high bulk density and low soil matric potential increases soil strength which can inhibit root development. This condition may have severely restricted the branched lateral root system of soybean whereas it may have only slightly retarded the strong central tap root of sunflower.

A more intriguing explanation for the soil water extraction differences between dryland sunflower and soybean is the osmotic adjustment theory concerning drought tolerance (Hsaio, et al., 1976; Turner and Jones, 1980). This theory states that crops which can actively concentrate solutes in their leaves in response to moisture stress can maintain turgor and photosynthetic activity under drought conditions. In 1981, dryland sunflower showed considerable osmotic adjustment. As a result, net photosynthetic rates were relatively high throughout the season (Cox and Jolliff, 1982b). In contrast, dryland soybean had limited osmotic adjustment and photosynthetic rates virtually ceased under high evaporative demand (Cox and Jolliff, 1982b). The maintenance of photosynthetic rates in dryland sunflower should provide more assimilates for sunflower root development in comparison to that of soybean. Turner (1980) suggests that an osmotically adjusting crop could explore a greater soil volume and deplete more available water at each soil depth. The data from this experiment support such an argument. Consequently, the sunflower root system may be more vigorous in this environment due to a crop physiological response and not just a physical characteristic of the root system.

In conclusion, sunflower appears well adapted to western Oregon climatic conditions. If an oilseed industry is developed in the Pacific Northwest, irrigated or dryland sunflower production is agronomically feasible. In contrast, the soybean cultivars that are adapted to western Oregon based on maturity group or photoperiodic response, are not adapted to the climatic conditions of this region. In order to establish the soybean crop in western Oregon, cultivars that are tolerant to cool night temperatures and/or sustained drought conditions are necessary.

TABLE I.1. Applied water in the 1980 and 1981 sunflower and soybean treatments.†

APPLIED WATER (cm)				
	Crop			
	Sunflower		Soybean	
	Year		Year	
Treatment	1980	1981	1980	1981
Dry	0.0	0.0	0.0	0.0
Severe deficit	3.1	3.0	4.7	8.4
Deficit	12.5	9.6	20.0	20.6
Optimum	26.6	20.0	28.7	26.6
Wet	31.8	30.8	34.4	33.2

†Data represents 4 replications.

TABLE I.2. Agronomic characteristics of sunflower in 3 selected treatments.†

Treatment	(Year)	Crop Yield kg ha^{-1}	ET (cm)	WUE kg ha^{-1} cm^{-1}	Seeds per Plant (no.)	1000 seed wt. (g)	Head Diam. (cm)
DRY	1980	1116	14.6	76.5	779	35.6	14.0
	1981	2014	19.2	104.9	1021	43.5	15.8
DEFICIT	1980	2658	24.0	110.8	1480	44.2	17.0
	1981	2582	26.3	98.2	1417	46.8	16.7
OPTIMUM	1980	3516	31.5	111.6	1890	48.7	19.1
	1981	3051	28.9	105.7	1858	48.5	18.7
	1980 $S_{\bar{x}}$*	51.46	0.83	3.92	31.27	0.57	0.29
	1981 $S_{\bar{x}}$	65.17	0.75	3.38	25.80	0.75	0.19

†Data averaged over 4 replications.

*Average standard error of the mean for the entire experiment.

TABLE I.3. Agronomic characteristics of soybean in 3 selected treatments.†

Treatment	(Year)	Crop yield kg ha^{-1}	ET (cm)	WUE kg ha cm^{-1}	Pods per plant (no.)	Seeds per pod (no.)	1000 seed wt. (g)
DRY	1980	101	8.4	12.1	8.2	1.46	111.5
	1981	539	9.4	57.1	23.8	1.52	101.8
DEFICIT	1980	1637	21.6	76.1	45.7	1.69	139.5
	1981	2215	24.0	92.3	62.6	1.50	136.8
OPTIMUM	1980	2767	27.2	101.3	60.3	1.60	146.0
	1981	2509	26.8	93.6	75.9	1.47	138.9
	1980 $S_{\bar{x}}$*	54.07	0.42	3.35	2.93	0.04	1.21
	1981 $S_{\bar{x}}$	65.43	0.68	4.22	2.65	0.04	0.75

†Data averaged over 4 replications.

*Average standard error of the mean for the entire experiment.

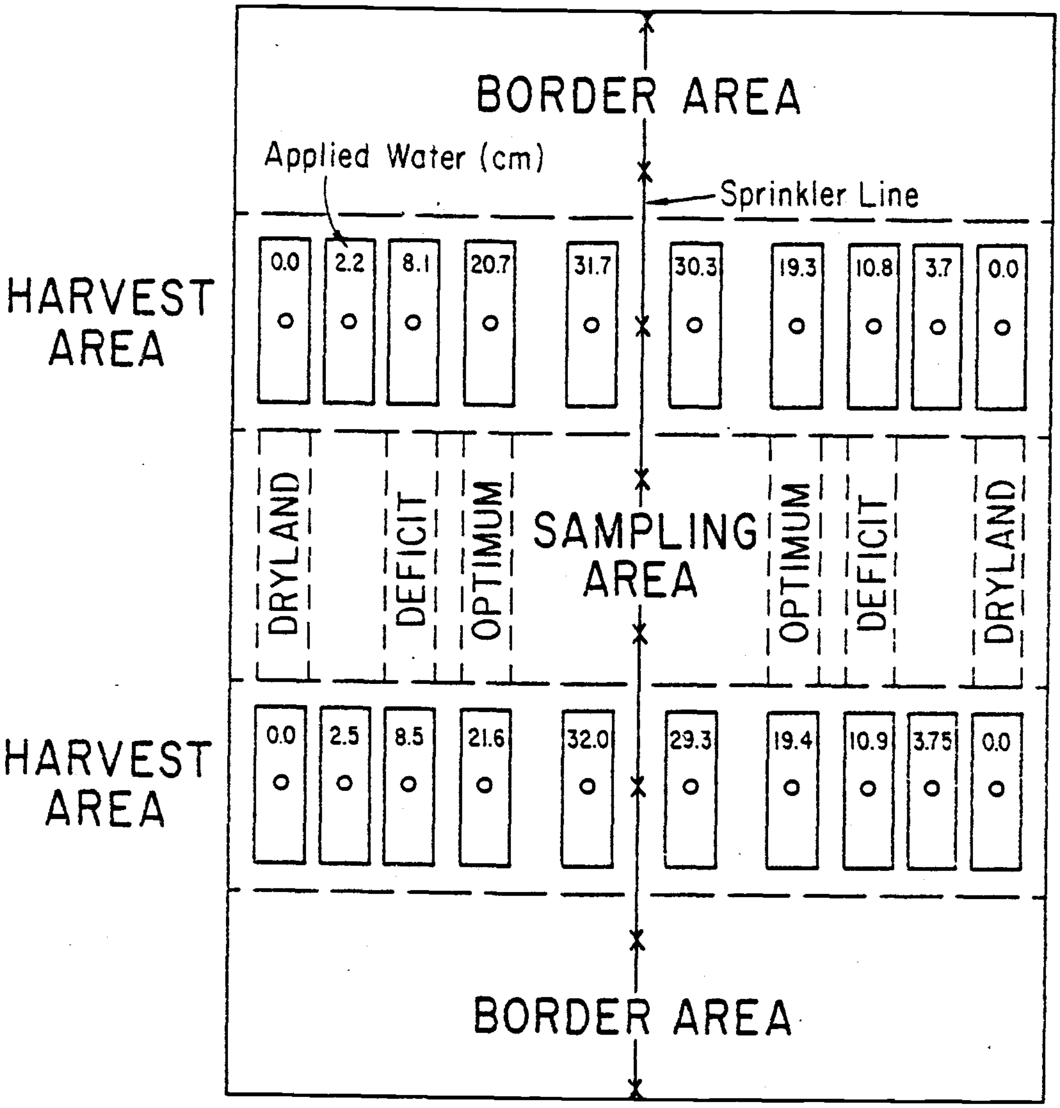

Figure I.1 Line source sprinkler design for the 1981 sunflower experiment. (O) neutron access tubes, and (X) sprinkler heads.

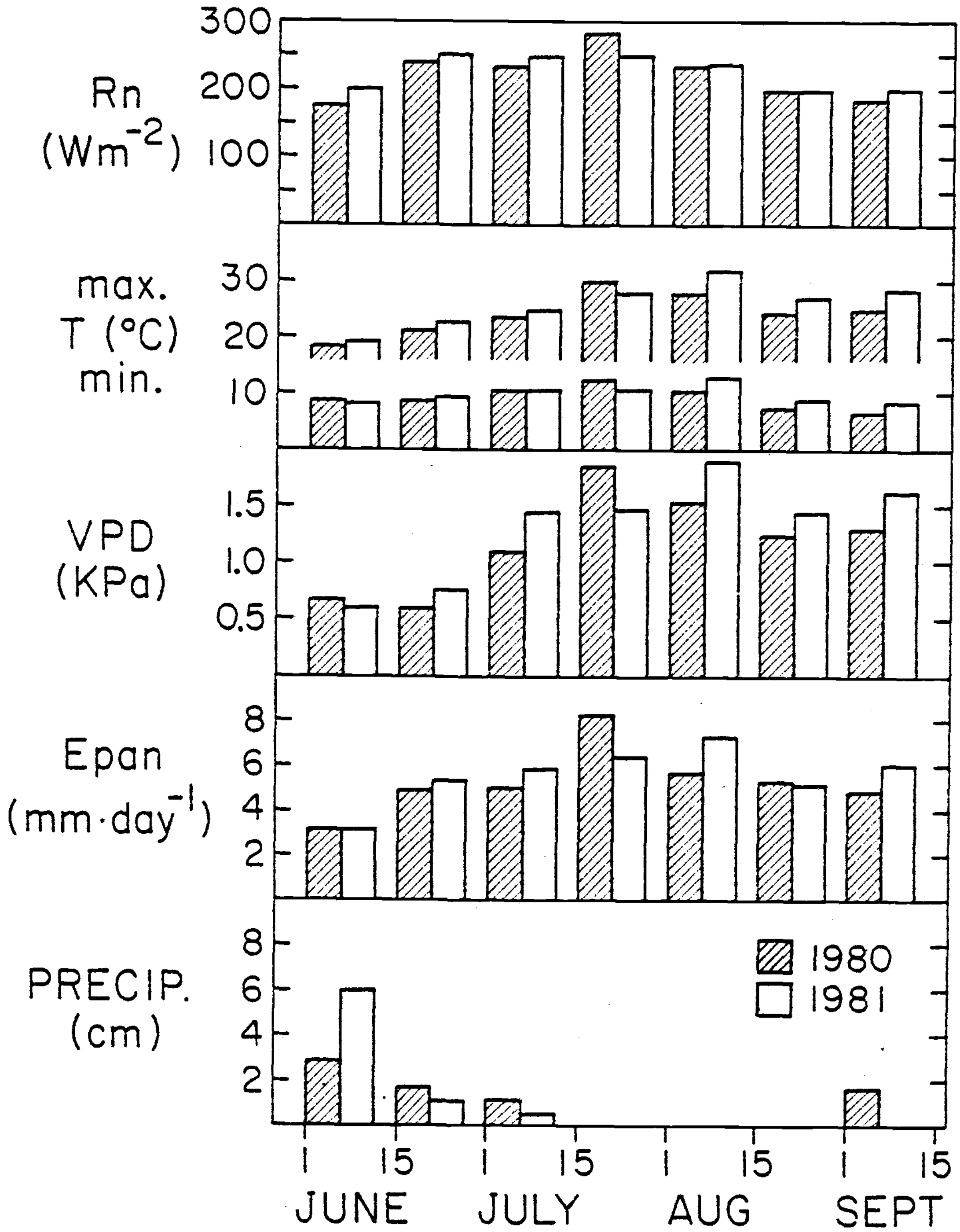

Figure I.2 15 day averages for selected weather characteristics in 1980 and 1981. (R_n) solar radiation, (T) ambient temperature, (VPD) vapor pressure deficit, (Epan) open pan evaporation, and (Precip.) precipitation.

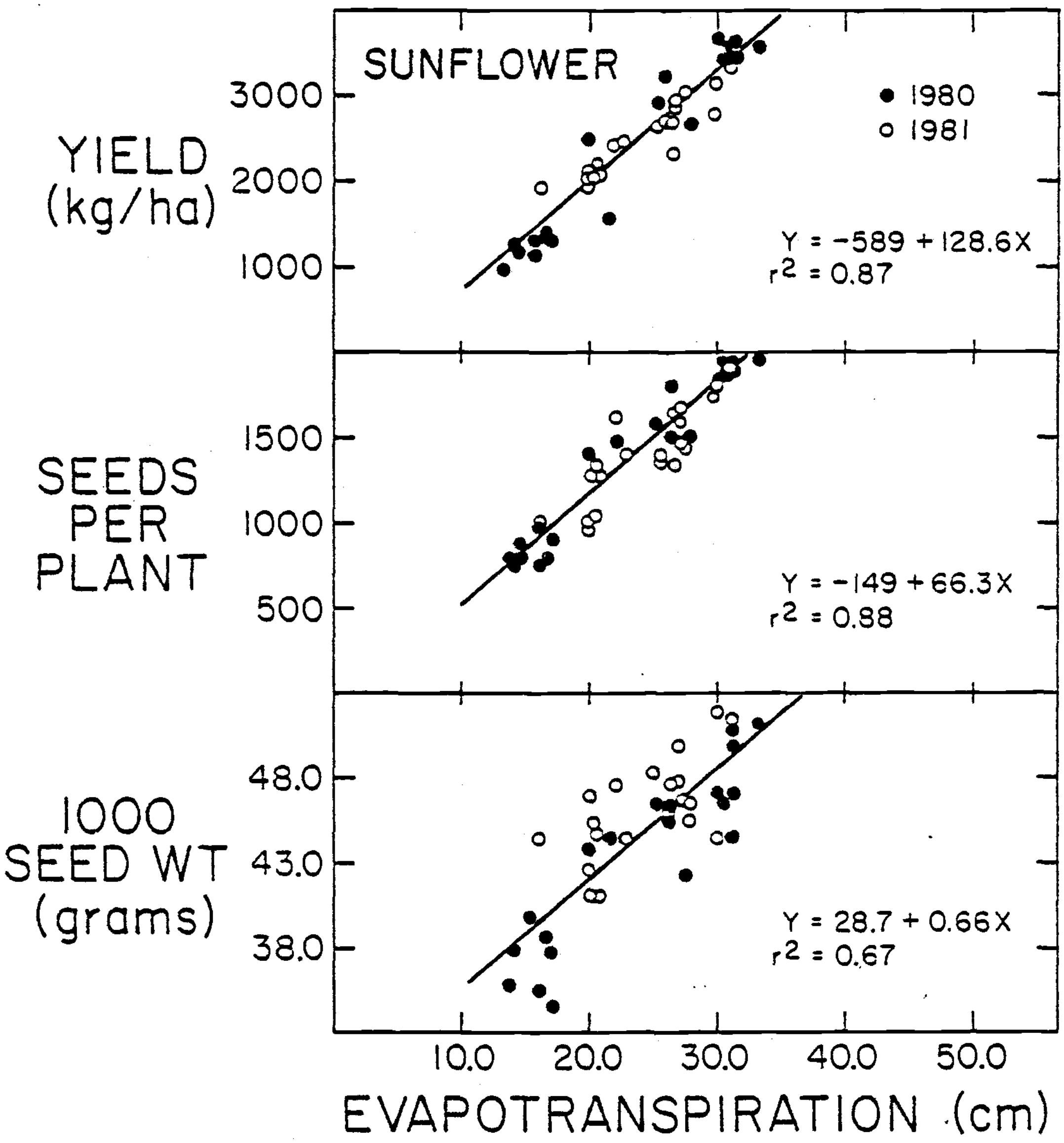

Figure I.3 Sunflower yield and selected component responses to evapotranspiration in 1980 and 1981.

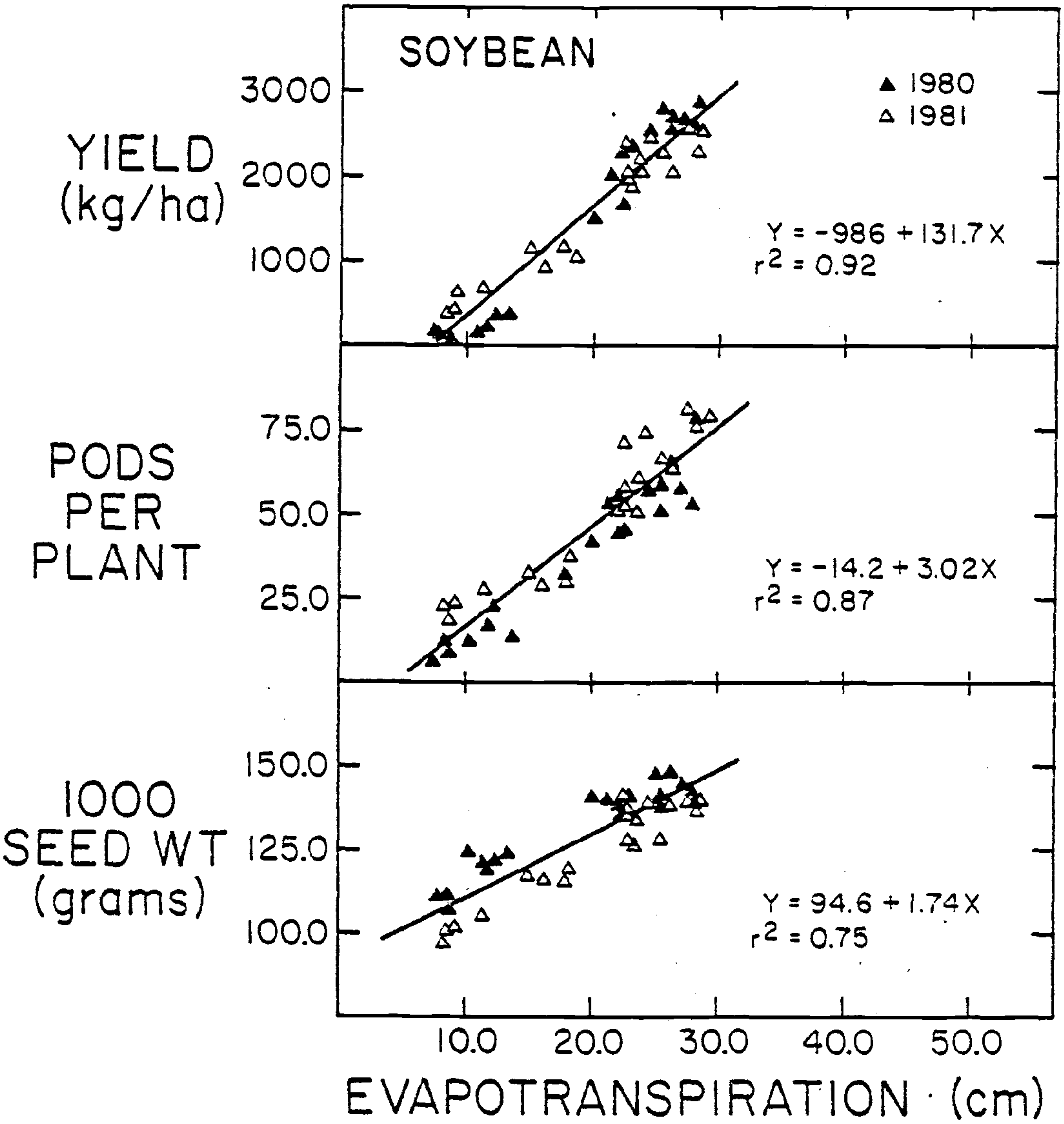

Figure I.4 Soybean yield and selected yield component responses to evapotranspiration in 1980 and 1981.

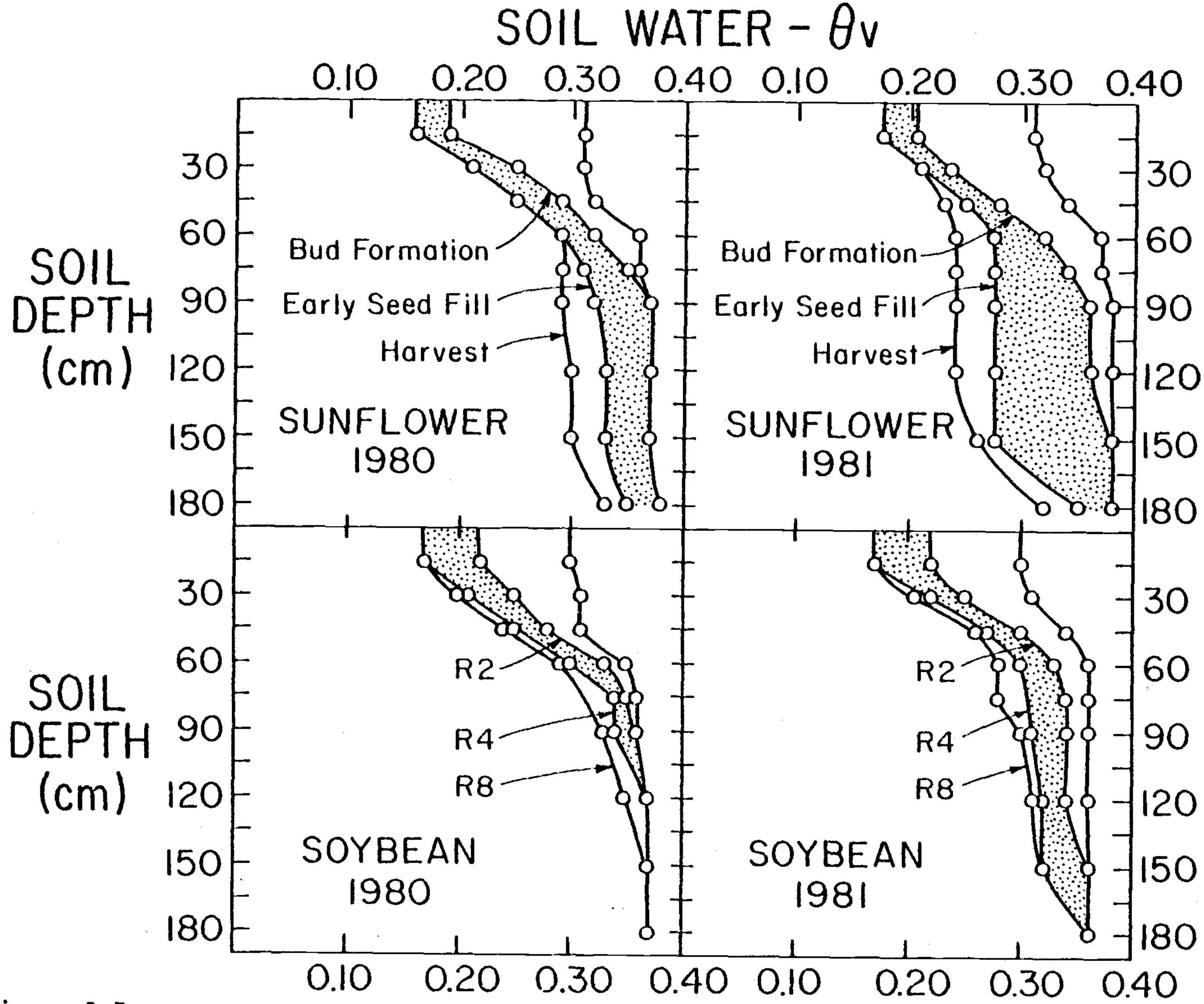

Figure I.5 Soil water depletion patterns in the 1980 and 1981 dryland sunflower and soybean treatments (averaged across 4 replications).

LITERATURE CITED

1. Burch, G.J., R.C.G. Smith, and W.K. Mason. 1978. Agronomic and physiological responses of soybean and sorghum crops to water deficits. II. Crop evaporation, soil water depletion, and root distribution. Aust. J. Plant Physiol. 5:169-177.
2. Cox, W.J. and G.D. Jolliff. 1982a. Sunflower and soybean adaptation to western Oregon. II. Crop growth and development. (manuscript in preparation)
3. Cox, W.J. and G.D. Jolliff. 1982b. Sunflower and soybean adaptation to western Oregon. III. Crop-water relations. (manuscript in preparation)
4. Divine, T.E., D.P. Alzheiner, J.W. Currie, K.A. McGinnis, and D.J. Wiggins. 1977. Research on the potential impact of advanced oilseed processing technology on Pacific Northwest agriculture. Battelle Northwest. Richland, WA. Final Report.
5. Doorenboors, J. and C. Kasaam. 1979. Yield response to water. Irrigation Drainage Paper 33. FAO, U.N. Rome.
6. Doss, B.D., R.W. Pearson, and H.T. Rodgers. 1974. Effect of soil water stress at various growth stages on soybean yield. Agron. J. 66:297-299.
7. Egli, D.B. and I.F. Wardlaw. 1980. Temperature response of seed growth characteristics of soybean. Agron. J. 72:560-564.
8. English, S.D., McWilliam, J.R., Smith, R.C.G., and Davidson, J.L. 1979. Photosynthesis and partitioning of dry matter in sunflower. Aust. J. Plant Physiol. 6:149-164.
9. Fehr, W.R. and C.E. Caviness. 1977. Stages of soybean

development. Spec. Rep. #80. Coop. Ext. Ser., Agric. and Home Econ. Exp. Stn., Iowa State Univ., Ames.

10. Hanks, R.J., J. Keller, V.P. Rasmussen, and G.D. Wilson. 1976. Line source sprinkler for continuous variable irrigation-crop production studies. Soil Sci. Soc. Am. Proc. 40:426-429.

11. Hanks, R.J., D.V. Sisson, R.L. Hurst, and K.G. Hubbard. 1980. Statistical analysis of results from irrigation experiments using the line source sprinkler system. Utah Agric. Exp. Stn. Journal Paper No. 2410.

12. Hanks, R.J. and R.W. Hill. 1980. Modeling crop responses to irrigation. International Irrigation Information Center, Israel. Pergamon Press, New York.

13. Hillel, D. 1980. Applications of soil physics. Academic Press, New York and London.

14. Holst, D.L., A.G. Nelson, and C.W. O'Connor. 1979. The economics of producing and marketing soybeans in Oregon. Oregon State Univ. Agric. Exp. Stn. Cir. of Info. 679.

15. Hsaio, T.C., E. Acevedo, E. Fereres, and D.W. Henderson. 1976. Water stress, growth, and osmotic adjustment. Philos. Trans. Roy. Soc. London, Ser. B. 273:471-500.

16. Hume, D.J. and A.K.H. Jackson. 1981. Pod formation in soybean at low temperatures. Crop Sci. 21:933-937.

17. Mason, W.K., H.M.Taylor, A.T.P. Bennie, H.R. Rowse, D.C. Reicosky, Y. Jung, A.A. Righes, R.L. Yang, T.C. Kaspar, and J.A. Stone. 1980. Soybean row spacing and soil water supply: their effect on growth, development, water relations, and

mineral uptake. Advances in Agricultural Technology. Science and Education Administration. U.S. Dept. of Agriculture. (also AAT-NC-5).

18. Momen, N.N., R.E. Carlson, R.H. Shaw, and O. Arjmand. 1979. Moisture-stress effects on the yield components of two soybean cultivars. Agron. J. 71:86-90.

19. Prunty, Lyle. 1981. Sunflower cultivar performance as influenced by soil water and plant population. Agron. J. 73:257-260.

20. Rawson, H.M. and G.A. Constable. 1980. Carbon production of sunflower cultivars in field and controlled environments. I. Photosynthesis and transpiration of leaves, stems, and heads. Aust. J. Plant Physiol. 7:555-573.

21. Reicosky, D.C. and D.E. Deaton. 1979. Soybean water extraction, leaf water potential, and evapotranspiration during drought. Agron. J. 71:45-50.

22. Robinson, R.G. 1978. Production and culture. In: J.F. Carter (ed). Sunflower science and technology. Agronomy 19:89-143. Am. Soc. of Agron., Madison, WI.

23. Shaw, R.H. and D.R. Laing. 1966. Moisture stress and plant response. p. 73-94. In: W.H. Pierre, Don Kirkham, John Pesek, and Robert Shaw (eds). Plant environment and efficient water use.

24. Sionit, N., S.R. Ghorashy, and M. Keradram. 1973. Effect of soil water potential on growth and yield of sunflower (Helianthus annus). J. Agric. Sci., Camb. 81:113-116.

25. Sionit, N. 1977. Water status and yield of sunflowers (*Helianthus annus*) subjected to water stress during four stages of development. J. Agric. Sci., Camb. 89:663-666. Am. Soc. Agron. and Soil Sci. Soc. Am., Madison, WI.

26. Summerfield, R.J., and H.C. Wien. 1980. Effects of photoperiod and air temperature on growth and yield of economic legumes. In: R.J. Summerfield and A.H. Bunting (eds). Advances in legume science. Royal Botanic Gardens, Kew.

27. Talha, M. and F. Osman. 1975. Effect of soil water stress and water economy on oil composition in sunflower (*Helianthus annus* L.). J. Agric. Sci., Camb. 84:49-56.

28. Thomas, J.F. and C.D. Raper, Jr. 1976. Photoperiodic control of seed filling for soybeans. Crop Sci. 16:667-672.

29. Turner, N.C. and M.M. Jones. 1980. Turgor maintenance by osmotic adjustment: a review and evaluation. In: N.C. Turner and P.J. Kramer (eds). Adaptation of plants to water and high temperature stress. p. 87-103. Wiley Interscience, New York.

30. Turner, N.C. and J.E. Begg. 1981. Plant-water relations and adaptation to stress. In: J. Monteith and C. Webb (eds). Soil water and nitrogen in Mediterranean-type environments. p. 97-131. Nijhoff/Junk, Boston, MA.

31. Unger, P.W. 1981. Tillage effects on wheat and sunflower grown in rotation. Soil Sci. Soc. Am. J. 45:941-945.

32. Vijayalakshmi, K., N.K. Sanghi, W.L. Pelton, and C.H. Anderson. 1975. Effect of plant populations and row spacings on sunflower agronomy. Can. J. Plant Sci. 55:491-499.

33. Warren Wilson, J. 1967. Effect of temperature on net assimilation rate. Ann. Bot. 30-753-761.

34. Willatt, S.T. and H.M. Taylor. 1978. Water uptake by soybean roots as affected by their depth and by soil water content. J. of Agric. Sci., Camb. 90:205-213.

MANUSCRIPT II

SUNFLOWER AND SOYBEAN ADAPTATION TO WESTERN OREGON II. CROP GROWTH AND DEVELOPMENT

ABSTRACT

Growth and development of sunflower (*Helianthus annus* L.) and soybean (*Glycine max* [L.] Merr.) were evaluated in 1980 and 1981 to identify environmental factors limiting successful crop introduction to western Oregon. In the growth analysis calculations, cubic polynomial exponential equations were utilized to fit the primary growth data of both crops.

Sunflower had more rapid seedling emergence than soybean which resulted in earlier canopy development and better early season water use efficiency (WUE). Sunflower also showed better tolerance to the cool June temperatures of this environment in comparison to soybean. The cool temperatures appeared to have restricted early season relative leaf growth rate (RLGR) in soybean. This may have contributed to the delay in physiological maturity of soybean cultivars of the 0 Maturity Group grown in western Oregon.

Maximum crop growth rate (CGR) in irrigated sunflower was approximately 30 g m^{-2} day^{-1}. This high CGR was reflected in high crop yield (3280 kg ha^{-1}) in the well-irrigated sunflower crop. Harvest index was only 30% in irrigated sunflower, however, which suggests a sink limitation in sunflower.

Maximum CGR was also high in irrigated soybean (30 and 20 g m^{-2} day^{-1} in 1980 and 1981, respectively). Crop yield, however, was only 2640 kg ha^{-1}. The low harvest index (30%) and high pod dry weight to seed dry weight ratio (0.85) suggests a dry matter allocation problem for soybean in this environment. It appeared that

cool night temperatures inhibited the reproductive development of soybean in this environment.

Soil water deficits limited leaf area development in both crops which resulted in approximately 50% light interception by the canopies. The low light interception by the dryland crops resulted in reduced CGR, dry matter production and evapotranspiration (ET) rates in comparison to the well-irrigated treatments.

Additional Index Words: Phenology, Evapotranspiration, Water use efficiency, Net assimilation rate, Harvest index, Dry matter partitioning, *Helianthus annus* L., *Glycine max* (L.) Merr.

SUNFLOWER AND SOYBEAN ADAPTATION TO WESTERN OREGON

INTRODUCTION

Environmental factors influencing crop adaptation to a particular region include day length, solar radiation, temperature, precipitation, and relative humidity. The successful introduction of a crop species to a new region requires a positive interaction of the crop genotype with these environmental factors. Growth analysis quantifies a crop's response to the prevalent environmental conditions, and thus identifies environmental stresses limiting successful crop adaptation (Kvet et al., 1971).

Sunflower can be classified as insensitive to photoperiod. Consequently, day length is not a factor in sunflower adaptation in northern latitudes (Robinson, 1978). Sunflower has extremely high relative growth rate (RGR) during early vegetative development (Rajan et al., 1973; Murata and Togari, 1975). Cool temperatures and low radiation levels, however, reduce RGR and net assimilation rate (NAR) during this growth stage (Blackman et al., 1955; Hodgson, 1967; Warren Wilson, 1967b; Rajan et al., 1973). NAR in sunflower exhibits a broad optimum temperature range (18-33°C) with maximum rates occurring at 28°C (Warren Wilson, 1967b). The crop utilizes light efficiently which results in NAR of greater than 28 g m^{-2} day^{-1} under high light intensity (Warren Wilson, 1967a). Sunflower NAR under field grown conditions is relatively insensitive to soil water deficits, whereas leaf area expansion and leaf area index (LAI) are severely curtailed (Rawson and Constable, 1980). NAR in sunflower is inversely related to relative humidity (Eze, 1973).

Low relative humidity, however, can induce poor water economy in sunflower (Rawson and Constable, 1980).

Soybean is a short-day plant and existing cultivars are adapted to a narrow range of latitudes due to this photoperiodic response (Hicks, 1978). RGR and NAR in soybean during early vegetative development are also sensitive to low temperature and low light intensity (Murata and Togari, 1975). The soybean canopy exhibits 95% light interception at an LAI of 3.1 to 4.5 (Shibles et al., 1975). Maximum soybean Crop Growth Rate (CGR) often ranges between 10 and 20 g m^{-2} day^{-1} (Buttery, 1969; Buttery, 1970; Koller et al., 1970; Hanway and Weber, 1971; Murata and Togari, 1975). Sivakumar and Shaw (1978), however, reported maximum CGR above 30 g m^{-2} day^{-1}. Under soil water deficits, soybean CGR, NAR, and LAI will respond to irrigation (Sivakumar and Shaw, 1978; Scott and Batchelor, 1979).

The growth and development of sunflower and soybean were evaluated throughout the 1980 and 1981 growing seasons under irrigated and dryland culture. The objective of this study was to characterize sunflower and soybean responses to environmental stresses in western Oregon. With this information, cultural practices or genetic characteristics could be identified which could facilitate sunflower and soybean adaptation to this environment.

MATERIALS AND METHODS

Field experiments were established in 1980 and 1981 at the Oregon State University Hyslop Crop Science Field Laboratory. Cultural practices, experimental design, treatment levels, soil characteristics, and weather conditions were described previously by Cox et al. (1982a). In this portion of the study, phenological events and growth analysis will be reported on 2 of the 5 treatments from the line source sprinkler designs which were established for both crops. The treatments are the optimum or well-irrigated treatments in which soil water was maintained above the 50% available level. Also, data will be presented on the dryland treatments which received no irrigation and minimal precipitation after seedling establishment. The sunflower cultivar '894' was planted in both years of this study. 'Evans' and 'S09-90' were the chosen soybean cultivars in 1980 and 1981, respectively.

Phenological Measurements

Elapsed days and Growing Degree Days (GDD) were recorded for selected phenological events in both crops. The selected phenological occurrences, concomitant sunflower growth stages (Schneiter and Miller, 1981) and soybean growth stages (Fehr and Caviness, 1977) are shown in Tables 1 and 2. A base temperature of 7.2°C was used to calculate GDD in this experiment. GDD accurately predicts sunflower phenological events (Robinson, 1971). GDD, however, is usually not a reliable index for post-flowering soybean events (Hicks, 1978).

Growth Analysis

Sampling for growth analysis commenced 30 to 40 days after crop emergence. Samples were taken at 7 to 10 day intervals throughout the season. Initially, 40 soybean and 20 sunflower plants were randomly selected from the 4 replications of each treatment. After canopy closure, sample size was reduced to 24 soybean and 12 sunflower plants per treatment. Measured parameters included leaf area, leaf dry weight, stem dry weight, head or pod dry weight, and seed dry weight. From these primary values, the derived values of CGR, NAR, and CGR of individual plant organs were calculated. Also, the apparent harvest index was calculated as the ratio of seed yield to mature plant weight.

Other Measurements

Soil water measurements were taken on the same date with a Neutron Probe. In this experiment, evapotranspiration rates (ET) were calculated by the Water Balance Equation and Potential Evapotranspiration (PET) was determined by the FAO Penman method (Cox et al., 1982). In addition, canopy light interception was evaluated on the 5 irrigation treatments in the line source sprinkler design of both crops. Measurements were taken at flowering in sunflower and during pod fill (R_6) in soybean. A LI-COR Line Quantum Sensor (LI-1915) and Solar Monitor (LI-1776) measured Photosynthetic Active Radiation (PAR) above the canopy and at ground level in the canopy. From this data, light interception was estimated.

Growth Analysis Calculations

Growth analysis methodology has received a great deal of attention recently. Kvet et al. (1971) and Hunt (1979) have listed the advantages of fitting the primary growth data to statistical equations. In contrast, Venus and Carston (1979) and Parsons and Hunt (1981) reveal the limitations of statistical curves. In this experiment, cubic polynomial exponential equations have been selected to characterize the primary growth curves of all plant parts in sunflower and soybean. The inclusion of the cubic term significantly increased the fit of the sunflower growth curves ($R^2 > 0.98$). In soybean, the parabolic exponential equation was usually adequate ($R^2 > 0.96$). The cubic term, however, was included in all soybean equations for consistency in describing the growth of individual organs as well as to facilitate comparisons with sunflower.

RESULTS

Crop Phenology

Sunflower emerged and completed its growth cycle more rapidly than did soybean (Tables 1 and 2). In both years, soil water deficits accelerated anthesis and physiological maturity in sunflower as well as post-flowering phenological events in soybean (Tables 1 and 2). In both years, the well-irrigated or optimum soybean treatments required an inordinate number of days to complete its growth cycle in comparison to other areas of production in the United States.

Dry Matter Production, ET and WUE

Sunflower and soybean exhibited sigmoidal dry matter production and ET patterns (Figure 1). During the early vegetative periods, sunflower produced more dry matter with higher ET rates and WUE than that of soybean (Fig. 1, and Tables 3 and 4). During the remainder of the season; dry matter production, ET rates, and WUE were similar between the well-irrigated sunflower and soybean treatments. In comparing sunflower and soybean dryland treatments, sunflower produced more dry matter with higher ET rates than did soybean (Fig. 1). Dryland soybean, however, had better WUE than that of dryland sunflower (Tables 3 and 4).

Growth Analysis

Leaf area developed more rapidly in sunflower. Both soybean treatments, however, had a higher maximum LAI than that of comparative sunflower treatments (Fig. 2). A maximum LAI of 5.0 was observed in the well-irrigated sunflower treatment at the initiation of seed development (Fig. 2). In the well-irrigated soybean treatment a maximum LAI of 7.0 occurred at the R_6 stage (Fig. 2). In both dryland crops, the maximum LAI was 60 to 70% lower and leaf senescence occurred 10 to 15 days earlier than that of the well-irrigated crops (Fig. 2).

Sunflower and soybean had similar NAR patterns. NAR in sunflower, however, was consistently higher than NAR in soybean on most measurement dates (Fig. 2). NAR in sunflower and soybean exhibited minimum sensitivity to ET deficits. In fact, the dryland sunflower treatments and the 1981 dryland soybean treatment had higher NAR than the comparative optimum treatments on most measurement dates (Fig. 2).

The early season CGR of sunflower exceeded the CGR of soybean in both years (Fig. 2). In the well-irrigated sunflower treatment, maximum CGR of 30 g m^{-2} day^{-1} occurred at the bud and anthesis stages (Fig. 2). In the well-irrigated soybean treatment maximum CGR of 30 and 20 g m^{-2} day^{-1} was observed during pod fill in 1980 and 1981, respectively (Fig. 2). In the dryland sunflower treatment, maximum CGR was between 12 and 20 g m^{-2} day^{-1} (Fig. 2). In contrast, maximum CGR in the dryland soybean treatment was less than 10 g m^{-2} day^{-1} (Fig. 2).

Light interception and crop yield in sunflower and soybean exhibited curvilinear relationships with LAI (Fig. 3). Full light interception in sunflower, estimated by regression analysis, occurred at an LAI of 3.0 (Fig. 4). Maximum crop yield was estimated to occur at an LAI of 4.0 (Fig. 3). In soybean, regression analysis estimated full light interception and maximum crop yield at an LAI of 4.0 and 9.0, respectively (Fig. 3).

Dry Matter Partitioning

Sunflower and soybean had different dry matter partitioning patterns. During the vegetative period, sunflower partitioned twice as much dry matter to the stem as it did to the leaf (Fig. 4). In contrast, soybean evenly allocated its dry matter between the leaf and stem (Fig. 4). During the reproductive period, maximum Head Growth Rate (HGR) in sunflower coincided with the cessation of vegetative growth, and maximum Seed Growth Rate (SGR) coincided with the cessation of head growth (Fig. 4). Soybean had more of an overlap in the Pod Growth Rate (PGR) and SGR periods (Fig. 4). In both years, the optimum sunflower and soybean treatments had maximum SGR of about 20 g m^{-2} day^{-1} (Fig. 4).

The dryland sunflower crop accentuated its dry matter partitioning to the stem (Fig. 4). As a result, the stem dry weight to leaf dry weight ratio was about 2.5 in dryland sunflower. The dryland sunflower crop also had the highest stem dry weight losses in comparison to other treatments (Fig. 4).

The rate and duration of dry matter accumulation by the seed in dryland sunflower and dryland soybean was significantly reduced by ET deficits (Fig. 4). Maximum SGR in dryland sunflower was 10 to 12 g m^{-2} day^{-1}. In dryland soybean, the maximum SGR was less than 5 g m^{-2} day^{-1}.

DISCUSSION

Cool wet spring and dry summer weather conditions characterize the growing season for summer annuals in western Oregon. The more rapid seedling emergence of sunflower enabled earlier crop development under the more favorable soil moisture conditions of the spring. As a result, sunflower had higher early season WUE than that of soybean because of better canopy development which increased transpiration rates and reduced soil evaporation losses. Consequently, sunflower utilized an environmental limiting resource more efficiently than did soybean.

The dry matter production curves and maximum CGR of the well-irrigated sunflower and soybean treatments indicate both crops can grow well under irrigated conditions in western Oregon. In both crops, the lag period in the production curves coincide with the cool June period in which temperatures averaged 14°C. The shorter lag period in the production curve and higher CGR by sunflower during this period suggests more tolerance to cool early season weather conditions by sunflower in comparison to that of soybean. Growth analysis revealed a similar LAI between crops with higher NAR in sunflower during this period. The cool cloudy weather conditions, however, probably limited the NAR in both crops. As a result, the higher NAR in sunflower was a result of its superior photosynthetic capacity in comparison to that of soybean. The similar LAI between crops, in view of the much lower sunflower plant population (50,000 vs. 240,000 plants ha^{-1}), indicated more leaf development in sunflower during this period. This was reflected in higher initial relative leaf growth rates (RLGR) in sunflower (0.13) in comparison to that of soybean (0.083). Consequently, leaf expansion in soybean appeared to be more sensitive to cool temperatures than that of sunflower. This sensitivity to cool temperatures may also explain the delay in physiological maturity of the tested soybean cultivars in this experiment in comparison to midwest conditions. Although both cultivars were adapted to the day length of this environment, physiological maturity occurred 20 to 30 days later than expected.

During the logarithmic phase of crop growth, the well-irrigated sunflower and soybean treatments had high CGR and WUE. In fact, the maximum CGR in soybean exceeded most reported values. Light and temperature factors during July and August in this environment were conducive to high photosynthetic rates and to a high NAR in both irrigated crops (Cox et al., 1982a). Also, vapor pressure deficits (VPD) averaged only 1.5 KPa at noon during July and August (Cox et al., 1982a). The low VPD as well as low soil evaporation losses resulted in high WUE for both crops. Consequently, irrigated sunflower and soybean maximized CGR and WUE in this experiment.

Soil water deficits curtailed leaf area development which resulted in approximately 50% light interception in both dryland canopies. The low canopy light interception subsequently resulted in reduced CGR, dry matter production and ET rates by the dryland crops in comparison to values of the irrigated crops. The low light interception also minimized shading within the canopy of the dryland crops. This contributed to the higher NAR in the dryland treatments compared to the NAR of the optimum treatments. Consequently, LAI and not NAR was the limiting growth characteristic for sunflower and soybean production under soil water deficits. This conclusion agrees with Rawson and Constable's findings (1980) on dryland sunflower production in Australia.

Crop yield in the well-irrigated sunflower treatments exceeded 3000 kg ha^{-1} which approaches the yield potential of sunflower (Robinson, 1978). The curvilinear relation of crop yield with LAI suggests that leaf area or source material was sufficient for high crop yield in the well-irrigated sunflower treatments. The harvest index in the well-irrigated sunflower crop, however, was only 30% (Table 1). Harvest index is often low in sunflower which has prompted English et al. (1979) to conclude that sunflower is a sink limited crop due to excessive dry matter partitioning to the stem at the expense of seed number or seed weight. The data from this experiment suggests that this is true only if environmental factors are not limiting.

LAI was the limiting growth characteristic for dryland sunflower which suggests a source limitation for the crop under soil water deficits. The accentuated stem to leaf ratio in response to water stress intensified this source limitation. Retranslocation of stem dry weight to the seed in the dryland crop could compensate for the low LAI (Fischer, 1980). The dryland sunflower crop had more stem dry weight loss than that of the well-irrigated treatment which suggests increased retranslocation of stem material or increased stem respiration losses. More retranslocation of stem material by the dryland crop should result in a higher harvest index. The similar harvest index between the dryland and optimum sunflower treatments indicates that respiration probably contributed to most of the excess loss of stem dry weight in the dryland crop. Consequently, the preferential partitioning of dry matter to the stem by sunflower in response to water stress may have contributed to the source and yield limitation that was observed in this experiment.

The well-irrigated soybean treatment had high CGR and dry matter production in this experiment. Crop yield, however, was only 2600 kg ha^{-1}. This resulted in a low harvest index (Table 4). The high CGR and low harvest index suggests a dry matter allocation problem or sink limitation for soybean in this experiment. The dry pod weight to dry seed weight ratio at physiological maturity averaged 0.85 (data not shown) in the well-irrigated soybean crop. This is relatively high compared to the 0.50 ratio of most cultivars studied by Fraser et al. (1982). The dry weight data suggest that the pod and seed may have been competing sinks for assimilates during the seed filling period. Maximum SGR, however, occurred later than maximum PGR in the well-irrigated soybean treatment (Fig. 3). Therefore, competition among reproductive organs probably did not account for the low harvest index of soybean in this experiment. The dryland soybean treatments also had a high pod dry weight to seed dry weight ratio. This suggests that immature pods in the irrigated treatment probably did not contribute substantially to the observed dry weight ratio of pod to seed. Therefore, it appears that night temperatures which were consistently below 10°C during the summer months restricted seed set and/or seed filling in soybean (Cox et al., 1982a). As a result, soybean did not realize its yield potential in this experiment due to an environmentally induced sink limitation.

Soil water deficits severely curtailed all aspects of crop growth in dryland soybean (Table 4 and Fig. 3). In addition, the harvest index was substantially lower in dryland soybean in comparison to the harvest index in the well-irrigated treatment (Table 4). The reduction in plant height restricted the number of nodes, pods, and ultimately seeds in dryland soybean. In addition, the accelerated seed filling period resulted in low 1000 seed weight in the dryland crop (Cox et al., 1982a). The combination of less seeds and seed weight resulted in the lower harvest index of the dryland crop in comparison to that of the optimum treatment.

In conclusion, sunflower tolerated the environmental stresses of western Oregon better than did soybean. The data suggest that irrigated sunflower realized its yield potential in this environment. In contrast, the soybean cultivars of the 0 Maturity Group appear poorly adapted to this region. Cool spring conditions limit early season RLGR, which may have contributed to a delay in physiological maturity. Also, cool night temperatures inhibited seed set or seed filling in soybean. Consequently, soybean cultivars that are tolerant to these conditions are necessary for successful soybean introduction to this area.

TABLE II.1. Phenological events in sunflower for the 1980 and 1981 seasons.*

		1980+		1981++	
		Dryland	Optimum	Dryland	Optimum
Emergence (VE)	Days	10	10	11	11
	GDD	61	61	69	69
Head visible (R_1)	Days	49	49	50	51
	GDD	366	366	365	381
Anthesis (R5.5)	Days	21	24	25	27
	GDD	280	311	275	304
Physiological maturity (R9)	Days	37	44	34	40
	GDD	408	514	434	518
Total	Days	117	127	120	129
	GDD	1115	1252	1143	1272

*Data averaged over 4 replications.

+Average C.V. for 1980 experiment was 6.8%.

++Average C.V. for 1981 experiment was 8.3%.

TABLE II.2. Phenological events in soybean for the 1980 and 1981 seasons.*

		1980+		1981++	
		Dryland	Optimum	Dryland	Optimum
Emergence (VE)	Days	14	14	21	21
	GDD	77	77	99	99
Flower initiation (R_1)	Days	45	45	46	46
	GDD	372	372	368	368
Pod initiation (R_3)	Days	23	24	30	30
	GDD	356	379	339	339
Full maturity (R_8)	Days	34	54	41	54
	GDD	302	466	510	624
Total	Days	116	137	138	151
	GDD	1107	1294	1316	1430

*Data averaged over 4 replications.

+Average C.V. for 1980 experiment was 10.2%.

++Average C.V. for 1981 experiment was 13.8%.

TABLE II.3. Selected sunflower characteristics for the 1980 and 1981 seasons.[+]

	1980		1981	
	Dryland	Optimum	Dryland	Optimum
Leaf number	26.5	27.0	26.0	26.0
Plant height (cm)	109	180	122	178
Harvest index*	0.30	0.29	0.31	0.30
WUE (kg ha^{-1} cm^{-1})				
Before July 10	30.5	32.0	51.6	53.9
After July 10	49.4	57.9	51.9	59.1

[+]Data averaged over 4 replications.

*Determined from seed yield of plants sampled for growth analysis.

TABLE II.4. Selected soybean characteristics for the 1980 and 1981 seasons.

	1980		1981	
	Dryland	Optimum	Dryland	Optimum
Node number	6	19	10	20
Plant height (cm)	28	90	36	97
Harvest Index*	0.22	0.29	0.23	0.29
WUE (kg ha^{-1} cm^{-1})				
Before July 10	22.6	17.4	35.2	24.1
After July 10	64.9	58.7	65.8	62.7

*Determined from seed yield of plants sampled for growth analysis.

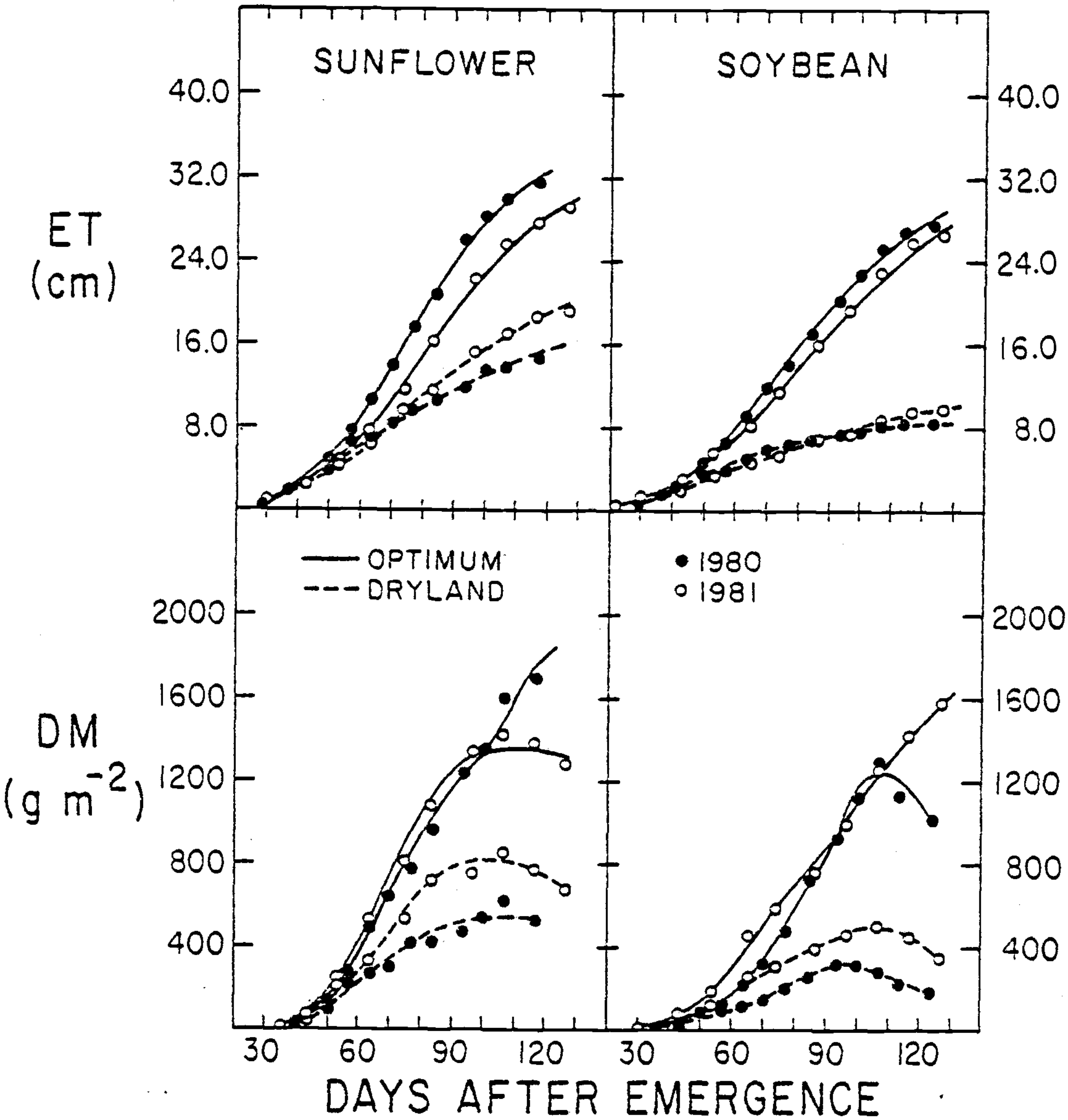

Figure II.1 Cumulative evapotranspiration (ET) and dry matter (DM) production patterns in the 1980 and 1981 well-irrigated (optimum) and dryland treatments of sunflower and soybean.

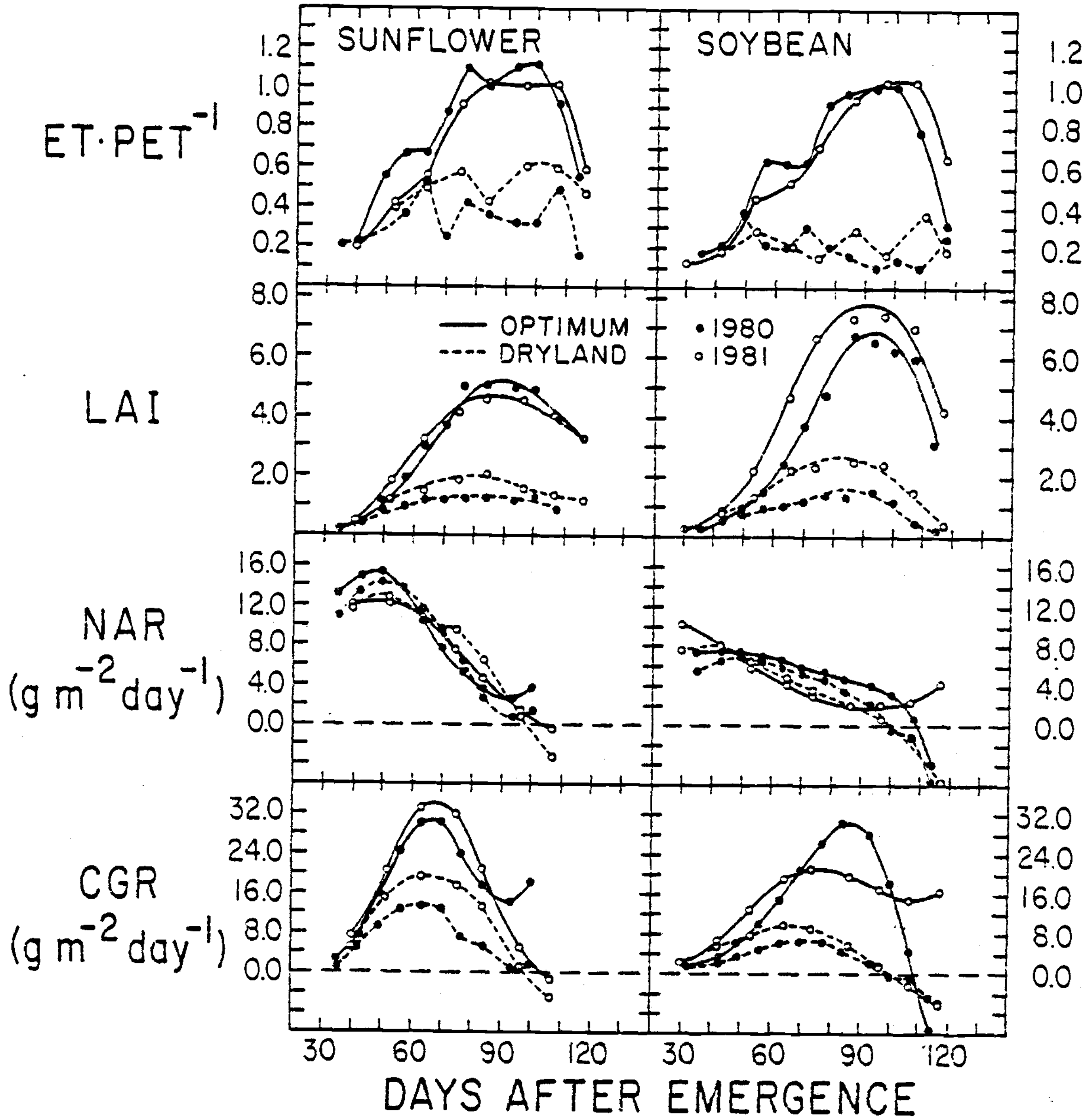

Figure II.2 Seasonal patterns in the crop evapotranspiration-potential evapotranspiration ratio ($ET \cdot PET^{-1}$), leaf area index (LAI), net assimilation rate (NAR) and crop growth rate (CGR) in the 1980 and 1981 well-irrigated (optimum) and dryland treatments of sunflower and soybean.

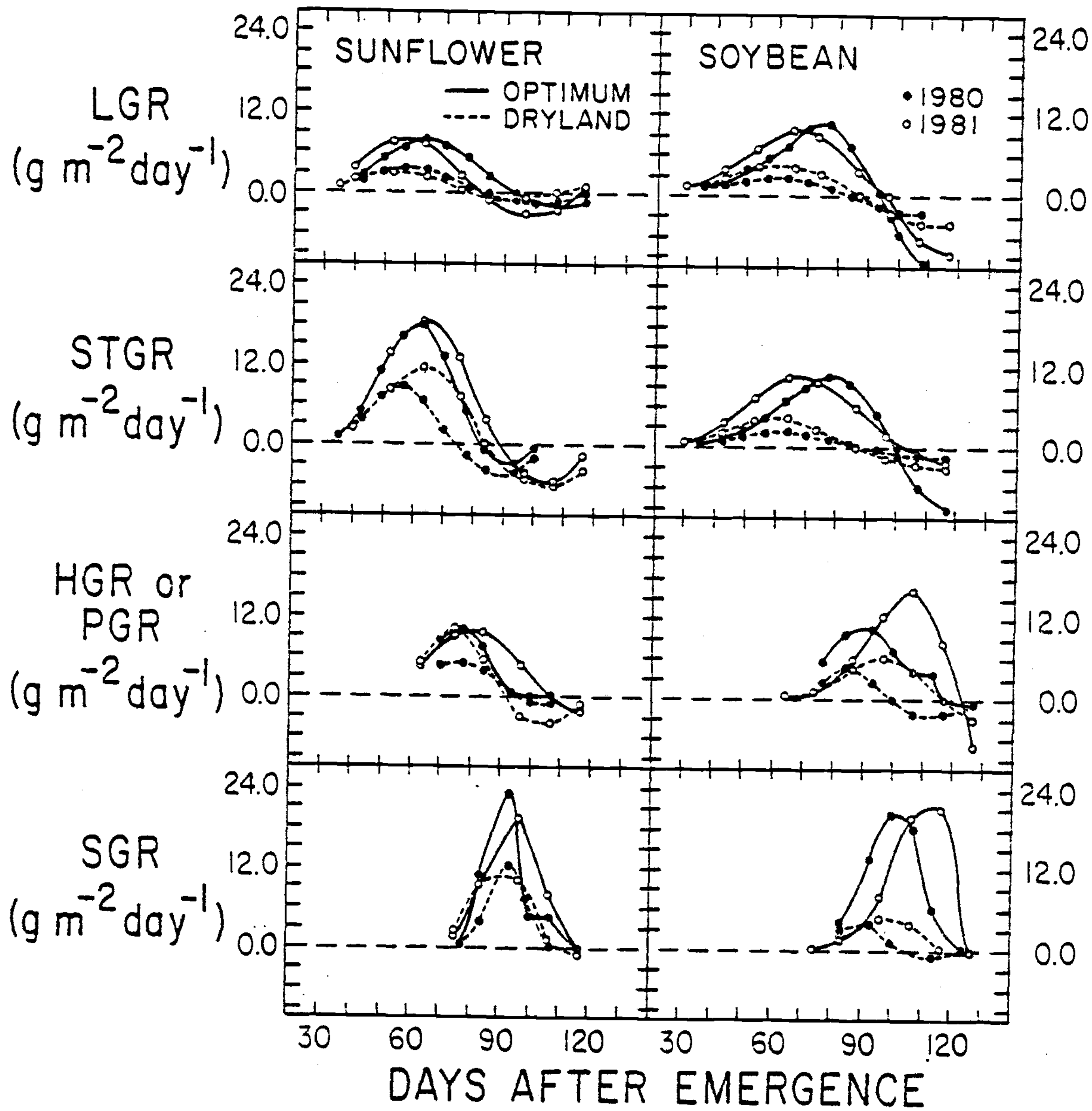

Figure II.3 Dry matter partitioning patterns in the 1980 and 1981 well-irrigated (optimum) and dryland treatments of sunflower and soybean. (LGR) leaf growth rate, (STGR) stem growth rate, (HGR) head growth rate, (PGR) pod growth rate, and (SGR) seed growth rate.

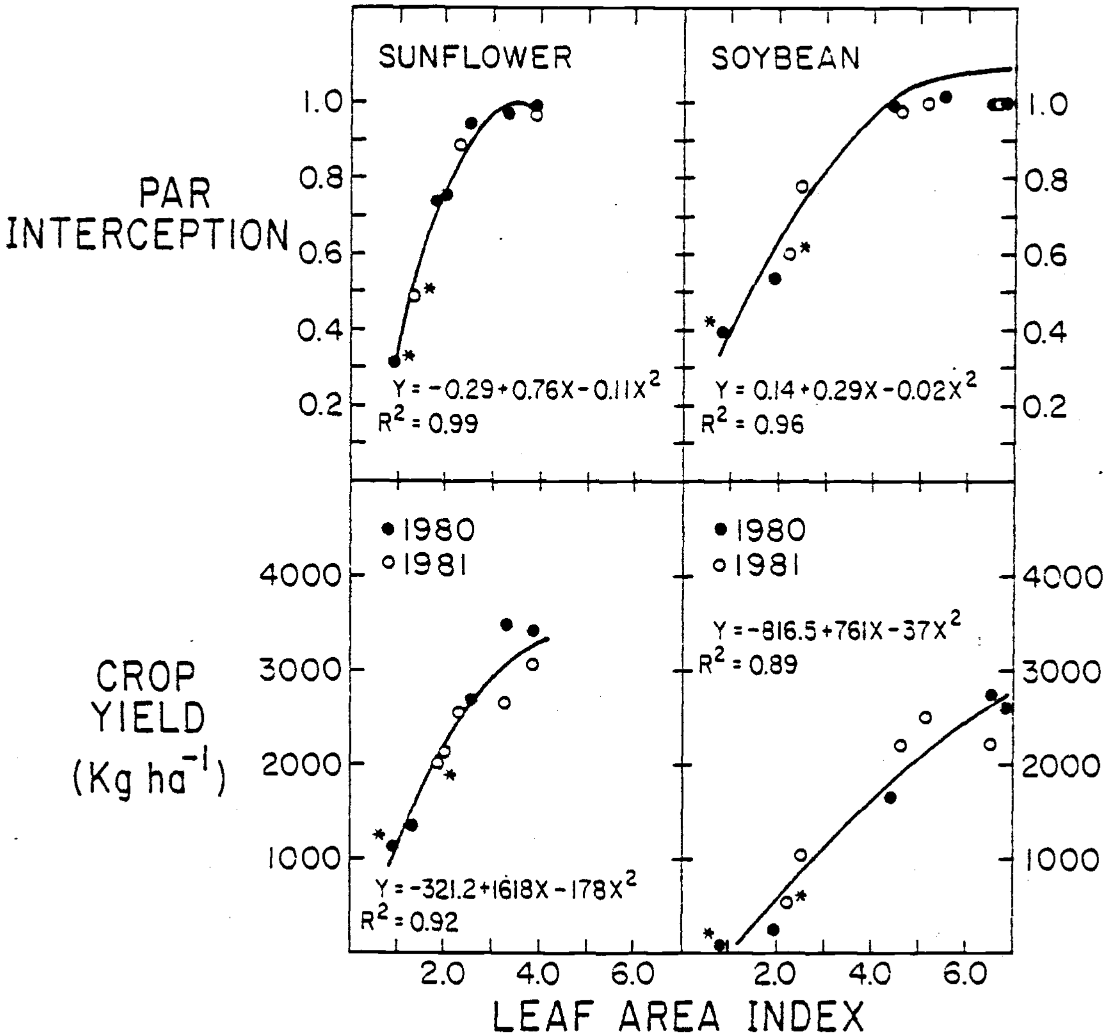

Figure II.4 Canopy light interception and crop yield as a function of leaf area index in 1980 and 1981 sunflower and soybean. Values are the means of 4 replications recorded in 5 sunflower treatments at flowering and 5 soybean treatments at the R_6 stage. (*) indicates the dryland treatments.

LITERATURE CITED

1. Blackman, G. E., J. N. Black, and A. W. Kemp. 1955. Physiological and ecological studies in the analysis of plant environment. X. An analysis of the effects of seasonal variation in daylength and temperature on the growth of Helianthus annus L. in the vegetative phase. Ann. Bot. N. S. 19, 527-548.

2. Buttery, B. R. 1969. Analysis of the growth of soybeans as affected by plant population and fertilizer. Can. J. Plant Sci. 49: 675-684.

3. Buttery, B R. 1970. Effects of variation in leaf area index on growth of maize and soybeans. Crop Sci. 10:9-13.

4. Cox, W. J., G. D. Jolliff, and R. H. Cuenca. 1982. Sunflower and soybean adaptation to western Oregon. I. Crop yield. (manuscript in preparation).

5. Cox, W. J. and G. D. Jolliff. 1982. Sunflower and soybean adaptation to western Oregon. III. Crop-water relations. (manuscript in preparation).

6. English, S. D., J. R. McWilliam, R. C. G. Smith, and J. L. Davidson. 1979. Photosynthesis and partitioning of dry matter in sunflower. Aust. J. Plant Physiol. 6:149-164.

7. Eze, J. M. O. 1973. The vegetative growth of Helianthus annus and Phaseolus vulgaris as affected by seasonal factors in Freeton, Sierra Leone. Ann. Bot. 37: 315-329.

8. Fehr, W. R. and C. E. Caviness. 1977. Stages of soybean development. Spec. Rep. #80. Coop. Ext. Ser., Agric. and Home Econ. Exp. Stn., Iowa State Univ., Ames.

9. Fischer, R. A. 1980. Influence of water stress on crop yield in semiarid regions. In: N. C. turner and P. J. Kramer (eds.). Adaptation of plants to water and high temperature stress. p. 323-340. Wiley Interscience, New York.

10. Fraser, Joanna, D. B. Egli, and J. E. Leggett. 1982. Pod and seed development in soybean cultivars with differences in seed size. Agron. J. 74: 81-85.

11. Hanway, J. J. and Weber, C. R. 1971. Dry matter accumulation in eight soybean [(Glycine max (L.) Merr] varieties. Agron. J. 63, 227-230.

12. Hicks, D. R. 1978. Growth and development. In: A. Geoffrey Norman (ed). Soybean physiology, agronomy and utilization. p. 17-44. Academic Press, Inc. New York.

13. Hodgson, G. S. 1967. Physiological and ecological studies in the analysis of plant environment. XIII. A comparison of the effects of seasonal variation in light energy and temperature on the growth of Helianthus annus and Vicia faba in the vegetative phase. Ann. Bot. N. S. 31: 291-308.

14. Hunt, R. 1979. Plant growth analysis: the rationale behind the use of the fitted mathematical function. Ann. Bot. 43: 245-249.

15. Koller, H. R., W. E. Nyquist, and I. S. Chorush. 1970. Growth analysis of the soybean community. Crop Sci. 10: 407-412.

16. Kvet, J., J. P. Ondok, J. Necas, and P. G. Jarvis. 1971. Methods of growth analysis. In: Z. Sestak, J. Catsky and P. G. Jarvis (eds.). Plant Photosynthetic Production. p. 343-391.

Dr. W. Junk, N. V., The Hauge.

17. Murata, Y. and Y. Togari. 1975. Summary of data. In: Y. Murata (ed). Crop productivity and solar energy utilization in various climates in Japan. p. 9-19. JIBP Synthesis II. Univ. of Tokyo Press.

18. Parsons, I. T. and R. Hunt. 1981. Plant growth analysis. A program for the fitting for the lengthy series of data by the method of B-splines. Ann. Bot. 45:541-552.

19. Rajan, A. K., B. Betteridge, and G. E. Blackman. 1973. Difference in the interacting effects of light and temperature on growth of four species in the vegetative stage. Ann. Bot. 37:287-313.

20. Rawson, H. M. and G. A. Constable. 1980. Carbon production of sunflower cultivars in field and controlled environments. II. Leaf growth. Aust. J. Plant Physiol. 7:575-586.

21. Robinson, R. G. 1971. Sunflower phenology--year, variety, and date of planting effects on day and growing degree day summations. Crop Sci. 11:635-638.

22. Robinson, R. G. 1978. Production and culture. In: J. F. Carter (ed). Sunflower Science and Technology. Agronomy 19:89-143. Am. Soc. of Agron., Madison, WI.

23. Schneiter, A. A. and J. F. Miller. 1981. Description of sunflower growth stages. Crop Sci. 21:901-904.

24. Scott, H. D. and J. T. Batchelor. 1979. Dry weight and leaf area production rates of irrigated determinate soybeans. Agron. J. 776-782.

25. Shibles, R. M., I. C. Anderson, A. H. Gibson. 1975. Soybean. In: L. T. Evans (ed). Crop physiology: some case histories. p. 151-189. Cambridge Univ. Press.

26. Sivakumar, M. V. K., and R. H. Shaw. 1978. Methods of growth analysis in field-grown soya beans (*Glycine max* [L.] Merrill). Ann. Bot. 42:213-222.

27. Venus, J. C. and D. R. Carston. 1979. Plant growth analysis: the use of the Richards function as an alternative to polynomial exponentials. Ann. Bot. 43:623-632.

28. Warren Wilson, J. 1967a. High net assimilation rates of sunflower plants in an arid climate. Ann. Bot. 30:745-751.

29. Warren Wilson, J. 1967b. Effect of temperature on net assimilation rate. Ann. Bot. 30:753-761.

MANUSCRIPT III

SUNFLOWER AND SOYBEAN ADAPTATION TO WESTERN OREGON III. CROP-WATER RELATIONS

ABSTRACT

Infrequent summer precipitation in western Oregon results in soil water deficits which limit the growth and yield of dryland sunflower (Helianthus annus L.) and soybean (Glycine max L. [Merr.]). In order to characterize the crop-water relations of both crops under soil water deficits and irrigated conditions, diurnal measurements of leaf water potential (leaf Ψ), osmotic potential (π) stomatal resistance (r_s), leaf temperature (leaf T°), carbon exchange rate (CER), and leaf expansion were taken on selected dates in 1980 and 1981.

The crop water status of the well-irrigated sunflower and soybean crops were similar on all measurement dates. The minimum leaf Ψ in both irrigated crops was -1.0 MPa which suggested minimum water stress. Leaf expansion, however, was limited to the nighttime hours in sunflower. In contrast, substantial leaf expansion in irrigated soybean occurred in the morning and evening hours as well as during the night. On days of high evaporative demand, r_s in both irrigated crops remained below 1.0 s cm^{-1}. CER on these days, however, were reduced by 20% in both irrigated crops.

In 1981, the dryland sunflower and soybean crops had similar leaf Ψ patterns with minimum values of -1.35 MPa. The responses of the π and pressure potential (P) components differed. The dryland sunflower crop decreased its dawn π by 0.25 MPa and daily π by 0.50 MPa. The decreases in π suggested osmotic adjustment which apparently contributed to the partial maintenance of P and CER in dryland sunflower.

Limited osmotic adjustment was observed in the dryland soybean crop. This may have contributed to the loss of P and CER under high evaporative demand. Increased r_s and leaf T° accompanied the loss of turgor. As a result, there was a 6° to 7° leaf T° differential between dryland crops at a leaf Ψ of -1.35 MPa.

Additional Index Words: Leaf water potential, Osmotic potential, Stomatal resistance, Leaf temperature, Carbon exchange rate, Leaf expansion, Osmotic adjustment, *Helianthus annus* L., *Glycine max* (L.) Merr.

SUNFLOWER AND SOYBEAN ADAPTATION TO WESTERN OREGON

INTRODUCTION

Infrequent summer precipitation in western Oregon results in soil water deficits. The growth and yield of dryland sunflower (Helianthus annus L.) and soybean (Glycine max L. [Merr.]) are restricted under these conditions (Cox et al., 1982). Crop growth, however, is controlled directly by crop water deficits and only indirectly by soil water deficits (Begg and Turner, 1976). In order to characterize a crop's response to soil water deficits, direct measurements of crop water status are useful.

Leaf water potential (leaf Ψ) is a common indicator of crop water status (Turner, 1981). There is no proof, however, that leaf Ψ has a direct effect on physiological processes (Turner, 1981). Furthermore, it is increasingly evident that the pressure (P) and osmotic (π) components of leaf Ψ are physiologically active (Hsaio et al.,1976; Turner, 1981). The P influences physiological, biochemical, and morphological processes (Turner, 1979). Some crops actively accumulate solutes in response to water stress which decreases the π of the tissue and allows for the partial or full maintenance of P under low leaf Ψ (Turner and Jones, 1980). This process is termed osmotic adjustment, and has been implicated as a crop mechanism for drought tolerance. Consequently, the measurement of leaf Ψ and its component potentials is necessary to adequately assess crop water status.

Leaf expansion in sunflower is extremely sensitive to water deficits (Boyer, 1968; Boyer, 1970a; and Rawson and Constable, 1980b). Boyer (1970a) reported a supression of sunflower leaf growth at a leaf Ψ of -0.4 MPa. From this data, he concluded that daytime leaf expansion in sunflower is inhibited by daily crop water deficits. Photosynthesis in sunflower is less sensitive to water deficits (Boyer, 1970a; Rawson and Constable, 1980a). Boyer (1970a) reported a decrease in sunflower photosynthesis at a leaf Ψ of -0.8 MPa; whereas, Rawson (1979; 1980a) noted a decline in sunflower photosynthesis at a leaf Ψ of -1.0 MPa. There does not appear to be a unique relationship between leaf Ψ and stomatal closure in sunflower. In fact, stomatal closure in sunflower has been reported to occur between -1.0 and -2.7 MPa of leaf Ψ (Turner et al., 1978; Rawson, 1979). Consequently, sunflower photosynthesis appears to be inhibited by non-stomatal responses at low leaf Ψ (Boyer, 1971). Osmotic adjustment has been documented in sunflower (Turner et al., 1978; Jones and Turner, 1980). This may account for the large range in leaf Ψ in which stomatal closure occurs.

Soybean leaf expansion is not as sensitive as that of sunflower to water deficits (Boyer, 1970a). Boyer (1970a) and Bunce (1977) reported a minimum threshold P of 0.1 MPa for soybean leaf expansion. Wenkert et al. (1978a) also noted that soybean leaf expansion was not affected by midday P depression. Soybean photosynthesis does not appear to be as sensitive as sunflower photosynthesis to low leaf Ψ (Boyer, 1970a). In contrast to sunflower, stomatal closure in soybean occurs at critical threshold values of -1.2 to -1.5 MPa of leaf Ψ (Boyer, 1970b; Turner et al., 1978). As a result, CER in soybean is controlled mostly by stomatal effects at low leaf Ψ (Boyer, 1970b; Turner et al., 1978). There are conflicting reports concerning osmotic adjustment in soybean. Turner et al. (1978) reported minimum soybean osmotic adjustment, whereas Wenkert et al. (1978b) presented evidence for soybean osmotic adjustment.

In this study, the crop-water relations of sunflower and soybean were evaluated under irrigated and dryland culture. The primary objective was to characterize the crop water status of both crops in an environment in which potential evapotranspiration (PET) averages only 4.5 mm day^{-1}. An additional objective was to determine if osmotic adjustment occurred in the dryland sunflower and soybean crops.

MATERIALS AND METHODS

Field experiments were established in 1980 and 1981 at the Oregon State University Hyslop Crop Science Field Laboratory. Cultural practices, experimental design, treatment levels, soil characteristics, and weather conditions were described previously by Cox et al. (1982). In this paper, detailed crop water measurements will be presented on 2 of the 5 irrigation treatments from the line source sprinkler designs which were established for both crops. The treatments include the optimum or well-irrigated treatments in which soil water was maintained above the 50% available level. Also, data will be presented on the dryland treatments which received no irrigation and minimal precipitation after stand establishment.

Measurements commenced in early July of both years which corresponded to the vegetative stage in sunflower and flower initiation or the R_1 stage (Fehr and Caviness, 1977) in soybean. Measurements were conducted at 1 week intervals in 1980 and approximate 10-day intervals in 1981 for a total of 7 and 5 measurement dates, respectively. Measurements were initiated at dawn on each date and repeated at 2.5-hour intervals throughout the day for a total of 6 daily measurements. Concurrent measurements of r_s, leaf T°, CER, leaf Ψ and π were made on the most recently expanded sunflower leaf and the center leaflet of the second most recently expanded soybean trifoliolate. Measurements were replicated on 4 similar leaves from separate plants in the sampling area. In addition, leaf expansion was measured on the most rapidly expanding leaves of 4 other randomly chosen plants in each treatment. On the following dawn, leaves were harvested from the dryland treatments for the determination of pressure-volume (p-v) curves.

Measurements

Leaf T° and r_s were measured first on the designated leaf with a LI-COR steady state porometer (LI-1600). Measurements were taken on the adaxial and abaxial sides of the leaf. Parallel resistance was assumed in both crops for the calculation of r_s (Nobel, 1974).

After r_s and leaf T° data were recorded, single leaf CER were then determined by the portable chamber and syringe technique of Clegg et al. (1978). In this method, a plexiglass air-tight chamber is flushed with ambient air before the individual leaf is positioned in the chamber. Gas is then immediately sampled in the chamber by a syringe. In this experiment, a subsequent gas sample was withdrawn from the chamber 10 and 30 s later in sunflower and soybean, respectively. After the completion of gas sampling on all replications, the syringes were brought into the lab for injection into an Infrared Gas Analyzer (Beckman 865). The difference in CO_2 between the 2 samples measured CER. Calculations of CER by this method, however, require leaf area measurements. Therefore, after leaf Ψ measurements, leaf area was determined for each individual leaf with a LI-COR leaf area meter (LI-3100).

Leaf Ψ was then estimated immediately after gas sampling by enclosing the leaf in a plastic bag, excising the petiole, and placing the leaf in a pressure chamber (Soil Moisture Equip. Corp.). After the leaf Ψ and leaf area were determined, the leaves were frozen on dry ice and transferred to a freezer until subsequent π measurements.

Before determining the π, samples were allowed to thaw for 1 hour. A small aliquot of expressed sap was absorbed on to a filter paper disc in a Wescor C-52 sample holder coupled to an HR-33T microvoltmeter operating in the dew point mode. Techniques described by Turner (1981) were followed to minimize potential errors. The π determined by the dew point hygrometer, however, does not represent the actual π of the cell due to apoplastic dilution in the thawing process (Tyree, 1976). Data from P-V curves can be used to estimate apoplastic dilution (Turner, 1981). The data from the P-V curves in this experiment did not give consistent values for apoplastic water content. Consequently, apoplastic dilution was not corrected for, and P was determined by difference from the pressure chamber and hygrometer reading.

Leaf expansion was measured with a ruler to the closest millimeter on the most rapidly expanding sunflower leaf and soybean trifoliolate. In order to assess differences between daytime and nighttime leaf expansion, initial leaf length was determined at 9:00 p.m. on the evening prior to the diurnal measurements dates.

On the following day, randomly chosen leaves in the dryland treatments were excised at dawn. The leaves were placed in water and allowed to rehydrate for 2 to 3 hours in a cool, low light environment. Simultaneous P-V curves were then determined for sunflower and soybean in separate pressure chambers. The "Hammell" method as described by Tyree et al. (1978) was utilized in this experiment.

Water use efficiency (WUE), based on vapor exchange rates, was estimated from the transpiration rates obtained with the porometer and CER determined by the syringe technique. WUE may be a conservative estimate in this experiment because of the smaller boundary layer in the porometer curvette in comparison to the boundary layer in the portable chamber (John Norman, personal communication). In order to facilitate comparisons of WUE between species, treatments, and dates, the WUE index (w) of Rawson and Begg (1977) was adopted. The index (w) describes the relationship of WUE with the leaf to air vapor pressure deficit (VPD). It is, thus, defined as the net mass of CO_2 per unit mass of H_2O transpired expressed per KPa of VPD (Rawson and Begg, 1977).

Weather Parameters

The diurnal measurement dates of 1981, which are presented in this paper, are July 16, July 27 and August 7. These dates occurred 25, 35 and 45 days, respectively, after the last significant precipitation. On all measurement dates, incident Photosynthetic Active Radiation (PAR) was monitored with a Line Quantum Sensor (LI-1915) and Solar Monitor (LI-1776). Ambient T° and relative humidity were recorded on hygrothermographs close to the plot area (Fig. 1). In determining the VPD of Fig. 1, a saturated surface at ambient T° was assumed.

RESULTS

1980

The minimum leaf Ψ and P in the well-irrigated or optimum sunflower and soybean treatments were -1.0 MPa and 0.4 MPa, respectively (Tables 1 and 2). Both values suggest minimum water stress in the well-irrigated treatments. In contrast, both dryland treatments were under water stress as indicated by the minimum leaf Ψ of -1.5 and -2.0 MPa in sunflower and soybean, respectively (Tables 1 and 2). The dawn leaf Ψ in dryland soybean on July 29 was -0.53 MPa in comparison to -0.26 MPa in dryland sunflower (Tables 1 and 2). This indicates that water stress occurred earlier and was more accentuated in dryland soybean. The more severe water stress in dryland soybean was reflected in a loss of P on all measurement dates after July 15 (Table 2). Overall, trends in the 2 treatments of both crops were similar across years, and the remainder of this paper will focus on the 1981 data.

1981

Optimum Treatments

The crop water status of the well-irrigated sunflower and soybean treatments was similar on all measurement dates (Fig. 2 and 3). Both treatments remained relatively stress free as indicated by their minimum leaf Ψ of -1.05 MPa (Fig. 2 and 3). Stomatal closure in both crops occurs at a leaf Ψ of less than -1.0 MPa; thus, r_s in both treatments was consistently below 1.0 s cm^{-1} (Fig. 2 and 3). Although r_s was low, afternoon CER in both irrigated treatments were significantly reduced from their morning values on July 27 and

August 7 (Fig. 2 and 3). The lower CER in conjunction with a similar r_s resulted in lower WUE on July 27 and August 7 in comparison to July 16 for both irrigated treatments (Table 3).

Most leaf expansion in the well-irrigated sunflower crop occurred during the nighttime hours (Fig. 2). In fact, leaf expansion virtually ceased in sunflower between 6:00 a.m. and 6:00 p.m. (Fig. 2). In contrast, substantial leaf expansion was observed in soybean during the morning and evening hours (Fig. 3).

Dryland Treatments

Leaf Ψ patterns were similar in the dryland crops and the minimum leaf Ψ in both crops was -1.35 MPa (Fig. 2 and 3). The responses of the component potentials, however, differed between dryland crops. The dawn π. of the dryland sunflower crop decreased by 0.25 MPa from July 15 to August 7 (Fig. 2). Also, the extrapolated π at full turgor (πo), as determined by the P-V curves, decreased by 0.2 MPa in this same time period (Table 4). In addition, the π in dryland sunflower decreased 0.4 to 0.5 MPa during the day on July 27 and August 7 (Fig. 2). Overall, the minimum P in dryland sunflower remained close to 0.2 MPa on all measurement dates (Fig. 2).

The P in the dryland sunflower crop was consistently lower than the P of the well-irrigated sunflower crop (Fig. 2). The lower P in the dryland crop was accompanied by a slight increase in r_s and leaf T° in comparison to the values of the well-irrigated sunflower crop (Fig. 2). CER, leaf expansion, and WUE were significantly lower in the dryland crop in comparison to values of the well-irrigated sunflower crop (Fig. 2 and Table 3).

The dawn π of the dryland soybean crop decreased by less than 0.1 MPa during this same period (Table 4). On a daily basis, the decrease in π by the dryland soybean crop was less than 0.25 MPa on all measurement dates (Fig. 3). In addition, the dryland soybean crop sustained a loss of P on July 27 and August 7 (Fig. 2 and 3). Substantial increases in r_s and decreases in CER accompanied the loss of P in dryland soybean (Fig. 3). A concomitant increase in leaf T° was observed with the increase in r_s (Fig. 3). As a result, the dryland soybean leaf T° was 3 to 4°C above ambient T° and 6 to 7°C above the leaf T° of dryland sunflower (Fig. 1, 2, and 3). Therefore, the leaf Ψ was similar in the dryland crops, but the other physiological parameters were significantly different.

The P in both dryland crops exhibited significant linear relationships with leaf Ψ on all measurement dates (Table 5). Averaged across the 3 dates, sunflower sustained a 0.55 MPa decrease in P with each megapascal decrease in leaf Ψ (Table 5). In contrast, dryland soybean exhibited a significantly greater decrease in P with a decrease in leaf Ψ (Table 5). An extrapolation of the regression equations to a value of zero P (Po) indicates the leaf Ψ at which the dryland crops would sustain a loss of P. Averaged across the 3 dates, the regression indicates a loss of P in dryland sunflower at a -1.65 MPa leaf Ψ in comparison to a -1.43 MPa leaf Ψ in dryland soybean (Table 5).

DISCUSSION

Potential evapotranspiration (PET), as computed by the FAO Penman method, was 4.7 mm day^{-1} on the July 16 measurement date. The mild evaporative demand of this date, as well as most days in this environment, resulted in minimum water stress in the well-irrigated sunflower crop. This was reflected in a minimum leaf Ψ of less than -0.9 MPa and very low r_s. Minimum water stress as well as favorable light and temperature factors induced high sunflower CER on the July 16 measurement date. These values agree with the Australian studies (English et al., 1979; Rawson and Constable, 1980), and approach the photosynthetic capacity of existing sunflower cultivars (Lloyd and Canvin, 1977). Sunflower WUE is inversely related to VPD. Consequently, the moderate VPD on July 16, as well as on most summer days in this environment, resulted in high sunflower WUE. The WUE-VPD relationship in sunflower on July 16 is consistent with Rawson's data (Rawson, 1979; Rawson and Constable, 1980).

Although the irrigated sunflower crop was under minimum water stress on July 16, the daily crop water deficit inhibited daytime leaf expansion. The data from this experiment corroborate Boyer's hypothesis (1970a) that sunflower leaf expansion occurs during the night under minimum crop water deficits. Cool night temperatures, however, also limit leaf expansion (Acevedo et al., 1979; Culter et al., 1980). The minimum night temperature on July 16 was 9°C which is the average minimum night temperature for this environment in July and August. Apparently, the cool night temperatures of this environment did not significantly inhibit sunflower leaf expansion. As a result, the leaf area index (LAI) was 5.0 in the well-irrigated sunflower crop (Cox and Jolliff, 1982).

The PET, as computed by the FAO Penman method, was 6.5 and 5.7 mm day^{-1} on July 27 and August 7, respectively. The P in the well-irrigated sunflower crop remained above 0.4 MPa which suggested minimum water stress. Nonetheless, afternoon CER were substantially reduced from the morning values. The r_s increased slightly on these days, but was not significantly correlated with CER ($r = -0.34$). Apparently, an increased mesophyll resistance (r_m) contributed to reduced CER. Increased temperatures can increase r_m and limit sunflower photosynthetic rates (Boyer, 1971). The ambient T° on these dates, however, remained within the broad optimum temperature range defined by English et al. (1979). Lawlor and Fock (1977) reported an association between the products of photorespiration in sunflower with decreases in leaf Ψ. Watson and Wardlaw (1981) suggested that the decrease in ^{14}C translocation in water stressed sunflower leaves may be due to this change in photosynthesis metabolism. Increased photorespiration could explain the lower CER as well as the concomitant decrease in π of the well-irrigated sunflower treatment on July 27 and August 7. However, more detailed studies would be necessary to validate this statement.

WUE, by definition, is a sensitive indicator of the relationship between r_s and r_m (Rawson and Woodward, 1976). In the well-irrigated sunflower treatment, r_s remained unchanged; whereas, r_m increased on July 27 and August 7. Consequently, WUE in the well-irrigated sunflower crop was lower on July 27 and August 7 in comparison to July 16. This data is consistent with Rawson and Constable's (1980) hypothesis that sunflower WUE is poor under high VPD.

Low soil water content and high VPD were conducive to plant water stress in the dryland treatment on the latter 2 measurement dates. Leaf Ψ in the dryland sunflower crop decreased to only -1.35 MPa on both dates. Apparently, adequate soil water extraction (Cox et al., 1982) and a low LAI (Cox and Jolliff, 1982b) resulted in relatively mild crop water stress in the dryland sunflower crop. The lower leaf Ψ incurred by the dryland crop in comparison to the well-irrigated sunflower crop implies a longer recovery period to regain full turgor (Boyer, 1968). Consequently, there is a shorter night period during which crop water status (and perhaps night temperature) is conducive to leaf growth. The shorter favorable period for growth resulted in less nighttime leaf expansion in the dryland crop in comparison to that of the well-irrigated sunflower crop.

The seasonal decreases in the dawn π and π_0 in dryland sunflower suggest an accumulation of cell solutes during the season. In addition, the daily decrease in π and the observed leaf Ψ-P relationship of dryland sunflower suggest a daily accumulation of cell solutes. Increased cell elasticity, or the reduction in cell volume, or cell water content can also decrease the π of a cell. Turner et al. (1978) and Jones et al. (1980) provided evidence that changes in the π of water stressed sunflower leaves were due to an active accumulation of solutes or osmotic adjustment. Likewise, the decreases in the π of sunflower observed in this experiment has been interpreted as osmotic adjustment and not physical changes in cell characteristics.

Osmotic adjustment in dryland sunflower allowed for the partial maintenance of P and the corresponding low r_s on July 27 and August 7. The CER were maintained above 0.75 mg m^{-2} s^{-1} on both dates; however, these values were 20% lower than the CER of the well-irrigated sunflower treatment. The r_s in dryland sunflower was only slightly higher than r_s of the well-irrigated sunflower crop. Consequently, r_m must have increased more in dryland sunflower than in the well-irrigated treatment on both dates. Photorespiration increases r_m which could explain the decreases in CER and π of the dryland crop. The higher r_m in the dryland sunflower crop also resulted in its lower WUE than the well-irrigated sunflower treatment on the latter 2 dates.

Environmental factors on the July 16 measurement date were also conducive to minimum water stress and high CER in the well-irrigated soybean crop. Leaf expansion in the well-irrigated soybean crop was less sensitive to daily water deficits than that of sunflower. Leaf expansion in soybean, however, ceased during the afternoon hours, which contrasted with the data of Bunce (1977) and Wenkert et al. (1978a). The rapid soybean leaf expansion during the evening hours is analogous to the compensatory or "stored" soybean growth described by Wenkert et al. (1978a). In that experiment, a similar rapid leaf elongation was observed in soybean following a period of transient turgor deficit. Substantial leaf growth during the night was also noted in the irrigated soybean treatment in this experiment. Apparently, the cool nights in July and August did not inhibit soybean leaf expansion as indicated by the LAI of 7.0 in the well-irrigated soybean treatment (Cox and Jolliff, 1982).

CER in the well-irrigated soybean crop was lower on July 27 and August 7 in comparison to the July 16 measurement date. CER and r_s were poorly correlated ($r = -0.25$), which suggests an increase in r_m. Maximum ambient T° on both dates was 38°C (Fig. 1). Photorespiration increases in soybean at 35°C (Laing et al., 1974). Consequently, photorespiration probably accounted for the decrease in CER on both dates. As in sunflower, the increase in r_m contributed to lower WUE in the well-irrigated crop on July 27 and August 7 in comparison to the July 16 measurement date.

Crop water measurements indicated less osmotic adjustment in dryland soybean in comparison to dryland sunflower. The limited osmotic adjustment contributed to a loss of P and CER on July 27 and August 7. CER and r_s were significantly correlated in dryland soybean ($r = -0.75$), which suggests that the decline in CER at low P was due to stomatal closure. Stomatal closure in dryland soybean also reduced transpiration rates. This resulted in leaf T° 3° to 4°C above ambient T° during periods of high evaporative demand. The large leaf T° differential at a similar leaf Ψ between the dryland sunflower and dryland soybean crops indicates that a leaf Ψ measurement alone is inadequate to describe crop water stress.

In conclusion, osmotic adjustment was observed in dryland sunflower on most measurement dates in this experiment. Osmotic adjustment allowed for partial maintenance of P and associated physiological parameters. In addition, the maintenance of CER in dryland sunflower may have provided sufficient photosynthates for good root development and soil water extraction (Cox et al., 1982).

In contrast, dryland soybean exhibited limited osmotic adjustment. The crop sustained a loss of P and CER under periods of high evaporative demand. The lack of osmotic adjustment may have contributed to the poor soil water extraction of dryland soybean in this experiment (Cox et al., 1982).

TABLE III.1. Dawn and afternoon values of sunflower characteristics on 4 dates during the 1980 season.[+]

	Leaf Ψ (MPa)	π (MPa)	P (MPa)	r_s (s cm^{-1})	CER (mg m^{-2} s^{-1})
DRYLAND					
7/15 a.m.	-0.14	-0.94	0.80	0.83	*
p.m.	-1.22	-1.41	0.19	0.53	*
7/29 a.m.	-0.26	-1.17	0.91	1.13	*
p.m.	-1.40	-1.55	0.15	1.20	*
8/11 a.m.	-0.40	-1.20	0.80	0.91	1.20
p.m.	-1.51	-1.58	0.11	1.57	0.52
8/26 a.m.	-0.53	-1.28	0.62	0.75	0.84
p.m.	-1.54	-1.69	0.15	1.13	0.54
OPTIMUM					
7/15 a.m.	-0.13	-1.02	0.89	0.68	*
p.m.	-0.89	-1.39	0.50	0.56	*
7/29 a.m.	-0.13	-1.08	0.94	0.56	*
p.m.	-1.08	-1.45	0.37	0.88	*
8/11 a.m.	-0.12	-1.06	0.94	0.39	1.51
p.m.	-0.93	-1.42	0.49	0.61	1.53
8/26 a.m.	-0.19	-1.10	0.91	0.82	1.13
p.m.	-0.91	-1.41	0.50	1.03	1.48

[+]Data is average of 4 replications.

*No measurements taken on this date.

TABLE III.2. Dawn and afternoon values of soybean characteristics on 4 dates during the 1980 season.+

	Leaf Ψ(MPa)	π(Mpa)	P(MPa)	r_s(s cm^{-1})	CER(mg m^{-2} s^{-1})
			DRYLAND		
7/15 a.m.	-0.18	-1.19	1.01	0.60	*
p.m.	-1.20	-1.44	0.24	1.04	*
7/29 a.m.	-0.53	-1.43	0.90	1.28	*
p.m.	-1.64	-1.65	-0.01	4.25	*
8/11 a.m.	-0.73	-1.50	0.76	0.90	0.53
p.m.	-1.63	-1.63	0.00	4.13	0.13
8/26 a.m.	-0.74	-1.45	1.71	2.16	0.18
p.m.	-2.02	-1.99	-0.03	9.18	0.07
			OPTIMUM		
7/15 a.m.	-0.08	-1.05	0.97	0.35	*
p.m.	-0.91	-1.31	0.40	0.67	*
7/29 a.m.	-0.17	-1.15	0.98	0.50	*
p.m.	-1.04	-1.51	0.47	1.19	*
8/11 a.m.	-0.10	-1.19	1.09	0.51	0.86
p.m.	-0.94	-1.34	0.40	0.92	0.98
8/26 a.m.	-0.13	-1.15	1.02	0.45	0.87
p.m.	-0.35	-1.43	0.48	1.63	0.96

+Data is average of 4 replications.

*No measurements taken on this date.

TABLE III.3. Regression equations of P-V curves illustrating the relationship of the inverse of applied pressure (I/P) and volume of water expressed (VE). πo represents the osmotic potential at full turgor.

Date	Regression Equation	r^2	πo (MPa)
	DRYLAND SUNFLOWER		
7/17	I/P = 1.25 - 0.42 VE+	0.92	-0.80
7/28	I/P = 1.09 - 0.37 VE	0.94	-0.92
8/8	I/P = 1.00 - 0.32 VE	0.88	-0.10
	DRYLAND SOYBEAN		
7/17	I/P = 1.22 - 2.26 VE	0.98	-0.82
7/28	I/P = 1.16 - 1.40 VE	0.90	-0.91
8/8	I/P = 1.09 - 1.07 VE	0.97	-0.92

+VE is expressed in ml.

TABLE III.4. Regression equations illustrating the relationship of water use efficiency (WUE) and leaf to air vapor pressure deficits (VPD).+

Date	Treatment	Regression equation	r^2	w*
		SUNFLOWER		
7/16	Optimum	WUE = 28.1 - 11.1 VPD	0.59	17.0
	Dryland	WUE = 27.3 - 10.3 VPD	0.60	17.0
7/27	Optimum	WUE = 13.6 - 3.6 VPD	0.59	10.0
	Dryland	WUE = 8.8 - 1.3 VPD	0.66	7.5
8/7	Optimum	WUE = 16.6 - 3.6 VPD	0.76	13.0
	Dryland	WUE = 10.8 - 1.9 VPD	0.71	8.9
Total**	Optimum	WUE = 16.2 - 3.9 VPD	0.55	12.3
	Dryland	WUE = 14.3 - 2.9 VPD	0.51	11.4
		SOYBEAN		
7/16	Optimum	WUE = 24.1 - 7.8 VPD	0.92	16.3
	Dryland	WUE = 22.2 - 5.4 VPD	0.54	16.8
7/27	Optimum	WUE = 12.2 - 2.6 VPD	0.60	9.6
	Dryland	WUE = 11.9 - 1.6 VPD	0.66	10.3
8/7	Optimum	WUE = 14.8 - 3.0 VPD	0.63	11.8
	Dryland	WUE = 29.4 - 5.0 VPD	0.82	24.4
Total**	Optimum	WUE = 15.3 - 3.3 VPD	0.61	12.0
	Dryland	WUE = 18.9 - 2.9 VPD	0.64	16.0

+Equations were derived from data of 16 observations between 9:30 a.m. and 5:30 p.m.

*$gCO_2(kg\ H_2O \cdot KPaVPD^{-1})^{-1}$

**Represents 48 observations of the 3 dates.

TABLE III.5. Regression equations illustrating the relationship of pressure potential (P) and leaf water potential (leaf Ψ). Po indicates the leaf Ψ value at 0 turgor.*

Date	Regression Equation	r^2	Po (MPa)
	DRYLAND SUNFLOWER		
7/16	P = -0.93 - 0.65 leaf Ψ	0.93	-1.43
7/27	P = -0.88 - 0.42 leaf Ψ	0.88	-2.10
8/7	P = -1.05 - 0.64 leaf Ψ	0.94	-1.64
Total+	P = -0.90 - 0.54 leaf Ψ	0.85	-1.65
	DRYLAND SOYBEAN		
7/16	P = -1.03 - 0.73 leaf Ψ	0.82	-1.41
7/27	P = -1.12 - 0.81 leaf Ψ	0.96	-1.38
8/7	P = -1.13 - 0.76 leaf Ψ	0.96	-1.49
Total+	P = -1.07 - 0.75 leaf Ψ	0.92	-1.43

*Equations were derived from data of 24 observations on each date.

+Represents 72 observations from the 3 dates.

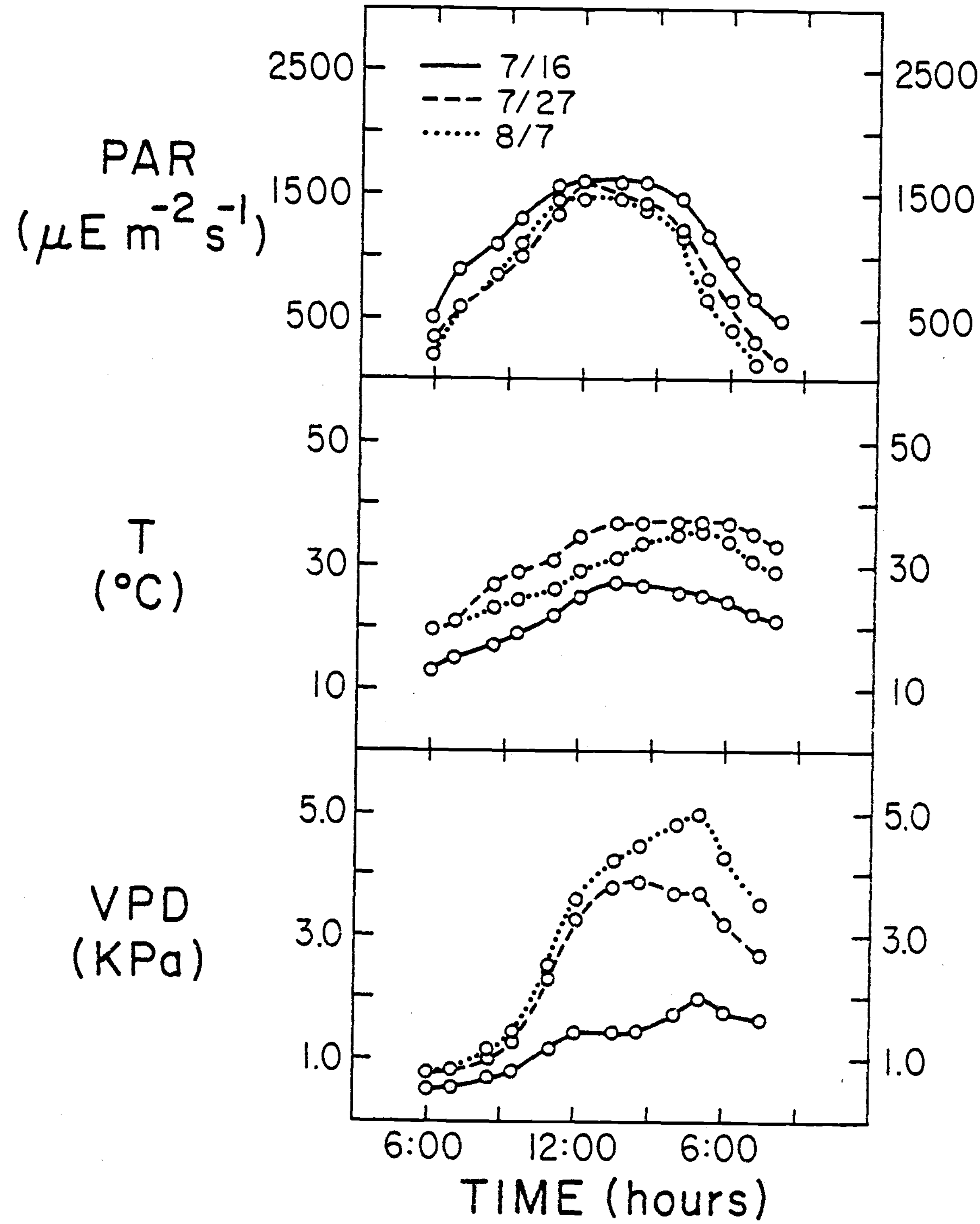

Figure III.1 Diurnal values of photosynthetic active radiation (PAR) ambient temperature (T°) and vapor pressure deficits (VPD) on 3 crop-water measurement dates in 1981.

Figure III.2 Diurnal responses of leaf water potential (leaf Ψ), osmotic potential (π), pressure potential (P), stomatal resistance (R_S), leaf temperature (Leaf T°), carbon exchange rate (CER), and cumulative leaf expansion (LE) in the 1981 optimum and dryland sunflower treatments. Bars indicate the standard error of the means of the 4 replicates.

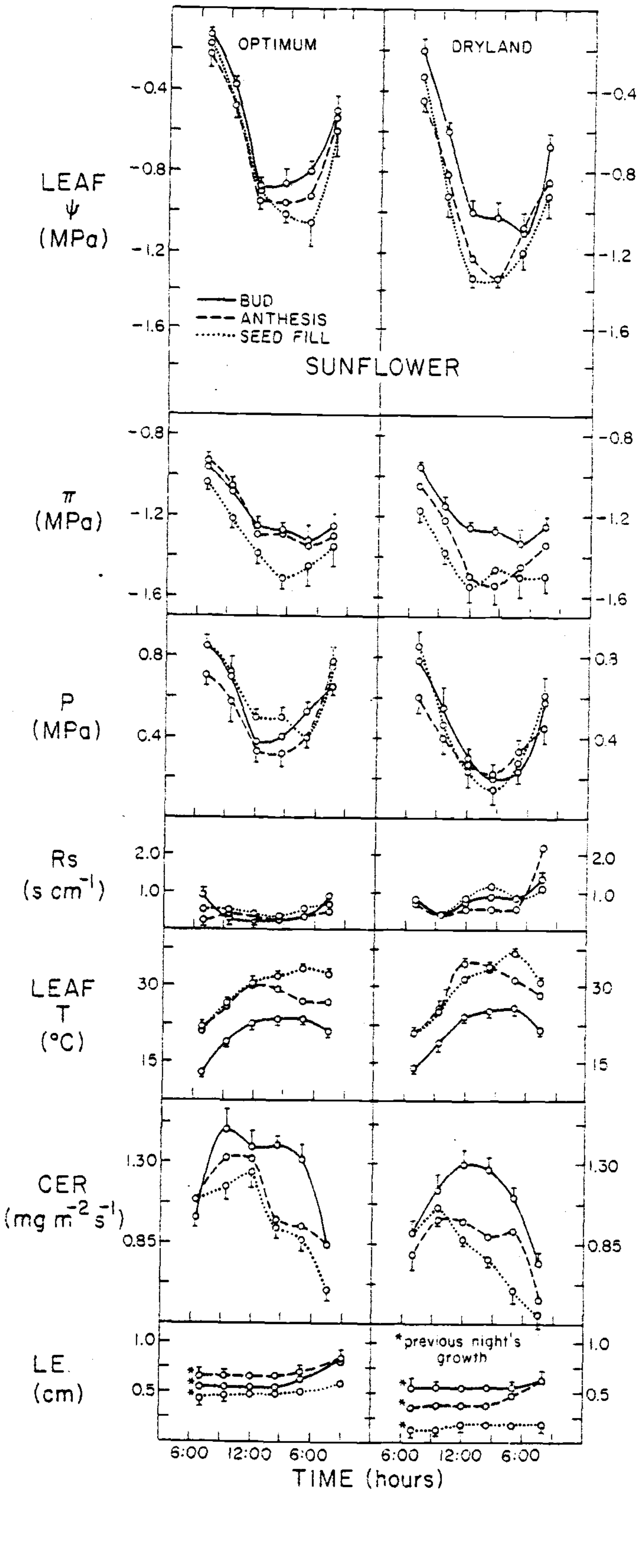
OPTIMUM
DRYLAND
LEAF ψ (MPa)
-0.4
-0.8
-1.2
-1.6
BUD
ANTHESIS
SEED FILL
SUNFLOWER
π (MPa)
P (MPa)
0.8
0.4
Rs (s cm⁻¹)
2.0
1.0
LEAF T (°C)
30
15
CER (mg m⁻² s⁻¹)
1.30
0.85
L.E. (cm)
0.5
*previous night's growth
6:00
12:00
TIME (hours)

Figure III.2

Figure III.3 Diurnal responses of leaf water potential (leaf Ψ). osmotic potential (π), pressure potential (p), stomotal resistance (R_s), leaf temperature (Leaf T°), carbon exhange rate (CER), and cumulative leaf expansion (LE) in the 1981 optimum and dryland soybean treatments. Bars indicate the standard error of the means of the 4 replicates.

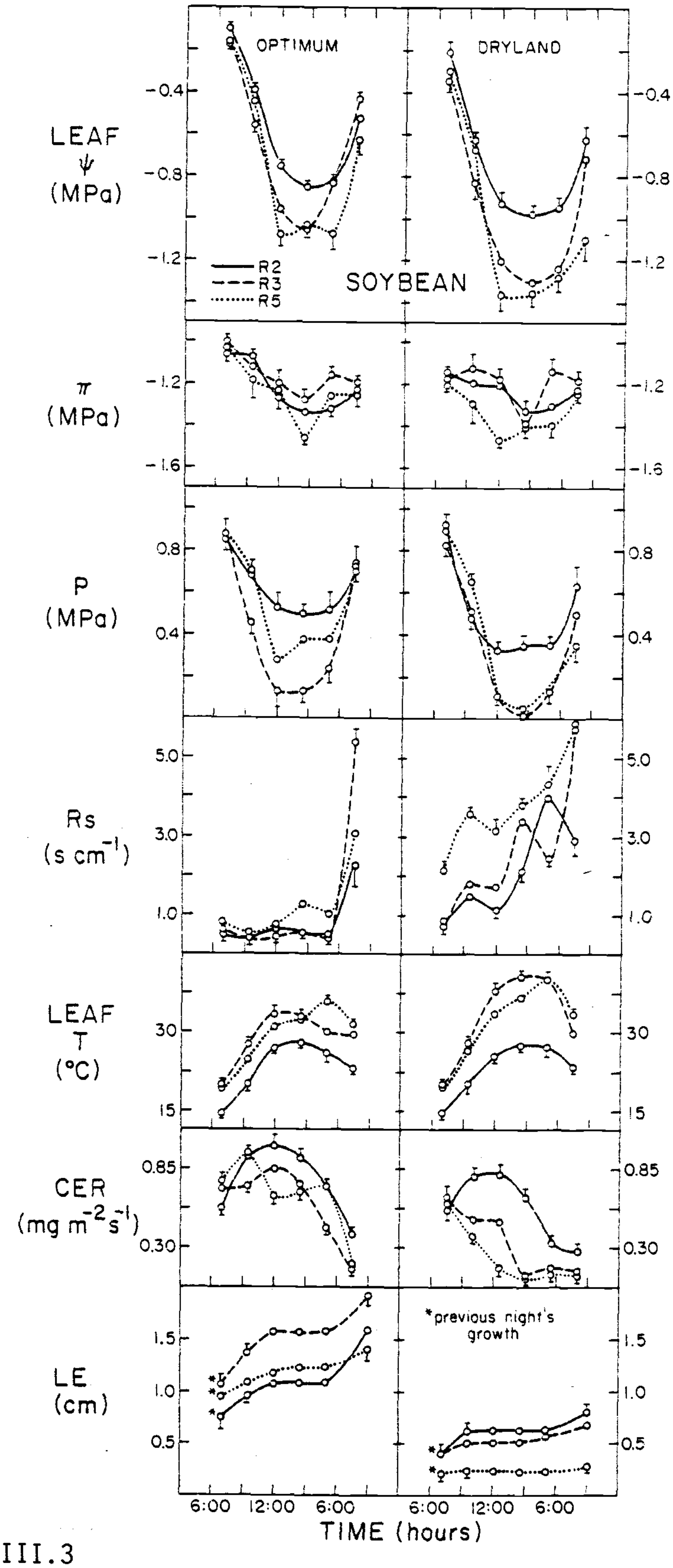
OPTIMUM
DRYLAND
SOYBEAN
R2
R3
R5
LEAF ψ (MPa)
-0.4
-0.8
-1.2
π (MPa)
-1.2
-1.6
P (MPa)
0.8
0.4
Rs (s cm^{-1})
5.0
3.0
1.0
LEAF T (°C)
30
15
CER (mg m^{-2}s^{-1})
0.85
0.30
LE (cm)
1.5
1.0
0.5
*previous night's growth
6:00
12:00
6:00
TIME (hours)

Figure III.3

LITERATURE CITED

1. Acevedo, E., E. Fereres, T.C. Hsaio, and D.W. Henderson. 1979. Diurnal growth trends, water potential, and osmotic adjustment of maize and sorghum leaves in the field. Plant Physiol. 64: 476-480.

2. Begg, J. and N.C. Turner. 1976. Crop water deficits. Adv. Agron. 28:161-217.

3. Boyer, J.S. 1968. Relationship of water potential to growth of leaves. Plant Physiol. 43:1056-1062.

4. Boyer, J.S. 1970a. Leaf enlargement and metabolic rates in corn, soybean, and sunflower at low leaf water potentials and high light intensities. Plant Physiol. 46:233-235.

5. Boyer, J.S. 1970b. Differing sensitivity of photosynthesis to low leaf water potentials in corn and soybean. Plant Physiol. 46:236-239.

6. Boyer, J.S. 1971. Nonstomatal inhibition of photosynthesis in sunflower at low leaf water potentials and high light intensities. Plant Physiol. 48:532-536.

7. Bunce, J.A. 1977. Leaf elongation in relation to leaf water potential in soybean. J. Exp. Bot. 28:156-161.

8. Clegg, M.D., C.V. Sullivan, and J.D. Eastin. 1978. A Sensitive technique for rapid measurement of carbon dioxide concentrations. Plant Physiol. 62:924-926.

9. Cox, W.J., G.D. Jolliff, and R.H. Cuenca. 1982. Sunflower and soybean adaptation to western Oregon. I. Crop Yield. (manuscript in preparation)

10. Cox, W.J. and G.D. Jolliff. 1982. Sunflower and soybean adaptation to western Oregon. II. Crop growth and development. (manuscript in preparation)

11. Cutler, J.M., P. Steponkus, M. Wach, and K. Shahan. 1980. Dynamic aspects and enhancement of leaf elongation in rice. Plant Physiol. 66:147-152.

12. English, S.D., J.R. McWilliam, R.C.G. Smith, and J.L. Davidson. 1979. Photosynthesis and partitioning of dry matter in sunflower. Aust. J. Plant Physiol. 6:149-164.

13. Fehr, W.R. and C.E. Caviness. 1977. Stages of soybean development. Spec. Report #80. Coop. Ext. Ser., Agric. and Home Econ. Exp. Stn., Iowa State Univ., Ames.

14. Hsaio, T.C., E. Acevedo, E. Fereres, and D.W. Henderson. 1976. Water stress, growth, and osmotic adjustment. Philos. Trans. Roy. Soc. London, Ser. B. 273:471-500.

15. Jones, M.M., and N.C. Turner. 1980. Osmotic adjustment in expanding and fully expanded leaves of sunflower in response to water deficits. Aust. J. Plant Physiol. 7:181-192.

16. Jones, M.M., C.B. Osmond, and N.C. Turner. 1980. Accumulation of solutes in leaves of sorghum and sunflower in response to water deficits. Aust. J. Plant Physiol. 7:193-205.

17. Laing, W.A., W.L. Ogren, and R.H. Hageman. 1974. Regulation of soybean net photosynthetic CO_2 fixation by the interaction of CO_2, O_2, and ribulose 1, 5-diphosphate carboxylase. Plant Physiol. 54:678-685.

18. Lawlor, D.W. and H. Fock. 1977. Photosynthetic assimilation

of $^{14}CO_2$ by water stressed sunflower leaves at two O_2 concentrations and the specific activity of products. J. of Exp. Bot. 28:320-328.

19. Lloyd, N.D.H. and D.T. Canvin. 1977. Photosynthesis and photorespiration in sunflower selections. Can. J. Bot. 55:3006-3012.

20. Nobel, P.S. 1974. Introduction to biophysical plant physiology. W.H. Freeman and Co., San Francisco.

21. Rawson, H.M., and R.G. Woodward. 1976. Photosynthesis and transpiration in dicotyledenous plants. I. Expanding leaves of tobacco and soybean. Aust. J. Plant Physiol. 247-256.

22. Rawson, H.M., and J.E. Begg. 1977. The effect of atmospheric humidity on photosynthesis, transpiration, and water use efficiency of leaves of several plant species. Planta 134:5-10.

23. Rawson, H.M. 1979. Vertical wilting and photosynthesis, transpiration, and water use efficiency of sunflower leaves. Aust. J. Plant Physiol. 6:109-120.

24. Rawson, H.M. and G.A. Constable. 1980. Carbon production of sunflower cultivars in field and controlled environments. I. Photosynthesis and transpiration of leaves, stems, and heads. Aust. J. Plant Physiol. 7:555-573.

25. Turner, N.C., J.E. Begg, and M.L. Tonnet. 1978. Osmotic adjustment of sorghum and sunflower crops in response to water deficits and its influence on the water potential at which stomata close. Aust. J. Plant Physiol. 5:597-608.

26. Turner, N.C. 1979. Drought resistance and adaptation to water deficits in crop plants. In: H. Mussell and R.C. Staples (eds). Stress physiology in crop plants. p. 343-372. Wiley Interscience, New York.

27. Turner, N.C. and M.M. Jones. 1980. Turgor maintenance by osmotic adjustment: a review and evaluation. In: N.C. Turner and P.J. Kramer (eds). Adaptation of plants to water and high temperature stress. p. 87-103. Wiley Interscience, New York.

28. Turner, N.C. 1981. Techniques and experimental approaches for the measurements of plant water status. Plant and Soil 58:339-366.

29. Tyree, M.T. 1976. Negative turgor pressure in plant cells: fact or fallacy? Can. J. Bot. 54:2738-2746.

30. Tyree, M.T., M.E. MacGregor, A. Petrov, and M.I. Upenieks. 1978. A comparison of systematic errors between the Richards and Hammel methods of measuring tissue-water relations parameters. Can. J. Bot. 56:2153-2161.

31. Watson, B.T. and I.F. Wardlaw. 1981. Metabolism and export of ^{14}C labelled photosynthate from water-stressed leaves. Aust. J. Plant Physiol. 8:143-153.

32. Wenkert, W., E.R. Lemon, and T.R. Sinclair. 1978a. Leaf elongation and turgor pressure in field-grown soybean. Agron. J. 70:761-764.

33. Wenkert, W., E.R. Lemon, and R.R. Sinclair. 1978b. Water content-potential relationship in soyabean: changes in component potentials for mature and immature leaves. Ann. Bot. 42:295-307.

CONCLUSION

Sunflower showed excellent adaptation to environmental factors in the Willamette Valley. The crop germinated and emerged rapidly in the cool wet spring soils of the Willamette Valley. After seedling establishment, vegetative development was only slightly impaired during the cool cloudy June period of both years in which radiation levels and temperatures were substantially below normal. In July and August, environmental factors induced maximum photosynthetic rates, crop growth rates (CGR) and water use-efficiency (WUE) in the well-irrigated sunflower crop. Also, ambient temperatures in August and September resulted in good seed set and seed development in sunflower. As a result, the well-irrigated sunflower crop attained its yield potential with high WUE in this study.

Precipitation was less than normal in July and August of both years. Only mild water stress, however, was observed in the dryland sunflower crop. The effective rooting depth of sunflower and the mild evaporative demand of the environment resulted in crop tolerance to the droughty summer conditions of the Willamette Valley. In addition, osmotic adjustment, a physiological mechanism which allows for the maintenance of turgor and turgor-mediated processes under water stress, was observed in sunflower. As a result, the dryland sunflower crop tolerated drought conditions with relatively high photosynthetic rates and CGR. This resulted in a crop yield of 2000 kg ha^{-1} in 1981 for the dryland sunflower crop. The national yield of sunflower is less than 1500 kg ha^{-1} (Robinson, 1978).

In contrast to sunflower, the soybean cultivars used in this experiment exhibited poor adaptation to environmental conditions in the Willamette Valley. In 1981, cool wet soils delayed germination and emergence considerably and stand establishment was relatively poor. After stand establishment, the cool June period of both years resulted in low relative leaf growth rate (RLGR) which retarded vegetative development of soybean. In July and August, the well-irrigated soybean crop had high photosynthetic rates, CGR and WUE. In fact, CGR exceeded most reported values for soybean. Consequently, soybean maximized its dry matter production potential in this environment. Reproductive development in soybean, however, was significantly impaired by the cool night temperatures. Seed set and seed growth rate appeared to be most effected by the cool night temperatures. As a result, the well-irrigated soybean crop did not attain high crop yields in this environment because of an environmentally induced sink limitation.

Crop growth and yield in dryland soybean was poor. In both years, the crop depleted only a minimum amount of stored soil water which resulted in severe crop water stress. In addition, limited osmotic adjustment was observed in soybean. This contributed to very low turgor and photosynthetic rates during the peak evaporative demand period of the day. As a result of its poor drought tolerance to Willamette Valley summer conditions, dryland soybean production is not recommended.

The data from this experiment indicated that sunflower is well adapted to Willamette Valley climatic conditions. If an oilseed industry is established in the Pacific Northwest, irrigated or dryland sunflower production is agronomically feasible in the Willamette Valley. Current agronomic problems for sunflower in this area include low pH soils, low boron levels in the soil, and potentially severe bird problems. With the commencement of commercial production, bird damage would be expected to diminish. Insect or disease problems, however, would be expected to increase.

Existing soybean cultivars of Maturity Group 0 are not adapted to soil water deficits or cool night temperatures in the Willamette Valley. In order to establish the soybean crop in western Oregon, cultivars that are tolerant to cool nights and/or sustained drought conditions are necessary.

BIBLIOGRAPHY

Acevedo, E., E. Fereres, T.C. Hsaio, and D.W. Henderson. 1979. Diurnal growth trends, water potential, and osmotic adjustment of maize and sorghum leaves in the field. Plant Physiol. 64:467-480.

Begg, J. and N.C. Turner. 1976. Crop water deficits. Adv. Agron. 28:161-217.

Blackman, G.E., J.N. Black, and A.W. Kemp. 1955. Physiological and ecological studies in the analysis of plant environment. X. An analysis of the effects of seasonal variation in day length and temperature on the growth of *Helianthus annus* L. in the vegetative phase. Ann. Bot. N. S. 19, 527-248.

Boyer, J.S. 1968. Relationship of water potential to growth of leaves. Plant Physiol. 43:1056-1062.

Boyer, J.S. 1970a. Leaf enlargement and metabolic rates in corn, soybean, and sunflower at low leaf water potentials and high light intensities. Plant Physiol. 46:233-235.

Boyer, J.S. 1970b. Differing sensitivity of photosynthesis to low leaf water potentials in corn and soybean. Plant Physiol. 46L236-239.

Boyer, J.S. 1971. Nonstomatal inhibition of photosynthesis in sunflower at low leaf water potentials and high light intensities. Plant Physiol. 48:532-536.

Bunce, J.A. 1977. Leaf elongation in relation to leaf water potential in soybean. J. Exp. Bot. 28:156-161.

Burch, G.J., R.C.G. Smith, and W.K. Mason. 1978. Agronomic and physiological responses of soybean and sorghum crops to water deficits. II. Crop evaporation, soil water depletion, and root distribution. Aust. J. Plant Physiol. 5:169-177.

Buttery, B.R. 1969. Analysis of the growth of soybeans as affected by plant population and fertilizer. Can. J. Plant Sci. 49:675-684.

Buttery, B.R. 1970. Effects of variation in leaf area index on growth of maize and soybeans. Crop Sci. 10:9-13.

Clegg, M.D., C.V. Sullivan, and J.D. Eastin. 1978. A sensitive technique for rapid measurement of carbon dioxide concentrations. Plant Physiol. 62:924-926.

Cox, W.J., G.D. Jolliff, and R.H. Cuenca. 1982. Sunflower and soybean adaptation to western Oregon. I. Crop Yield. (manuscript in preparation).

Cox, W.J. and G.D. Jolliff. 1982a. Sunflower and soybean adaptation to western Oregon. II. Crop growth and development. (manuscript in preparation).

Cox, W.J. and G.D. Jolliff. 1982b. Sunflower and soybean adaptation to western Oregon. III. Crop-water relations. (manuscript in preparation).

Cutler, J.M., P. Steponkus, M. Wach, and K. Shahan. 1980. Dynamic aspects and enhancement of leaf elongation in rice. Plant Physiol. 66:147-152.

Divine, T.E., D.P. Alzheiner, J.W. Currie, K.A. McGinnis, and D.J. Wiggins. 1977. Research on the potential impact of advanced oilseed processing technology on Pacific Northwest agriculture. Battelle Northwest. Richland, WA. Final Report.

Doorenboors, J. and C. Kasaam. 1979. Yield response to water. Irrigation Drainage Paper 33. FAO, U.N. Rome.

Doss, B.D., R.W. Pearson, and H.T. Rodgers. 1974. Effect of soil water stress at various growth stages on soybean yield. Agron. J. 66:297-299.

Egli, D.B. and I.F. Wardlaw. 1980. Temperature response of seed growth characteristics of soybean. Agron. J. 72:560-564.

English, S.D., J.R. McWilliam, R.C.G. Smith, and J.L. Davidson. 1979. Photosynthesis and partitioning of dry matter in sunflower. Aust. J. Plant Physiol. 6:149-164.

Eze, J.M.O. 1973. The vegetative growth of <u>Helianthus annus</u> and <u>Phaseolus vulgaris</u> as affected by seasonal factors in Freeton, Sierra Leone. Ann. Bot. 37:315-329.

Fehr, W.R. and C.E. Caviness. 1977. Stages of soybean development. Spec. Rep. #80. Coop. Ext. Ser., Agric. and Home Econ. Exp. Stn., Iowa State Univ., Ames.

Fischer, R.A. 1980. Influence of water stress on crop yield in semiarid regions. <u>In</u>: N.C. Turner and P.J. Kramer (eds.). Adaptation of plants to water and high temperature stress. p. 323-340. Wiley Interscience, New York.

Fraser, Joanna, D.B. Egli, and J.E. Leggett. 1982. Pod and seed development in soybean cultivars with differences in seed size. Agron. J. 74:81-85.

Hanks, R.J., J. Keller, V.P. Rasmussen, and G.D. Wilson. 1976. Line source sprinkler for continuous variable irrigation-crop production studies. Soil Sci. Soc. Am. Proc. 40:426-429.

Hanks, R.J., D.V. Sisson, R.L. Hurst, and K.G. Hubbard. 1980. Statistical analysis of results from irrigation experiments using the line source sprinkler system. Utah Agric. Exp. Stn. Journal Paper No. 2410.

Hanks, R.J. and R.W. Hill. 1980. Modeling crop responses to irrigation. International Irrigation Information Center, Israel. Pergamon Press, New York.

Hanway, J.J. and Weber, C.R. 1971. Dry matter accumulation in eight soybean [(Glycine max (L.) Merr] varieties. Agron. J. 63:227-230.

Hicks, D.R. 1978. Growth and development. In: A. Geoffrey Norman (ed). Soybean physiology, agronomy and utilization. p. 17-44. Academic Press, Inc. New York.

Hillel, D. 1980. Applications of soil physics. Academic Press, New York and London.

Hodgson, G.S. 1967. Physiological and ecological studies in the analysis of plant environment. XIII. A comparison of the effects of seasonal variation in light energy and temperature on the growth of Helianthus annus and Vicia faba in the vegetative phase. Ann. Bot. N. S. 31:291-308.

Holst, D.L., A.G. Nelson, and C.W. O'Connor. 1979. The economics of producing and marketing soybeans in Oregon. Oregon State Univ. Agric. Exp. Stn. Cir. of Info. 679.

Hsaio, T.C., E. Acevedo, E. Fereres, and D.W. Henderson. 1976. Water stress, growth and osmotic adjustment. Phil. Trans. R. Soc. Lond. B. 273:479-500.

Hume, D.J. and A.K.H. Jackson. 1981. Pod formation in soybean at low temperatures. Crop Sci. 21:933-937.

Hunt, R. 1979. Plant growth analysis: the rationale behind the use of the fitted mathematical function. Ann. Bot. 43:245-249.

Jones, M.M., and N.C. Turner. 1980. Osmotic adjustment in expanding and fully expanded leaves of sunflower in response to water deficits. Aust. J. Plant Physiol. 7:181-192.

Jones, M.M., C.B. Osmond, and N.C. Turner. 1980. Accumulation of solutes in leaves of sorghum and sunflower in response to water deficits. Aust. J. Plant Physiol. 7:193-205.

Laing, W.A., W.L. Ogren, and R.H. Hageman. 1974. Regulation of soybean net photosynthetic CO_2 fixation by the interaction of CO_2, O_2, and ribulose 1, 5-diphosphate carboxylase. Plant Physiol. 54:678-685.

Lawlor, D.W. and H. Fock. 1977. Photosynthetic assimilation of $^{14}CO_2$ by water stressed sunflower leaves at two O_2 concentrations and the specific activity of products. J. of Exp. Bot. 28:320-328.

Lloyd, N.D.H. and D.T. Canvin. 1977. Photosynthesis and photorespiration in sunflower selections. Can. J. Bot. 55:3005-3012.

Mason, W.K., H.M. Taylor, A.T.P. Bennie, H.R. Rowse, D.C. Reicosky, Y. Jung, AA. Righes, R.L. Yang, T.C. Kaspar, and J.A. Stone. 1980. Soybean row spacing and soil water supply: their effect on growth, development, water relations, and mineral uptake. Advances in Agricultural Technology. Science and Education Administration. U.S. Dept. of Agriculture. (also AAT-NC-5).

Momen, N.N., R.E. Carlson, R.H. Shaw, and O. Arjmand. 1979. Moisture-stress effects on the yield components of two soybean cultivars. Agron. J. 71:86-90.

Nobel, P.S. 1974. Introduction to biophysical plant physiology. W.H. Freeman and Co., San Francisco.

Parsons, I.T. and R. Hunt. 1981. Plant growth analysis. A program for the fitting of the lengthy series of data by the method of B-splines. Ann. Bot. 45:541-552.

Prunty, Lyle. 1981. Sunflower cultivar performance as influenced by soil water and plant population. Agron. J. 73:257-260.

Rajan, A.K., B. Betteridge, and G.E. Blackman. 1973. Difference in the interacting effects of light and temperature on growth of four species in the vegetative stage. Ann. Bot. 37:287-313.

Rawson, H.M. and R.G. Woodward. 1976. Photosynthesis and transpiration in dicotyledenous plants. I. Expanding leaves of tobacco and soybean. Aust. J. Plant Physiol. 247-256.

Rawson, H.M., and J.E. Begg. 1977. The effect of atmospheric humidity on photosynthesis, transpiration, and water use efficiency of leaves of several plant species. Planta 134:5-10.

Rawson, H.M. 1979. Vertical wilting and photosynthesis, transpiration, and water use efficiency of sunflower leaves. Aust. J. Plant Physiol. 6:109-120.

Rawson, H.M. and G.A. Constable. 1980a. Carbon production of sunflower cultivars in field and controlled environments. I. Photosynthesis and transpiration of leaves, stems, and heads. Aust. J. Plant Physiol. 7:555-573.

Rawson, H.M. and G.A. Constable. 1980b. Carbon production of sunflower cultivars in field and controlled environments. II. Leaf growth. Aust. J. Plant Physiol. 7:575-586.

Reicosky, D.C. and D.E. Deaton. 1979. Soybean water extraction, leaf water potential, and evapotranspiration during drought. Agron. J. 71:45-50.

Robinson, R.G. 1971. Sunflower phenology--year, variety, and date of planting effects on day and growing degree day summations. Crop Sci. 11:635-638.

Robinson, R.G. 1978. Production and culture. In: J.F. Carter (ed). Sunflower Science and Technology. Agronomy 19:89-143. Am. Soc. of Agron., Madison, WI.

Schneiter, A.A. and J.F. Miller. 1981. Description of sunflower growth stages. Crop Sci. 21:901-904.

Scott, H.D. and J.T. Batchelor. 1979. Dry weight and leaf area production rates of irrigated determinate soybeans. Agron. J. 776-782.

Shaw, R.H. and D.R. Laing. 1966. Moisture stress and plant response. p. 73-04. In: W.H. Pierre, Don Kirkham, John Pesek, and Robert Shaw (eds.). Plant environment and efficient water use.

Shibles, R.M., I.C. Anderson, A.H. Gibson. 1975. Soybean. In: L.T. Evans (ed). Crop physiology: some case histories. p. 151-189. Cambridge Univ. Press.

Sionit, N., S.R. Ghorashy, and M. Keradram. 1973. Effect of soil water potential on growth and yield of sunflower (Helianthus annus). J. Agric. Sci., Camb. 81:113-116.

Sionit, N. 1977. Water status and yield of sunflowers (Helianthus annus) subjected to water stress during four stages of development. J. Agric. Sci., Camb. 89:663-666.

Sivakumar, M.V.K., and R.H. Shaw. 1978. Methods of growth analysis in field-grown soya beans (Glycine max [L.]) Merrill). Ann. Bot. 42:213-222.

Summerfield, R.J., and H.C. Wien. 1980. Effects of photoperiod and air temperature on growth and yield of economic legumes. In: R.J. Summerfield and A.H. Bunting (eds.). Advances in legume science. Royal Botanic Gardens. Kew.

Talha, M. and F. Osman. 1975. Effect of soil water stress and water economy on oil composition in sunflower (Helianthus annus L.). J. Agric. Sci., Camb. 84:49-56.

Thomas, J.F. and C.D. Raper, Jr. 1976. Photoperiodic control of seed filling for soybeans. Crop Sci. 16:667-672.

Turner, N.C., J.E. Begg, and M.L. Tonnet. 1978. Osmotic adjustment of sorghum and sunflower crops in response to water deficits and its influence on the water potential at which stomata close. Aust. J. Plant Physiol. 5:597-608.

Turner, N.C. 1979. Drought resistance and adaptation to water deficits in crop plants. In: H. Mussell and R.C. Staples (eds.). Stress physiology in crop plants. p. 343-372. Wiley Interscience, New York.

Turner, N.C. and M.M. Jones. 1980. Turgor maintenance by osmotic adjustment: a review and evaluation. In: N.C. Turner and P.J. Kramer (eds.). Adaptation of plants to water and high temperature stress. p. 87-103. Wiley Interscience, New York.

Turner, N.C. 1981. Techniques and experimental approaches for the measurements of plant water status. Plant and Soil. 58:339-366.

Turner, N.C. and J.E. Beggy. 1981. Plant-water relations and adaptation to stress. In: J. Monteith and C. Webb (eds.). Soil water and nitrogen in Mediterranean-type environments. p. 97-131. Nijhoff/Junk, Boston, MA.

Tyree, M.T. 1976. Negative turgor pressure in plant cells: fact or fallacy? Can. J. Bot. 54:2738-2746.

Tyree, M.T., M.E. MacGregor, A. Petrov, and M.I. Upenieks. 1978. A comparison of systematic errors between the Richards and Hammel methods of measuring tissue-water relations parameters. Can. J. Bot. 56:2153-2161.

Unger, P.W. 1981. Tillage effects on wheat and sunflower grown in rotation. Soil Sci. Soc. Am. J. 45:941-945.

Venus, J.C. and D.R. Carston. 1979. Plant growth and analysis: the use of the Richards function as an alternative to polynomial exponentials. Ann. Bot. 43:623-632.

Vijayalaksmi, K., N.K. Sanghi, W.L. Pelton, and C.H. Anderson. 1975. Effect of plant populations and row spacings on sunflower agronomy. Can. J. Plant Sci. 55:491-499.

Warren Wilson, J. 1967a. High net assimilation rates of sunflower plants in an arid climate. Ann. Bot. 30:745-751.

Warren Wilson, J. 1967b. Effect of temperature on net assimilation rate. Ann. Bot. 30:753-761.

Watson, B.T. and I.F. Wardlaw. 1981. Metabolism and export of ^{14}C labelled photosynthate from water-stressed leaves. Aust. J. Plant Physiol. 8:143-153.

Wenkert, W., E.R. Lemon, and R.R. Sinclair. 1978a. Leaf elongation and turgor pressure in field-grown soybean. Agron. J. 70:761-764.

Wenkert, W., E.R. Lemon, and R.R. Sinclair. 1978b. Water content-potential relationship in soyabean: changes in component potentials for mature and immature leaves. Ann. Bot. 42:295-307.

Willatt, S.T. and H.M. Taylor. 1978. Water uptake by soybean roots as affected by their depth and by soil water content. J. of Agric. Sci. Camb.

APPENDIX TABLES

Table 1. 1951-1980 monthly average weather data at the Hyslop Crop Science Field Laboratory

Month	Ambient Temperature (°C) Max	Min	Precipitation (cm)	Radiation (W m^{-2})	Relative Humidity (%) 10:00 A.M.	4:00 P.M.	Pan Evaporation (cm)
January	7.2	0.6	18.8	43.7	84	79	
February	10.0	1.5	12.2	65.8	80	68	
March	12.0	2.3	11.7	113.8	71	58	
April	15.2	3.8	6.1	156.5	63	49	6.8
May	18.9	6.2	4.9	208.7	55	44	11.2
June	22.6	9.0	3.1	235.0	53	39	14.5
July	27.1	10.3	0.8	257.6	45	31	19.9
August	26.9	10.5	2.1	212.0	50	31	17.7
September	24.2	8.9	3.8	163.6	59	48	12.2
October	17.8	5.3	8.5	98.7	78	54	5.3
November	11.3	2.9	15.8	49.4	84	80	
December	8.1	1.4	19.8	32.4	88	85	
Year	16.8	5.2	107.6	136.4	68	55	

Table 2. Selected agronomic characteristics in the 1980 sunflower treatments.

Treatment	Crop yield (kg ha-1)	ET (cm)	WUE (kg ha^{-1} cm-1)	Seeds per plant (no.)	1000 seed wt. (g)	Head Diam. (cm)
Dry	1134	16.0	70.9	758	35.5	13.0
	1146	14.5	79.0	801	35.5	15.0
	1225	14.1	86.9	763	35.5	14.0
	960	13.9	69.1	794	36.0	14.1
Severe Deficit	1454	17.1	85.0	901	34.5	15.0
	1358	16.8	80.8	882	37.5	14.1
	1390	16.7	83.2	800	38.4	13.9
	1219	16.0	76.2	993	39.6	15.0
Deficit	2690	27.7	97.1	1512	42.5	17.5
	2593	21.7	119.4	1496	44.5	17.5
	2826	26.4	107.0	1500	45.5	17.5
	2524	20.0	126.2	1414	44.0	15.5
Optimum	3424	33.5	102.2	1912	51.0	19.5
	3627	31.5	115.1	1987	47.0	20.0
	3466	31.0	111.8	1931	44.5	19.5
	3549	29.9	118.9	1839	47.0	19.0
Over-Irrigated	3436	31.4	109.4	1876	49.5	19.0
	3460	30.5	113.4	1893	46.5	18.5
	3447	26.5	130.0	1821	46.5	18.5
	3251	26.2	124.0	1581	44.0	17.5

Table 3. Linear regression of 1980 sunflower yield and ET.

yield = -868.1 + 142.8 ET(cm)

Source	df	Mean square
Total	19	
Regression	1	18910700
Error	18	105882

$r^2 = 0.91$

Table 4. Linear regression of 1980 sunflower seeds per plant and ET.

seeds per plant = 153.2 + 66.3 ET(cm)

Source	df	Mean square
Total	19	
Regression	1	4075130
Error	18	16095

$r^2 = 0.93$

Table 5. Linear regression of 1980 sunflower 1000 seed wt. and ET.

1000 seed wt. = 26.4 + 0.69 ET(cm)

Source	df	Mean square
Total	19	
Regression	1	446.6
Error	18	4.4

$r^2 = 0.84$

Table 6. Selected agronomic characteristics in the 1981 sunflower treatments.

Treatment	Crop yield (kg ha^{-1})	ET (cm)	WUE (kg ha^{-1} cm^{-1})	Seeds per plant (no.)	1000 seed wt. (g)	Head Diam. (cm)
Dry	2043	20.3	100.7	1047	45.4	15.6
	1908	16.1	108.5	1012	44.8	15.5
	2155	20.4	107.5	1053	41.1	16.0
	2100	20.0	105.0	972	42.6	16.0
Severe Deficit	2397	23.1	103.8	1391	44.6	16.8
	2008	20.2	99.4	1285	47.3	16.1
	2100	20.8	100.9	1302	41.8	16.0
	2088	20.6	101.4	1270	45.1	16.9
Deficit	2735	25.6	106.8	1387	48.6	16.9
	2646	27.4	96.6	1464	47.0	16.3
	2305	26.7	86.3	1447	45.2	16.5
	2644	25.5	103.8	1372	46.6	16.3
Optimum	3213	31.1	103.3	1927	45.0	19.3
	3026	30.0	100.9	1896	51.2	18.3
	3033	27.7	110.0	1809	46.8	19.0
	2934	26.9	109.1	1799	49.4	18.3
Over-Irrigated	2686	26.5	101.3	1669	47.4	18.8
	2755	29.9	92.1	1836	44.9	17.6
	2423	22.2	109.1	1738	47.6	17.3
	2900	26.7	108.6	1786	47.9	17.6

Table 7. Linear regression of 1981 sunflower yield and ET.

$$\text{yield} = 259.1 + 91.8\ \text{ET(cm)}$$

Source	df	Mean square
Total	19	
Regression	1	2720410
Error	18	27469

$r^2 = 0.85$

Table 8. Linear regression of 1981 sunflower seeds per plant and ET.

$$\text{seeds per plant} = -136.8 + 66.0\ \text{ET(cm)}$$

Source	df	Mean square
Total	19	
Regression	1	1407510
Error	18	27075

$r^2 = 0.74$

Table 9. Linear regression of 1981 sunflower 1000 seed wt. and ET.

$$\text{1000 seed wt.} = 35.8 + 0.43\ \text{ET(cm)}$$

Source	df	Mean square
Total	19	
Regression	1	60.0
Error	18	4.5

$r^2 = 0.43$

Table 10. Linear regression of 1980 and 1981 sunflower with ET.

yield = -589.0 + 128.6 ET(cm)

Source		Mean square
Total	19	
Regression	1	20974300
Error	18	82072

$r^2 = 0.87$

Table 11. Linear regression of 1980 and 1981 sunflower seeds per plant with ET.

seeds per plant = -149.2 + 66.3 ET(cm)

Source	df	Mean square
Total	19	
Regression	1	5582620
Error	18	20476

$r^2 = 0.88$

Table 12. Linear regression of 1980 and 1981 sunflower 1000 seed wt. with ET.

1000 seed wt. = 28.7 + 0.66 ET(cm)

Source	df	Mean square
Total	19	
Regression	1	551.3
Error	18	7.2

$r^2 = 0.67$

Table 13. Selected agronomic characteristics in the 1980 soybean treatments.

Treatment	Crop yield (kg ha^{-1})	ET (cm)	WUE (kg na^{-1} cm^{-1})	Pods per plant (no.)	Seeds per pod (no.)	1000 seed wt. (g)
Dry	129	8.2	15.7	7.0	1.45	114.0
	129	7.7	16.8	6.0	1.47	112.0
	52	8.6	6.05	9.5	1.50	108.0
	92	8.6	10.8	10.8	1.42	112.0
Severe Deficit	390	12.2	32.0	23.2	1.71	123.1
	212	11.6	18.3	17.0	1.58	120.0
	367	13.3	27.6	15.0	1.49	125.3
	129	10.3	12.5	12.4	1.53	125.1
Deficit	2049	21.2	96.7	52.9	1.70	140.5
	1523	20.0	76.2	42.6	1.68	142.0
	1661	22.3	74.5	45.1	1.75	136.5
	1314	22.3	58.9	44.9	1.63	139.0
Optimum	2797	25.5	109.7	54.6	1.63	142.5
	2870	28.2	101.8	76.1	1.52	149.5
	2620	27.9	93.9	53.5	1.65	143.0
	2736	27.2	100.6	57.0	1.60	148.5
Over-Irrigated	2616	24.3	107.7	57.0	1.59	146.0
	2579	25.4	101.5	75.3	1.55	139.0
	2828	26.1	108.4	64.9	1.58	140.5
	2397	22.8	105.1	55.6	1.56	142.0

Table 14. Linear regression of 1980 soybean yield with ET.

yield (kg ha^{-1}) = -1291.6 + 148.0 ET(cm)

Source	df	Mean square
Total	19	
Regression	1	24165200
Error	18	77375

$r^2 = 0.95$

Table 15. Linear regression of 1980 soybean pods per plant with ET.

pods per plant = -17.5 + 3.03 ET(cm)

Source	df	Mean square
Total	19	
Regression	1	10091
Error	18	52

$r^2 = 0.92$

Table 16. Linear regression of 1980 soybean 1000 seed wt. with ET.

1000 seed wt. (g) = 101.1 + 1.67 ET(cm)

Source	df	Mean square
Total	19	
Regression	1	3091
Error	18	22

$r^2 = 0.89$

Table 17. Selected agronomic characteristics in the 1981 soybean treatments.

Treatment	Crop yield (kg ha^{-1})	ET (cm)	WUE (kg ha^{-1} cm^{-1})	Pods per plant (no.)	Seeds per pod (no.)	1000 seed wt. (g)
Dry	687	11.4	60.3	28.5	1.55	105.3
	380	8.3	45.8	23.0	1.50	98.5
	644	9.0	71.6	24.5	1.49	101.8
	436	8.7	50.1	19.0	1.54	101.7
Severe Deficit	909	16.3	55.8	24.0	1.49	116.2
	1152	18.5	62.3	38.0	1.53	119.9
	1160	18.1	64.1	32.5	1.61	116.0
	1146	15.1	75.9	31.5	1.44	117.6
Deficit	2031	26.3	77.2	66.0	1.57	139.5
	2115	22.6	93.6	72.0	1.43	135.4
	1947	22.8	85.4	53.5	1.53	136.6
	2336	22.6	103.3	59.0	1.47	136.7
Optimum	2570	28.6	89.9	75.5	1.44	140.1
	2546	24.3	104.8	75.0	1.48	139.0
	2604	27.5	94.7	79.5	1.49	139.7
	2315	28.3	81.8	74.5	1.47	136.8
Over-Irrigated	2312	25.5	90.7	68.0	1.39	128.5
	1895	22.9	82.8	51.0	1.50	125.0
	2112	23.8	88.7	60.5	1.46	126.9
	2241	23.6	95.0	49.0	1.47	126.6

Table 18. Linear regression of 1981 soybean yield with ET.

Yield (kg ha^{-1}) = -556.6 + 110.5 ET(cm)

Source	df	Mean square
Total	19	
Regression	1	10343700
Error	18	52272

$r^2 = 0.92$

Table 19. Linear regression of 1981 soybean pods per plant and ET.

pods per plant = -8.48 + 2.91 ET(cm)

Source	df	Mean square
Total	19	
Regression	1	7169
Error	18	69

$r^2 = 0.85$

Table 20. Linear regression of 1981 soybean 1000 seed wt. with ET.

1000 seed wt. (g) = 83.7 + 2.0 ET(cm)

Source	df	Mean square
Total	19	
Regression	1	3418
Error	18	19

$r^2 = 0.91$

Table 21. Linear regression of 1980 and 1981 soybean crop yield with ET.

yield (kg ha^{-1}) = -986.5 + 131.8 ET(cm)

Source	df	Mean square
Total	19	
Regression	1	34244200
Error	18	79159

$r^2 = 0.92$

Table 22. Linear regression of 1980 and 1981 soybean pods per plant with ET.

pods per plant = -14.2 + 3.03 ET(cm)

Source	df	Mean square
Total	19	
Regression	1	18079
Error	18	69

$r^2 = 0.87$

Table 23. Linear regression of 1980 and 1981 soybean 1000 seed wt. with ET.

1000 seed wt. (g) = 94.6 + 1.74 ET(cm)

Source	df	Mean square
Total	19	
Regression	1	5943
Error	18	52

$r^2 = 0.75$

Table 24. Soil moisture release curve and bulk density values for the Woodburne silt loam soil at the experimental site.

Soil depth (cm)	Soil Moisture Tension (MPa) 0.01	0.03	0.08	0.2	1.5	Bulk density (g cm^{-3})
30	27.9	24.7	23.7	19.4	12.6	1.43
	26.7	23.9	22.6	19.0	13.0	1.47
	28.7	25.5	24.1	19.2	12.8	1.19
	28.0	24.2	23.5	19.0	12.7	1.45
45	*					1.40
						1.35
						1.37
						1.35
90	42.2	32.2	30.1	25.5	16.3	1.31
	34.1	33.0	30.0	24.7	16.0	1.37
	38.1	32.4	30.3	25.2	16.1	1.37
	34.9	32.9	30.4	25.7	16.5	1.28
120	*					1.36
						1.30
						1.29
						1.35
150	*					1.34
						1.32
						1.40
						1.28

* moisture release curve not determined at this depth.

Table 25. Soil water depletion pattern for the 1980 dryland sunflower treatment.[†]

Soil depth increment (cm)	DATE													
	6/23	7/2	7/7	7/15	7/24	7/29	8/5	8/12	8/19	8/28	9/4	9/11	9/19	Total (mm)
0-15	2.75	3.75	8.0	4.0	7.0	3.0	0.0	0.0	0.0	0.0	4.5	0.0	0.0	33.0
15-30	2.75	4.0	2.25	1.75	1.75	2.75	1.75	0.75	0.75	0.25	0.0	0.0	0.25	19.0
30-45	1.0	1.75	0.75	0.5	2.5	4.0	2.75	1.5	0.5	0.5	0.75	0.0	1.0	17.5
45-60	0.25	0.75	1.0	0.25	1.75	2.75	1.25	0.75	0.75	0.75	0.5	0.25	0.5	11.5
60-75	0.5	0.25	0.75	0.0	0.75	1.75	2.75	1.50	0.75	0.75	1.0	0.25	0.0	11.0
75-90	0.75	0.5	0.5	0.25	0.75	1.0	1.25	2.5	0.75	2.0	0.75	0.0	0.75	11.75
90-120	0.0	0.0	0.0	0.0	0.0	0.0	1.75	3.5	2.5	3.5	2.5	1.75	2.25	17.75
120-150	0.0	0.0	0.0	0.0	0.0	0.0	1.5	1.75	2.75	2.75	2.25	2.0	2.5	15.5
150-180	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.25	2.5	2.0	1.75	0.75	1.0	9.25
180-210	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total (mm)	8.0	11.0	13.25	6.75	14.5	15.25	13.0	13.5	11.25	12.5	14.0	5.0	8.25	146.25

[†] average of 4 replications

Table 26. Soil water depletion pattern for the 1980 deficit sunflower treatment.†

Soil depth increment (cm)	DATE 6/23	7/2	7/7	7/15	7/24	7/29	8/5	8/12	8/19	8/28	9/4	9/11	9/18	Total (mm)
0-15	3.5	3.25	6.25	6.75	9.75	13.0	8.5	10.5	9.5	9.5	6.5	1.25	0.25	88.0
15-30	3.0	4.0	1.25	2.75	6.0	5.25	4.75	6.0	4.5	5.5	1.5	1.0	0.75	46.25
30-45	1.25	1.75	1.5	1.25	4.0	3.75	3.75	5.25	3.0	4.75	0.75	0.5	1.25	32.75
45-60	0.5	0.75	0.75	2.0	0.5	2.5	2.5	2.5	0.5	2.0	0.25	0.5	1.25	16.5
60-75	0.75	0.5	0.5	1.25	0.0	1.0	1.75	1.5	1.5	0.5	1.0	1.25	0.75	12.25
75-90	0.5	0.5	0.25	0.5	0.0	0.25	2.5	1.75	0.75	1.5	1.0	1.25	1.25	12.0
90-120	0.0	0.0	0.0	0.0	0.25	0.0	0.75	2.5	0.75	3.0	3.25	1.75	2.75	15.0
120-150	0.0	0.0	0.0	0.0	0.0	0.25	0.0	1.75	0.25	2.5	2.5	0.75	1.5	9.5
150-180	0.0	0.0	0.0	0.0	0.0	0.0	0.25	1.5	0.5	2.0	1.75	0.75	1.5	8.25
180-210	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total (mm)	9.5	10.75	10.5	14.5	20.5	26.0	24.75	33.25	21.25	31.25	18.0	9.0	11.25	239.5

† average of 4 replications

Table 27. Soil water depletion pattern for the 1980 optimum sunflower treatment.†

Soil depth increment (cm)	DATE 6/23	7/2	7/7	7/15	7/24	7/29	8/5	8/12	8/19	8/28	9/4	9/11	9/18	Total (mm)
0-15	3.75	5.75	5.25	7.5	10.75	15.0	13.0	8.25	9.25	9.25	7.0	3.75	2.0	102.0
15-30	2.0	3.0	2.25	5.25	7.0	7.0	6.25	7.0	6.5	6.75	2.75	2.5	1.25	59.5
30-45	0.75	1.0	1.25	4.0	3.25	6.0	6.0	6.0	5.75	5.5	1.5	1.5	2.25	44.75
45-60	0.25	1.25	0.5	0.5	1.5	2.25	3.25	4.5	4.75	5.25	1.75	1.75	0.75	28.25
60-75	0.5	0.5	0.5	0.25	0.5	1.0	2.5	4.0	4.25	5.5	1.0	1.5	1.75	23.75
75-90	0.75	0.5	1.25	0.75	0.75	0.5	1.75	3.25	3.75	4.0	2.0	0.75	1.75	21.75
90-120	0.0	0.0	0.0	0.0	0.0	0.0	0.25	2.25	2.0	4.5	2.75	2.0	1.25	15.0
120-150	0.0	0.0	0.0	0.0	0.0	0.0	0.25	1.25	2.0	2.5	2.0	0.75	3.25	12.0
150-180	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.25	1.5	2.0	1.25	1.0	8.0
180-210	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total (mm)	8.0	12.0	11.0	18.25	25.25	31.75	33.25	37.5	39.5	44.75	22.75	15.75	15.25	315.0

† average of 4 replications

Table 28. Soil water depletion pattern for the 1980 dryland soybean treatment.†

Soil depth increment (cm)	DATE													
	6/23	7/2	7/7	7/15	7/24	7/29	8/5	8/12	8/19	8/28	9/4	9/11	9/18	Total (mm)
0-15	1.75	2.75	5.0	2.25	3.5	6.25	0.5	0.25	0.25	0.25	0.5	1.5	0.0	24.75
15-30	2.5	3.75	2.0	1.5	1.5	2.5	1.5	1.25	0.75	0.75	0.25	1.0	0.0	19.25
30-45	0.75	2.5	0.5	0.5	1.0	2.0	1.25	1.25	0.5	1.0	0.25	0.5	1.0	13.0
45-60	0.75	1.5	0.75	0.0	0.75	1.25	0.5	1.25	0.75	0.25	0.75	0.5	0.25	9.25
60-75	0.25	1.0	0.75	0.25	0.0	0.0	1.25	0.5	0.25	1.0	0.25	0.25	0.0	5.75
75-90	0.0	0.0	0.0	0.5	0.25	0.0	0.75	0.5	0.5	0.5	0.0	1.0	0.0	4.0
90-120	0.0	0.0	0.0	0.0	0.0	0.0	0.25	1.0	0.25	0.75	0.25	1.5	0.5	4.5
120-150	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.25	0.75	0.25	1.6	0.25	3.6
150-180	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
180-210	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total (mm)	6.0	11.5	9.0	5.0	7.0	12.0	6.0	6.5	3.5	5.25	2.5	7.85	2.0	84.1

† average of 4 replications

Table 29. Soil water depletion pattern for the 1980 deficit soybean treatment.†

Soil depth increment (cm)	DATE 6/23	7/2	7/7	7/15	7/24	7/29	8/5	8/12	8/19	8/28	9/4	9/11	9/18	9/27	Total (mm)
0-15	2.75	3.25	5.0	6.5	9.0	12.5	10.5	10.75	9.0	9.0	8.0	3.25	2.5	0.5	92.5
15-30	2.75	3.5	1.75	4.5	3.25	4.25	3.0	6.25	4.25	6.75	7.0	3.25	0.5	0.25	51.25
30-45	0.0	1.0	1.0	1.75	0.75	1.5	1.25	1.5	3.25	3.75	2.25	2.0	0.0	1.0	21.0
45-60	0.25	1.25	0.25	1.75	0.75	1.25	1.0	2.25	1.75	1.75	2.25	0.75	0.25	0.5	16.0
60-75	0.25	1.25	0.25	1.5	0.75	0.75	1.25	1.25	1.5	2.25	1.0	1.25	0.25	1.0	14.5
75-90	0.25	1.0	0.0	1.25	0.5	1.25	1.25	2.0	1.0	1.0	0.75	0.25	0.75	0.25	11.5
90-120	0.0	0.0	0.0	0.0	0.0	0.0	0.25	0.25	0.25	0.5	0.25	1.75	0.75	0.5	4.5
120-150	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.25	0.0	0.25	0.25	1.75	0.75	1.25	4.5
150-180	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
180-210	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total (mm)	6.25	11.25	8.25	17.25	15.0	21.5	18.5	24.5	21.0	25.25	21.75	14.25	5.75	5.25	215.75

† average of 4 replications.

Table 30. Soil water depletion pattern for the 1980 optimum soybean treatment.†

Soil depth increment (cm)	DATE														
	6/23	7/2	7/7	7/15	7/24	7/29	8/5	8/12	8/19	8/28	9/4	9/11	9/18	9/27	Total (mm)
0-15	2.0	3.25	4.75	7.0	7.5	13.25	14.0	10.5	9.5	7.75	6.25	6.0	3.75	1.25	96.75
15-30	2.25	3.5	1.5	6.5	6.5	6.0	7.5	8.25	7.0	7.75	6.0	5.0	1.5	1.0	70.25
30-45	1.25	2.25	0.75	4.5	3.75	3.75	4.0	4.75	5.0	6.25	5.5	2.75	1.75	0.75	47.0
45-60	0.5	1.0	0.5	1.5	0.5	0.5	1.0	1.75	2.25	3.75	3.5	2.5	1.0	0.0	20.25
60-75	0.5	0.75	0.25	1.0	0.5	1.25	0.75	1.5	1.5	3.25	3.0	1.75	0.5	1.25	17.5
75-90	0.25	0.5	0.25	0.5	0.25	0.5	0.75	1.0	1.25	2.0	2.0	1.5	0.5	0.25	11.25
90-120	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.25	0.75	0.5	1.5	0.25	1.75	6.0
120-150	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.25	0.25	0.0	1.5	0.5	0.5	3.0
150-180	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
180-210	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total (mm)	6.75	11.25	7.75	21.0	19.0	25.25	28.0	28.75	27.0	31.75	26.75	22.5	9.75	6.5	272.0

† average of 4 replications.

Table 31. Potential ET as determined by 4 methods for June of 1981.†

June 1981	Blaney	Radiation	Penman	Corr. Pen.
01	5.340	5.741	4.896	5.468
02	3.259	3.367	3.363	3.590
03	3.773	3.895	3.714	4.035
04	3.458	2.706	3.226	3.274
05	1.865	1.578	2.115	2.119
05	1.678	1.586	2.101	2.095
07	3.577	3.370	3.446	3.646
08	1.138	.695	1.061	1.002
09	2.427	2.098	2.698	2.649
10	2.533	2.174	2.659	2.693
11	3.327	3.577	3.435	3.712
12	4.109	3.957	3.923	4.215
13	3.824	3.823	3.956	4.213
14	3.050	3.477	3.387	3.659
15	3.779	4.233	3.813	4.197
16	5.424	5.645	5.025	5.571
17	3.671	3.660	3.771	4.004
18	4.483	4.809	4.264	4.701
19	2.104	2.033	3.548	2.514
20	2.930	2.316	2.962	2.945
21	4.076	4.120	4.133	4.465
22	4.935	4.618	4.565	4.971
23	2.976	2.448	3.062	3.034
24	5.115	5.206	5.031	5.589
25	6.185	6.048	5.457	6.081
26	5.698	5.646	5.032	5.569
27	3.874	3.710	3.743	3.988
28	5.496	5.699	5.302	5.949
29	6.255	6.057	5.406	6.022
30	6.169	5.773	5.247	5.803
Total (mm)	116.526	114.057	113.339	121.773
Average per day (mm)	3.884	3.802	3.778	4.059

† ET is expressed in mm

Table 32. Potential ET as determined by 4 methods for July of 1981.†

July 1981	Blaney	Radiation	Penman	Corr. Pen.
01	3.355	2.988	3.511	3.534
02	6.935	6.886	7.030	7.767
03	7.362	6.776	6.204	6.933
04	6.330	5.825	5.226	5.760
05	6.133	5.444	5.301	5.832
06	4.160	3.501	3.846	3.995
07	1.844	1.063	1.729	1.650
08	3.877	3.618	3.923	4.079
09	5.811	5.805	5.185	5.750
10	4.118	4.050	4.025	4.319
11	3.786	4.021	3.866	4.191
12	4.662	4.959	4.469	4.933
13	5.660	5.469	5.096	5.634
14	4.724	3.088	4.504	4.691
15	7.203	6.521	6.388	7.107
16	6.054	5.694	5.193	5.737
17	5.594	5.549	4.948	5.468
18	4.420	4.253	4.061	4.398
19	4.511	4.463	4.220	4.605
20	5.396	5.154	4.966	5.474
21	5.539	5.180	5.124	5.644
22	5.381	5.132	4.942	5.449
23	5.155	4.876	4.554	5.001
24	4.362	3.660	3.864	4.044
25	4.176	3.780	3.843	4.064
26	6.756	5.755	5.510	6.078
27	8.295	6.350	6.459	7.130
28	6.876	5.512	5.348	5.841
29	4.956	4.744	4.382	4.811
30	3.028	2.221	2.888	2.868
31	5.757	5.572	5.077	5.641
Total (mm)	162.218	148.910	145.680	158.426
Average per day (mm)	5.233	4.804	4.699	5.111

† ET is expressed in mm

Table 33. Potential ET as determined by 4 methods for August of 1981.†

August 1981	Blaney	Radiation	Penman	Corr. Pen.
01	5.141	5.379	4.840	5.348
02	5.231	5.335	4.797	5.290
03	2.177	1.677	2.282	2.304
04	3.500	3.256	3.425	3.572
05	4.089	3.648	3.861	4.016
06	6.142	5.556	5.332	5.867
07	6.416	5.626	5.199	5.710
08	7.181	5.873	5.655	6.194
09	8.028	6.166	6.208	6.796
10	10.905	7.965	10.208	9.325
11	8.201	6.308	6.281	6.910
12	5.509	4.861	4.538	4.917
13	4.946	4.820	4.363	4.772
14	4.572	4.159	3.924	4.209
15	5.087	4.786	4.382	4.773
16	3.667	3.394	3.328	3,521
17	5.141	4.836	4.423	4.825
18	5.678	4.982	4.613	5.008
19	5.480	4.705	4.510	4.842
20	1.894	.720	1.412	1.342
21	2.501	1.989	2.425	2.458
22	5.014	4.726	4.255	4.637
23	5.764	4.964	4.523	4.905
24	5.845	4.865	4.781	5.112
25	4.183	3.567	3.614	3.753
26	3.042	2.430	2.764	2.811
27	4.384	4.047	3.754	4.001
28	6.174	5.086	5.043	5.433
29	5.130	4.326	3.994	4.261
30	2.998	2.233	2.728	2.700
31	2.908	2.109	2.641	2.623
Total (mm)	156.927	134.392	134.102	142.236
Average per day (mm)	5.062	4.335	4.326	4.588

† ET is expressed in mm

Table 34. Potential ET as determined by 4 methods for the first 18 days in September of 1981.†

September 1981	Blaney	Radiation	Penman	Corr. Pen.
01	4.072	3.856	3.844	4.006
02	3.474	3.308	3.423	3.510
03	4.392	4.405	4.164	4.438
04	3.760	3.934	3.563	3.793
05	4.091	3.960	3.899	4.067
06	5.259	4.816	4.979	5.225
07	6.946	5.596	6.420	6.553
08	5.092	4.129	3.960	4.161
09	4.543	3.914	3.690	3.874
10	2.055	1.362	2.244	2.136
11	4.764	4.334	4.353	4.536
12	5.265	4.437	4.437	4.628
13	4.726	4.197	3.912	4.116
14	4.471	4.005	3.507	3.716
15	5.001	4.196	3.798	4.008
16	5.554	4.163	4.155	4.305
17	4.144	3.306	3.306	3.401
18	3.527	3.127	2.983	3.083
Total (mm)	81.136	71.046	70.638	73.557
Average per day (mm)	4.508	3.947	3.924	4.087

† ET is expressed in mm

Table 35. Soil water depletion pattern for the 1981 dryland sunflower treatment.†

Soil depth increment (cm)	DATE 6/15	6/25	7/5	7/16	7/27	8/6	8/17	8/27	9/6	9/16	Total (mm)
0-15	4.0	8.0	5.25	5.5	2.0	1.25	0.5	0.25	0.0	0.0	26.75
15-30	3.0	3.75	5.0	3.5	1.75	0.5	1.25	2.0	0.0	0.5	21.25
30-45	2.0	2.5	3.0	4.0	1.75	0.75	2.0	0.0	0.25	0.5	16.75
45-60	1.0	0.0	2.0	5.5	3.25	1.0	1.25	2.0	1.0	0.75	17.75
60-75	0.0	0.0	1.5	3.0	5.75	2.0	2.0	2.5	0.75	0.25	17.75
75-90	0.0	0.0	0.75	2.75	4.5	3.25	3.25	2.25	1.5	0.25	18.5
90-120	0.0	0.0	0.5	1.5	4.5	6.75	13.0	3.0	2.75	1.25	33.25
120-150	0.0	0.0	0.75	0.25	2.75	3.5	7.25	3.5	3.25	0.75	22.0
150-180	0.0	0.0	0.0	0.0	0.5	0.75	4.75	3.75	5.75	2.0	17.5
180-210	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total (mm)	10.0	14.25	18.75	26.0	26.25	19.75	35.25	19.25	15.25	6.25	191.5

† average of 4 replications.

Table 36. Soil water depletion pattern for the 1981 deficit sunflower treatment.[†]

Soil depth increment (cm)	DATE 6/15	6/26	7/5	7/16	7/27	8/6	8/17	8/27	9/6	9/16	Total (mm)
0-15	4.0	8.25	8.5	9.25	7.5	11.75	11.0	1.5	1.0	1.5	64.25
15-30	2.75	5.0	6.0	7.75	4.25	11.75	10.75	0.25	1.75	0.5	50.75
30-45	2.0	3.0	3.5	5.0	4.0	3.0	4.75	0.75	0.75	0.5	27.25
45-60	1.0	1.25	2.0	4.25	3.5	0.75	2.0	1.75	1.5	1.5	19.5
60-75	0.0	0.25	1.5	3.5	3.75	1.0	2.5	2.5	1.25	4.0	20.25
75-90	0.0	0.0	1.0	1.5	4.0	2.75	2.75	2.75	1.75	3.75	20.25
90-120	0.0	0.0	0.0	0.25	3.25	4.0	9.25	5.5	4.25	2.0	28.5
120-150	0.0	0.0	0.0	0.0	1.5	3.0	5.5	3.0	5.25	0.75	18.0
150-180	0.0	0.0	0.0	0.0	0.75	1.0	1.0	4.25	4.75	2.25	14.0
180-210	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total (mm)	9.75	17.75	22.5	31.5	32.5	38.0	49.50	22.25	22.25	16.75	262.75

[†] average of 4 replications

Table 37. Soil water depletion pattern for the 1981 optimum sunflower treatment.†

Soil depth increment (cm)	DATE 6/15	6/25	7/5	7/16	7/27	8/6	8/17	8/27	9/6	9/16	Total (mm)
0-15	4.0	6.75	8.75	8.25	9.75	8.75	10.5	2.5	3.0	1.25	63.5
15-30	3.0	4.0	6.25	8.0	9.5	9.5	10.75	1.75	2.5	0.25	55.5
30-45	2.0	2.25	3.75	6.25	8.25	8.25	9.25	1.25	3.25	2.0	46.5
45-60	1.0	0.75	0.5	3.0	5.5	5.75	6.5	3.0	2.25	1.75	30.0
60-75	0.0	0.0	0.75	2.25	4.5	5.0	7.5	3.25	1.5	1.25	26.5
75-90	0.0	0.0	1.25	2.0	2.5	3.25	7.25	3.5	2.5	1.25	23.5
90-120	0.0	0.0	0.0	0.25	2.25	2.0	2.25	3.75	4.0	6.0	20.5
120-150	0.0	0.0	0.0	0.0	0.25	1.0	2.5	2.75	3.5	2.25	12.25
150-180	0.0	0.0	0.0	0.0	0.0	0.0	1.75	3.0	3.0	2.75	10.5
180-210	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total(mm)	10.0	14.25	21.25	30.0	42.5	43.5	58.25	25.25	25.0	18.75	288.75

† average of 4 replications.

Table 38. Soil water depletion pattern for the 1981 dryland soybean treatment.†

Soil depth increment (cm)	DATE 6/15	6/25	7/5	7/16	7/27	8/6	8/17	8/27	9/6	9/16	9/26	Total (mm)
0-15	2.0	3.5	4.25	5.0	2.25	1.25	2.75	0.0	1.25	0.0	1.5	23.75
15-30	1.0	0.5	2.5	3.25	2.25	1.0	1.5	0.25	0.75	1.0	0.25	14.25
30-45	1.0	0.25	1.5	1.75	1.75	1.5	2.0	0.0	1.75	0.5	0.0	12.0
45-60	0.0	0.25	0.75	1.25	2.25	1.25	2.0	1.25	0.75	0.25	0.25	10.25
60-75	0.0	0.75	0.25	0.75	1.25	1.0	2.5	0.25	1.5	2.0	0.0	10.25
75-90	0.0	0.0	1.0	0.0	0.25	0.75	2.0	0.25	2.25	1.0	0.25	7.75
90-120	0.0	0.0	0.0	0.5	0.0	0.5	2.0	0.75	2.0	0.75	0.75	6.5
120-150	0.0	0.0	0.0	0.0	0.0	0.25	1.0	1.0	1.25	0.5	0.75	4.75
150-180	0.0	0.0	0.0	0.0	0.0	0.0	0.75	0.25	1.5	1.25	0.25	4.0
180-210	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total (mm)	4.0	5.25	10.25	12.5	10.0	7.5	16.5	4.0	13.0	7.25	3.25	93.5

† average of 4 replications.

Table 39. Soil water depletion pattern for the 1981 deficit soybean treatment.†

Soil depth increment (cm)	DATE 6/15	6/25	7/5	7/16	7/27	8/6	8/17	8/27	9/6	9/16	9/26	Total (mm)
0-15	2.0	4.5	7.5	7.5	9.75	8.75	13.0	9.75	4.75	2.25	2.75	73.0
15-30	1.25	1.25	3.25	4.25	5.25	8.5	10.25	8.25	4.0	2.25	1.25	49.75
30-45	1.0	0.25	1.25	2.5	2.5	5.5	9.25	7.5	4.25	2.0	1.0	37.0
45-60	0.0	0.5	1.25	1.75	2.0	4.25	6.25	6.25	4.5	2.75	0.5	30.0
60-76	0.0	0.25	0.75	1.0	0.5	2.0	2.5	3.0	3.0	3.75	2.0	18.75
75-90	0.0	0.0	0.5	1.0	0.5	2.0	1.0	3.25	3.0	2.75	3.25	14.75
90-120	0.0	0.0	0.0	0.0	0.0	0.5	1.0	0.25	2.5	2.5	0.5	7.25
120-150	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	1.75	3.0	0.0	5.75
150-180	0.0	0.0	0.0	0.0	0.0	0.0	0.25	0.0	1.0	1.75	0.25	3.25
180-210	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total (mm)	4.25	6.75	14.5	18.0	20.5	31.5	42.0	38.75	28.75	23.0	11.5	239.5

Table 40. Soil water depletion pattern for the 1981 optimum soybean treatment.†

Soil depth increment (cm)	DATE 6/15	6/25	7/5	7/16	7/27	8/6	8/17	8/27	9/6	9/16	9/26	Total (mm)
0-15	2.0	6.0	7.75	9.75	10.25	10.75	14.0	10.75	6.25	3.75	0.0	81.25
15-30	1.25	2.0	5.0	7.0	8.5	9.25	13.0	8.75	6.5	2.75	1.5	65.5
30-45	1.0	0.25	2.5	4.0	4.5	6.0	8.75	6.5	5.75	2.75	0.5	42.5
45-60	0.0	0.25	0.25	1.75	2.25	3.75	6.75	6.0	4.5	2.5	0.0	28.0
60-75	0.0	0.0	0.5	1.25	1.25	1.5	3.75	2.75	5.25	3.5	1.25	21.0
75-90	0.0	0.0	0.25	0.75	1.0	1.0	2.0	1.75	3.75	3.75	0.0	14.75
90-120	0.0	0.0	0.0	0.0	0.25	0.0	1.25	1.0	3.75	1.5	0.5	8.25
120-150	0.0	0.0	0.0	0.0	0.0	0.0	0.75	0.0	1.0	2.5	0.0	4.25
150-180	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.5	0.0	2.5
180-210	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total (mm)	4.25	8.5	16.25	24.5	28.0	32.35	50.75	37.5	37.75	24.5	3.75	208.0

† average 4 replications.

DELIBERATE BLANK PAGE

Table 41. Cubic polynomial exponential equation describing the relationship of cumulative ET and days after emergence in the 1980 dryland sunflower treatment.

$$ET(cm) = \ln(-4.31 + 0.20X - 0.002X^2 + 0.00007X^3)$$

Source	df	Mean square
Total	12	
Regression	2	3.03
Error	9	0.008

$R^2 = 0.99$

Days after emergence	Observed ET†	C.V. (%)	Predicted ET
28	0.8	14.1	0.9
36	1.9	9.5	1.8
41	3.2	10.3	2.6
49	3.9	9.7	4.3
56	5.8	10.1	5.8
63	6.9	12.3	7.3
70	8.2	9.6	8.6
77	9.5	9.7	9.7
84	10.7	10.2	10.6
93	11.9	11.1	11.5
100	13.3	8.9	12.4
107	13.8	9.3	13.6
114	14.6	10.0	15.4

† average of 4 replications

Table 42. Cubic polynomial exponential equation describing the relationship of total dry matter production and days after emergence in the 1980 dryland sunflower treatment.

$$\text{Total dry weight (g m}^{-2}) = \ln(-7.05 + 0.41X - 0.004X^2 + 0.00002X^3)$$

Source	df	Mean square
Total	11	
Regression	3	4.91
Error	8	0.05

$R^2 = 0.98$

Days after emergence	Observed total dry wt. (g m^{-2})†	C.V. (%)	Predicted total dry wt. (g m^{-2})
35	17.4	9.1	15.5
42	29.4	5.3	43.6
49	118.7	6.7	96.7
56	237.2	15.2	175.9
63	261.2	8.6	268.3
70	288.9	13.1	355.9
77	426.2	11.7	422.6
84	420.8	9.5	463.7
93	471.0	7.6	489.5
100	576.0	14.3	504.5
107	608.6	9.7	532.4
114	524.1	11.2	593.8

† average of 4 replications.

Table 43. Cubic polynomial exponential equation describing the relationship of leaf dry weight with days emergence in the 1980 dryland sunflower treatment.

$$\text{Leaf wt. } (\text{g m}^{-2}) = \ln(-5.38 + 0.32X - 0.003X^2 + 0.0001X^3)$$

Source	df	Mean square
Total	11	
Regression	3	2.53
Error	8	0.03

$R^2 = 0.98$

Days after emergence	Observed leaf wt. (g m^{-2})†	C.V. (%)	Predicted leaf wt. (g m^{-2})
35	9.3	8.5	10.7
42	20.8	11.3	15.0
49	39.1	12.1	41.5
56	62.3	6.9	76.1
63	86.2	7.7	95.2
70	105.9	16.2	91.0
77	118.3	15.0	120.3
84	122.7	8.4	112.6
93	119.6	9.1	115.6
100	113.8	12.2	118.8
107	108.3	13.0	131.6
114	105.1	8.6	97.4

† average of 4 repolications.

Table 44. Cubic polynomial exponential equation decribing the relationship of stem dry weight with day after emergence in the 1980 dryland sunflower treatment.

$$\text{Stem wt. } (g\ m^{-2}) = \ln(-12.73 + 0.63X - 0.007X^2 - 0.00003X^3)$$

Source	df	Mean square
Total	11	
Regression	3	4.31
Error	8	0.06

Days after emergence	Observed leaf wt. ($g\ m^{-2}$)	C.V. (%)	Predicted leaf wt. ($g\ m^{-2}$)
35	6.7	7.3	5.8
42	14.4	8.7	22.7
49	77.2	14.1	60.7
56	161.1	9.6	116.7
63	166.0	11.5	171.5
70	155.8	13.9	203.7
77	207.9	8.7	206.7
84	190.6	14.0	189.7
93	143.5	11.8	160.4
100	170.2	8.1	144.3
107	155.4	7.6	141.3
114	143.3	9.5	159.0

† average of 4 replications.

Table 45. Cubic polynomial exponential equation describing the relationship of head dry weight and days after emergence in the 1980 dryland sunflower treatment.

$$\text{Head wt. } (g\ m^{-2}) = \ln(-27.9 - 0.95X - 0.009X^2 - 0.0003X^3)$$

Source	df	Mean square
Total	6	
Regression	3	0.27
Error	3	0.04

$R^2 = 0.87$

Days after emergence	Observed head weight ($g\ m^{-2}$)†	C.V. (%)	Predicted head weight ($g\ m^{-2}$)
70	42.1	18.1	45.6
77	96.4	7.9	80.0
84	104.4	11.7	110.2
93	116.0	11.2	128.0
100	115.3	13.3	126.3
107	149.4	7.9	118.6
114	102.2	6.8	112.2

† average of 4 replications.

Table 46. Cubic polynomical exponential equation describing the relationship between seed dry weight and days after emergence in the 1980 dryland sunflower treatment.

$$\text{Seed wt. } (g\ m^{-2}) = \ln(-121.6 + 3.2X - 0.027X^2 - 0.00007X^3)$$

Source	df	Mean square
Total	5	
Regression	3	6.45
Error	2	0.02

$R^2 = 0.99$

Days after emergence	Observed seed weight $(g\ m^{-2})^{\dagger}$	C.V. (%)	Predicted seed weight $(g\ m^{-2})$
70	1.5	14.0	1.4
77	12.8	8.4	14.4
84	96.0	7.3	86.2
100	171.6	9.2	166.8
107	182.3	12.6	200.9
114	181.7	13.0	175.0

† average of 4 replications.

Table 47. Cubic polynomial exponential equation describing the relationship of leaf area index (LAI) and days after emergence in the 1980 sunflower treatment.

$$LAI = \ln(-6.62 + 0.22X - 0.002X^2 + 0.000008X^3)$$

Source	df	Mean square
Total	11	
Regression	3	0.89
Error	8	0.01

$R^2 = 0.97$

Days after emergence	Observed LAI†	C.V. (%)	Predicted LAI
35	0.27	5.9	0.26
42	0.38	7.1	0.45
49	0.75	13.3	0.68
56	1.02	6.6	0.92
63	1.15	5.9	1.12
70	1.12	11.2	1.25
77	1.25	13.3	1.31
84	1.25	9.7	1.29
93	1.21	8.8	1.20
100	1.32	10.6	1.10
107	0.88	11.3	1.01
114	0.95	9.9	0.93

† average of 4 replications.

Table 48. Relative growth rate (RGR), leaf area ratio (LAR), leaf weight ratio (LWR), specific leaf area (SLA) and relative leaf growth rate (RLGR) in the 1980 dryland sunflower treatment.

Days after emergence	RGE ($g\ g^{-1}\ day^{-1}$)	LAR ($cm^2\ g^{-1}$)	LWR ($g\ g^{-1}$)	SLA ($cm^2\ g^{-1}$)	RLGR ($cm^2\ cm^{-2}\ day^{-1}$)
42	0.17	167	0.60	279	0.09
49	0.13	103	0.48	216	0.07
56	0.10	70	0.40	174	0.05
63	0.07	52	0.35	148	0.03
70	0.05	42	0.32	130	0.02
77	0.03	35	0.30	118	0.01
84	0.02	31	0.28	111	0.00
93	0.01	28	0.27	104	-0.01
100	0.00	24	0.24	100	-0.01
127	0.00	22	0.23	97	-0.01
114	0.00	19	0.20	92	-0.01

Table 49. Cubic polynomial exponential equation describing the relationship of cumulative ET and days after emergence in the 1980 dryland soybean treatment.

$$ET = \ln(-4.41 + 0.02X - 0.002X^2 + 0.000008X^3)$$

Source	df	Mean square
Total	13	
Regression	3	2.37
Error	10	0.02

$R^2 = 0.98$

Days after emergence	Observed ET†	C.V. (%)	Predicted ET
28	0.6	12.0	0.7
36	1.8	8.9	1.5
41	2.6	10.3	2.1
49	3.2	9.7	3.3
56	3.9	11.5	4.3
63	5.0	5.8	5.3
70	5.7	9.2	6.0
77	6.3	5.9	6.5
84	6.7	6.3	6.8
93	7.2	7.9	7.0
100	7.4	6.8	7.2
107	8.2	7.1	7.5
114	8.4	5.2	8.0
123	8.4	5.0	9.0

† average of 4 replications

Table 50. Cubic polynomial exponential equation describing the relationship of total dry matter production and days after emergence in the 1980 dryland soybean treatment.

$$\text{Total dry wt. } (g\ m^{-2}) - \ln(-0.04 + 0.1X - 0.0003X^2 - 0.000001X^3)$$

Source	df	Mean square
Total	12	
Regression	3	2.91
Error	9	0.02

$R^2 = 0.98$

Days after emergence	Observed total dry wt. ($g\ m^{-2}$)†	C.V. (%)	Predicted total dry wt. ($g\ m^{-2}$)
35	22.8	6.8	22.1
42	29.9	9.3	36.9
49	71.3	12.8	58.3
56	102.5	11.7	87.8
63	122.6	9.5	125.4
70	141.5	10.2	169.1
77	199.3	7.9	214.8
84	250.5	11.3	256.1
93	332.7	8.9	291.3
100	311.9	9.7	297.0
107	269.4	10.2	281.4
114	245.4	9.3	247.0
123	184.1	5.8	185.6

† average of 4 replications.

Table 51. Cubic polynomial exponential equation describing the relationship of leaf dry weight with days after emergence in the 1980 dryland soybean treatment.

$$\text{Leaf wt. } (g\ m^{-2}) = \ln(-0.89 + 0.12X - 0.0005X^2 - 0.000001X^3)$$

Source	df	Mean square
Total	11	
Regression	3	1.40
Error	8	0.02

$R^2 = 0.98$

Days after emergence	Observed leaf wt. ($g\ m^{-2}$)†	C.V. (%)	Predicted leaf wt. ($g\ m^{-2}$)
35	15.3	11.1	14.9
42	21.3	12.3	24.8
49	44.9	8.4	38.8
56	62.8	11.0	55.9
63	68.7	9.6	74.4
70	79.3	18.2	91.5
77	106.8	12.1	103.3
84	105.9	5.6	106.9
93	104.4	9.3	97.9
100	90.8	12.0	82.2
107	50.5	10.1	62.7
114	46.4	9.6	43.3

† average of 4 replications

Table 52. Cubic polynomial exponential equation describing the relationship of stem dry weight with days after emergence in the 1980 dryland soybean treatment.

$$\text{Stem wt. } (g\ m^{-2}) = \ln(-4.3 + 0.24X - 0.002X^2 + 0.000006X^3)$$

Source	df	Mean square
Total	12	
Regression	3	2.75
Error	9	0.02

$R^2 = 0.98$

Days after emergence	Observed stem wt. $(g\ m^{-2})$†	C.V. (%)	Predicted stem wt. $(g\ m^{-2})$
35	7.4	5.7	6.2
42	8.7	18.1	12.8
49	26.4	12.2	23.0
56	39.7	6.9	36.5
63	53.9	8.7	51.6
70	62.2	11.3	66.1
77	79.2	9.2	77.5
84	80.7	12.1	84.4
93	95.4	13.0	86.1
100	79.2	6.8	83.0
107	72.7	11.1	77.4
114	72.1	10.4	70.1
123	63.9	9.3	62.8

† average of 4 replications.

Table 53. Cubic polynomial exponential equation describing the relationship of pod dry weight with days after emergence in the 1980 dryland soybean treatment.

$$\text{Pod wt. } (g\ m^{-2}) = \ln(-89.4 + 2.6X - 0.002X^2 + 0.00007X^3)$$

Source	df	Mean square
Total	6	
Regression	3	0.90
Error	3	0.02

$R^2 = 0.98$

Days after emergence	Observed pod wt. (g m^{-2})†	C.V. (%)	Predicted pod wt. (g m^{-2})
77	11.3	8.7	12.3
84	47.8	9.6	39.4
93	73.1	14.2	78.4
100	75.7	12.7	85.6
107	74.9	11.5	74.2
114	67.0	10.6	59.2
123	47.1	9.3	49.5

† average of 4 replications.

Table 54. Cubic polynomial exponential equation describing the relationship of seed dry weight with days after emergence in the 1980 dryland soybean treatment.

$$\text{Seed wt. } (g\ m^{-2}) = \ln(-132.0 + 3.76X - 0.03X^2 + 0.0001X^3)$$

Source	df	Mean square
Total	5	
Regression	3	0.57
Error	2	0.02

$R^2 = 0.98$

Days after emergence	Observed Seed wt. (g m^{-2})†	C.V. (%)	Predicted Seed wt.(g m^{-2})
84	15.9	15.1	16.4
93	59.8	11.2	52.8
100	62.0	8.6	71.1
107	71.3	9.3	71.2
114	70.0	7.5	65.8
123	72 8	11.2	74.3

† average of 4 replications.

Table 55. Cubic polynomial exponential equation describing the relationship of leaf area index (LAI) and days after emergence in the 1980 dryland soybean treatment.

$$LAI = \ln(-0.98 - 0.07X + 0.002X^2 - 0.00001X^3)$$

Source	df	Mean square
Total	11	
Regression	3	1.53
Error	8	0.06

$R^2 = 0.98$

Days after emergence	Observed LAI†	C.V. (%)	Predicted LAI†
35	0.28	12.0	0.31
42	0.39	8.7	0.41
49	0.69	13.1	0.56
56	0.91	6.8	0.77
63	1.04	9.3	1.03
70	1.08	8.1	1.30
77	1.37	11.6	1.50
84	1.09	10.3	1.55
93	1.57	8.7	1.29
100	1.37	6.9	0.90
107	0.45	11.0	0.51
114	0.20	13.1	0.22

† average of 4 replications

Table 56. Relative growth rate (RGR), leaf area ratio (LAR), leaf weight ratio (LWR), specific leaf area (SLA), and relative leaf growth rate (RLGR) in the 1980 dryland soybean treatment.

Days after emergence	RGR ($g\ g^{-1}\ day^{-1}$)	LAR ($cm^2\ g^{-1}$)	LWR ($g\ g^{-1}$)	SLA ($cm^2\ g^{-2}$)	RLGR ($cm^2\ cm^{-2}\ day^{-1}$)
35	0.08	140	0.67	209	0.04
42	0.07	111	0.68	163	0.04
49	0.06	97	0.66	147	0.04
56	0.06	88	0.64	138	0.04
63	0.05	82	0.59	139	0.04
70	0.04	77	0.54	143	0.03
77	0.03	70	0.48	146	0.01
84	0.02	59	0.42	140	0.00
93	0.01	44	0.34	130	-0.04
100	0.00	30	0.28	107	-0.06
107	-0.00	18	0.22	82	-0.09
114	-0.02	15	0.18	83	-0.13
123	-0.03	0	0.00	0	0.00

Table 57. Cubic polynomial exponential equation describing the relationship of cumulative ET and days after emergence in the 1980 optimum sunflower treatment.

$$ET(cm) = \ln(-4.07 + 0.17X - 0.0014X^2 + 0.00004X^3)$$

Source	df	Mean square
Total	12	
Regression	3	5.499
Error	9	0.002

$R^2 = 1.00$

Days after emergence	Observed ET†	C.V. (%)	Predicted ET
28	0.8	4.6	0.9
36	2.0	7.8	1.9
41	3.1	14.3	2.9
49	4.9	11.2	5.1
56	7.5	7.8	7.7
63	10.6	6.9	10.9
70	14.0	5.3	14.4
77	17.7	8.2	17.9
84	21.7	7.3	21.3
93	26.1	6.8	25.2
100	28.4	6.2	27.8
107	30.0	5.4	30.1
114	31.5	5.0	32.1

† average of 4 replications.

Table 58. Cubic polynomial exponential equation describing the relationship of total dry matter production and days after emergence in the 1980 optimum sunflower treatment.

$$\text{Total dry wt. } (g\ m^{-2}) = (-9.18 + 0.49X - 0.005X^2 + 0.00002X^3)$$

Source	df	Mean sqaure
Total	11	
Regression	3	8.52
Error	8	0.06

$R^2 = 0.98$

Days after emergence	Observed total dry wt. ($g\ m^{-2}$)†	C.V. (%)	Predicted total dry wt. ($g\ m^{-2}$)
35	16.4	8.2	13.7
42	29.6	11.3	48.4
49	158.0	10.6	129.4
56	349.5	11.2	272.2
63	500.0	9.8	467.4
70	624.9	12.7	680.7
77	760.0	16.3	872.9
84	899.4	14.1	1023.7
93	1249.4	7.8	1170.9
100	1363.4	8.9	1290.1
107	1598.4	11.3	1471.5
114	1509.4	12.2	1604.5

† average of 4 replications.

Table 59. Cubic polynomial exponential equation describing the relationship of leaf dry weight and days after emergence in the 1980 optimum sunflower treatment.

$$\text{Leaf wt. } (g\ m^{-2}) = \ln(-6.68 + 0.36X - 0.004X^2 + 0.00001X^3)$$

Source	df	Mean square
Total	11	
Regression	3	5.06
Error	8	0.04

$R^2 = 0.98$

Days after emergence	Observed leaf wt. ($g\ m^{-2}$)†	C.V. (%)	Predicted leaf wt. ($g\ m^{-2}$)
35	10.1	11.3	8.5
42	15.1	12.1	22.9
49	60.1	10.7	50.6
56	97.3	8.4	93.3
63	171.5	13.0	146.9
70	183.3	9.6	201.9
77	268.8	7.5	248.1
84	236.6	11.2	278.4
93	280.0	8.4	293.3
100	305.6	11.3	291.8
107	321.2	10.1	285.5
114	262.4	9.6	281.3

Table 60. Cubic polynomial exponential equation describing the relationship of stem dry weight and days after emergence in the 1980 optimum sunflower treatment.

$$\text{Stem wt. (g m}^{-2}) = \ln(-13.9 + 0.7X - 0.007X^2 + 0.00003X^3)$$

Source	df	Mean square
Total	11	
Regression	3	8.12
Error	8	0.08

$R^2 = 0.98$

Days after emergence	Observed stem wt. (g m^{-2})†	C.V. (%)	Predicted stem wt. (g m^{-2})
35	6.2	3.8	5.3
42	14.5	14.2	24.6
49	97.9	9.5	78.3
56	252.2	11.0	177.7
63	327.5	6.9	304.7
70	377.7	10.1	417.7
77	349.0	11.3	483.4
84	463.0	7.5	499.5
93	545.5	8.4	482.1
100	523.0	16.1	473.4
107	566.7	9.3	497.9
114	516.8	9.3	582.8

† average of 4 replications.

Table 61. Cubic polynomial exponential equation describing the relationship of head dry weight and days after emergence in the 1980 optimum sunflower treatment.

$$\text{Head wt. } (g\ m^{-2}) = \ln(39.9 + 1.35X - 0.013X^2 + 0.00004X^3)$$

Source	df	Mean square
Total	6	
Regression	3	0.530
Error	3	0.009

$R^2 = 0.98$

Days after emergence	Observed dry wt. ($g\ m^{-2}$)†	C.V. (%)	Predicted dry wt. ($g\ m^{-2}$)
70	63.9	8.4	65.7
77	141.4	13.0	133.4
84	199.8	9.2	198.4
93	230.8	11.6	242.0
100	233.9	8.1	248.5
107	282.7	6.2	251.7
114	263.1	9.9	275.5

† average of 4 replications

Table 62. Cubic polynomial exponential equation describing the relationship of seed dry weight and days after emergence in the 1980 optimum sunflower treatment.

$$\text{seed wt. } (g\ m^{-2}) = \ln(-326.5 + 9.62X - 0.09X^2 + 0.0003X^3)$$

Source	df	Mean square
Total	5	
Regression	3	9.21
Error	2	0.08

$R^2 = 0.99$

Days after emergence	Observed seed wt. ($g\ m^{-2}$)†	C.V. (%)	Predicted seed wt. ($g\ m^{-2}$)
77	0.9	29.2	1.0
84	39.9	6.3	31.8
93	180.8	13.2	216.5
100	280.8	9.4	314.7
107	426.9	11.0	337.7
114	455.0	8.5	495.1

† average of 4 replications

Table 63. Cubic polynomial exponential equation describing the relationship of leaf area index (LAI) and days after emergence in the 1980 optimum sunflower treatment.

$$LAI = \ln(-8.62 + 0.28X - 0.002X^2 + 0.00006X^3)$$

Source	df	Mean square
Total	11	
Regression	3	3.83
Error	8	0.01

$R^2 = 0.99$

Days after emergence	Observed LAI†	C.V. (%)	Predicted LAI
35	0.25	11.0	0.21
42	0.40	8.6	0.50
49	1.11	10.1	1.04
56	1.80	6.8	1.81
63	3.03	7.9	2.77
70	3.59	10.2	3.74
77	5.01	10.6	4.54
84	4.74	11.3	5.03
93	4.83	9.7	5.08
100	4.92	8.5	4.73
107	3.96	10.3	4.18
114	3.69	10.0	3.55

Table 64. Relative growth rate (RGR), lear area ratio (LAR), leaf weight ratio (LWR), specific leaf area (SLA), and relative leaf growth rate (RLGR) in the 1980 optimum sunflower treatment.

Days after emergence	RGR ($g\ g^{-1}\ day^{-1}$)	LAR ($cm^2\ g^{-1}$)	LWR ($g\ g^{-1}$)	SLA ($cm^2\ g^{-1}$)	RLGR ($cm^2\ cm^{-2}\ day^{-1}$)
35	0.20	161	0.62	260	0.14
42	0.16	110	0.47	230	0.11
49	0.12	80	0.39	211	0.09
56	0.09	71	0.34	183	0.07
63	0.06	63	0.31	187	0.05
70	0.04	51	0.30	172	0.04
77	0.03	50	0.28	181	0.02
84	0.02	50	0.27	182	0.01
93	0.01	43	0.25	161	-0.01
100	0.01	43	0.23	172	-0.02
107	0.02	32	0.21	163	-0.02
114	0.02	23	0.19	160	-0.03

Table 65. Cubic polynomial exponential equation describing the relationship of cumulative ET and days after emergence in the 1980 optimum soybean treatment.

$$ET(cm) = \ln(-4.45 + 0.19X - 0.002X^2 - 0.000005X^3)$$

Source	df	Mean square
Total	13	
Regression	3	5.737
Error	10	0.002

$R^2 = 0.99$

Days after emergence	Observed ET†	C.V. (%)	Predicted ET
28	0.7	9.6	0.7
36	1.8	10.3	1.6
41	2.6	8.7	2.5
49	4.7	9.7	4.5
56	6.6	9.4	6.8
63	9.1	6.9	9.4
70	11.9	11.2	12.3
77	14.8	6.7	15.1
84	17.5	5.3	17.7
93	20.7	6.8	20.6
100	23.3	8.2	22.6
107	25.6	7.8	24.4
114	26.5	6.3	26.2
123	27.2	5.0	28.4

† average of 4 replications

Table 66. Cubic polynomial exponential equation describing the relationship of total dry matter production and days after emergence in the 1980 optimum soybean treatment.

$$\text{Total dry wt. } (g\ m^{-2}) = \ln(-0.48 + 0.19X + 0.00003X^2 - 0.000003X^3)$$

Source	df	Mean square
Total	12	
Regression	3	7.86
Error	9	0.01

$R^2 = 0.99$

Days after emergence	Observed total dry wt. ($g\ m^{-2}$)†	C.V. (%)	Predicted total dry wt. ($g\ m^{-2}$)
35	23.5	9.1	20.8
42	30.2	10.3	39.6
49	81.4	6.7	72.7
56	134.3	14.6	127.9
63	222.9	8.0	214.6
70	329.2	9.7	340.8
77	487.8	13.1	509.4
84	747.0	8.8	711.7
93	950.1	9.7	980.9
100	1143.4	11.2	1147.2
107	1308.8	9.6	1228.3
114	1108.4	10.3	1196.1
123	1022.9	8.7	995.3

† average of 4 replications.

Table 67. Cubic polynomial exponential equation describing the relationship of leaf dry weight and days after emergence in the 1980 optimum soybean treatment.

$$\text{Leaf wt. } (g\ m^{-2}) = \ln(-0.35 + 0.078X + 0.005X^2 - 0.000006X^3)$$

Source	df	Mean square
Total	11	
Regression	3	4.09
Error	8	0.01

$R^2 = 0.99$

Days after emergence	Observed leaf wt. (g m-2)†	C.V. (%)	Predicted leaf wt. ($g\ m^{-2}$)
35	15.9	12.3	14.6
42	21.4	10.1	26.7
49	53.8	16.0	47.2
56	84.3	8.4	79.5
63	127.6	9.3	126.4
70	179.3	6.8	186.9
77	241.9	12.2	253.8
84	331.4	7.1	312.5
93	319.7	9.4	346.0
100	330.0	8.6	324.0
107	285.6	11.2	263.5
114	175.6	10.0	183.7

† average of 4 replications.

Table 68. Cubic polynomial exponential equation describing the relationship of stem dry weight with days after emergence in the 1980 optimum soybean treatment.

$$\text{Stem wt. } (\text{g m}^{-2}) = \ln(-2.98 + 0.15X - 0.0003X^2 - 0.000003X^3)$$

Source	df	Mean square
Total	12	
Regression	3	7.24
Error	9	0.03

$R^2 = 0.99$

Days after emergence	Observed stem wt. (g m^{-2})†	C.V. (%)	Predicted stem wt. (g m^{-2})
35	7.6	4.8	5.9
42	8.9	9.1	13.1
49	27.6	7.3	26.8
56	50.1	12.6	50.9
63	95.4	8.8	89.4
70	149.9	11.2	143.7
77	210.4	9.8	210.4
84	307.8	10.3	278.9
93	343.8	7.6	343.0
100	363.8	11.5	354.4
107	313.9	10.2	324.3
114	205.9	9.8	262.0
123	192.4	12.6	164.0

† average of 4 replications

Table 69. Cubic polynomial exponential equation describing the relationship of pod dry weight with days after emergence in the 1980 optimum soybean treatment.

$$\text{Pod wt. } (g\ m^{-2}) = \ln(-57.9 + 1.70X - 0.015X^2 + 0.00005X^3)$$

Source	df	Mean square
Total	6	
Regression	3	1.58
Error	3	0.01

$R^2 = 0.99$

Days after emergence	Observed pod wt. ($g\ m^{-2}$)	C.V. (%)	Predicted pod wt. ($g\ m^{-2}$)
77	32.7	6.0	32.6
84	86.2	15.9	87.2
93	192.7	12.3	184.5
100	224.9	11.6	249.5
107	332.1	7.3	291.0
114	298.5	8.6	322.1
123	401.2	9.9	395.6

† average of 4 replications.

Table 70. Cubic polynomial exponential equation describing the relationship of seed dry weight and days after emergence in the 1980 optimum soybean treatment.

$$\text{Seed wt. } (\text{g m}^{-2}) = \ln(-51.33 + 1.20X - 0.008X^2 + 0.00002X^3)$$

Source	df	Mean square
Total	5	
Regression	3	2.342
Error	2	0.003

$R^2 = 0.99$

Days after emergence	Observed seed wt. (g m^{-2})†	C.V. (%)	Predicted seed wt. (g m^{-2})
84	21.6	8.5	21.3
93	94.9	10.3	98.8
100	224.9	11.6	220.1
107	377.4	9.2	360.9
114	428.5	9.7	450.6
123	429.2	8.4	423.8

† average of 4 replications.

Table 71. Cubic polynomial exponential equation describing the relationship of leaf area index (LAI) and days after emergence in the 1980 optimum soybean treatment.

$$LAI = \ln(-3.7 + 0.04X + 0.001X^2 - 0.000009X^3)$$

Source	df	Mean square
Total	11	
Regression	3	4.48
Error	8	0.01

$R^2 = 0.99$

Days after emergence	Observed LAI†	C.V. (%)	Predicted LAI
35	0.28	11.0	0.26
42	0.40	8.5	0.47
49	0.87	7.6	0.83
56	1.45	12.2	1.43
63	2.54	13.7	2.35
70	3.66	8.2	3.60
77	4.70	9.1	5.07
84	6.69	6.5	6.38
93	6.46	19.3	7.09
100	6.20	8.4	6.47
107	5.94	9.2	4.96
114	2.90	10.0	3.13

† average of 4 replications.

Table 72. Relative growth rate (RGR) leaf area ratio (LAR), leaf weight ratio (LWR), specific leaf area (SLA), and relative leaf growth rate (LRGR) in the optimum soybean treatment.

Days after emergence	RGR ($g\ g^{-1}\ day^{-1}$)	LAR ($cm^2\ g^{-1}$)	LWR ($g\ g^{-1}$)	SLA ($cm^2\ g^{-1}$)	RLGR ($cm^2\ cm^{-2}\ day^{-1}$)
35	0.09	125	0.70	178	0.08
42	0.09	119	0.67	176	0.08
49	0.08	114	0.65	176	0.08
56	0.08	112	0.62	180	0.07
63	0.07	110	0.59	187	0.07
70	0.06	106	0.55	193	0.06
77	0.05	99	0.50	198	0.04
84	0.04	90	0.44	205	0.03
93	0.03	72	0.35	204	0.00
100	0.02	56	0.28	198	-0.02
107	0.03	40	0.21	186	-0.05
114	-0.01	26	0.15	169	-0.08

Table 73. Canopy light interception and leaf area index at flowering in the 1980 sunflower treatments and at pod fill in the 1980 soybean treatments.†

SUNFLOWER

Treatment	Canopy light interception (C.V.)	LAI (C.V.)
Dryland	0.32 (12%)	0.90 (8.2%)
Severe deficit	0.49 (10%)	1.34 (7.4%)
Deficit	0.94 (10%)	2.51 (4.6%)
Optimum	0.98 (2%)	3.33 (8.2%)
Over-irrigated	0.99 (3%)	3.83 (9.3%)

SOYBEAN

Dryland	0.40 (7%)	0.77 (9.1%)
Severe deficit	0.53 (6%)	1.89 (8.3%)
Deficit	0.99 (8%)	4.38(16.1%)
Optimum	0.99 (2%)	6.51(15.2)
Over-irrigated	0.99 (3%)	6.86 (7.9%)

† average of 4 replications

Table 74. Cubic polynomial exponential equation describing the relationship of cumulative ET with days after emergence in the 1981 dryland sunflower treatment.

$$ET(cm) = \ln(-3.19 + 0.14X - 0.001X^2 + 0.000003X^3)$$

Source	df	Mean square
Total	9	
Regression	3	2.912
Error	6	0.003

$R^2 = 1.0$

Days after emergence	Observed ET†	C.V. (%)	Predicted ET
30	1.0	8.9	1.1
42	2.4	10.3	2.2
53	4.3	11.6	4.3
65	6.9	10.5	6.9
74	9.6	13.1	10.0
86	11.6	14.2	12.1
96	15.2	11.7	14.7
106	17.0	9.5	16.5
116	18.6	10.6	18.1
126	19.2	11.0	19.8

† average of 4 replications.

Table 75. Cubic polynomial exponential equation describing the relationship of total dry matter production and days after emergence in the 1981 dryland sunflower treatment.

$$\text{Total dry wt. } (g\ m^{-2}) = \ln(-4.20 + 0.29X - 0.003X^2 + 0.000007X^3)$$

Source	df	Mean square
Total	8	
Regression	3	2.69
Error	5	0.03

$R^2 = 0.99$

Days after emergence	Observed total dry wt. ($g\ m^{-2}$)†	C.V. (%)	Predicted total dry wt. ($g\ m^{-2}$)
40	41.8	8.6	47.2
52	221.9	15.1	161.8
63	293.6	9.7	348.8
75	546.2	10.8	583.5
84	730.1	11.2	719.8
96	752.3	7.5	800.9
106	881.2	14.3	791.8
116	775.2	9.6	749.5
126	676.0	8.7	710.1

† average of 4 replications.

Table 76. Cubic polynomial exponential equation describing the relationship of leaf weight and days after emergence in the 1981 dryland sunflower treatment.

$$\text{Leaf wt. } (\text{g m}^{-2}) = \ln(-3.75 + 0.28X - 0.003X^2 + 0.00001X^3)$$

Source	df	Mean square
Total	7	
Regression	3	0.58
Error	4	0.02

$R^2 = 0.98$

Days after emergence	Observed leaf wt. (g m^{-2})	C.V. (%)	Predicted leaf wt. (g m^{-2})
40	23.7	11.0	26.0
52	74.2	12.1	58.6
63	81.5	10.3	87.1
75	91.0	7.4	103.4
84	101.7	6.9	105.1
96	106.1	12.1	101.8
106	116.2	11.0	102.1
116	104.5	8.5	113.4

† average of 4 replications.

Table 77. Cubic polynomial exponential equation describing the relationship of stem weight and days after emergence in the 1981 dryland sunflower treatment.

$$\text{Stem wt. } (g\ m^{-2}) = \ln(-10.26 + 0.49X - 0.005X^2 + 0.00002X^3)$$

Source	df	Mean square
Total	8	
Regression	3	2.984
Error	5	0.002

R^2 1.0

Days after emergence	Observed stem wt. ($g\ m^{-2}$)†	C.V. (%)	Predicted stem wt. ($g\ m^{-2}$)
40	13.1	7.2	13.2
52	74.2	8.7	73.0
63	187.5	9.3	188.3
75	312.5	10.7	311.9
84	350.7	11.8	348.4
96	302.6	19.5	321.3
106	293.0	6.8	273.1
116	230.7	8.4	235.4
126	225.4	12.2	225.9

† average of 4 replications.

Table 78. Cubic polynomial exponential equation describing the relationship of head weight and days after emergence in the 1981 dryland sunflower treatments.

$$\text{Head wt. } (\text{g m}^{-2}) = \ln(-37.9 + 1.28X - 0.013X^2 + 0.00004X^3)$$

Source	df	Mean square
Total	6	
Regression	3	1.0418
Error	3	0.0005

$R^2 = 1.0$

Days after emergence	Observed head wt. (g m^{-2})†	C.V. (%)	Predicted head wt. (g m^{-2})
63	24.6	8.6	26.6
75	142.7	12.2	124.1
84	205.8	7.5	201.5
96	164.4	9.7	215.0
106	206.7	11.8	179.3
116	168.0	12.0	155.9
126	170.3	6.8	179.7

† average of 4 replications.

Table 79. Cubic polynomial exponential equation describing the relationship of seed weight and days after emergence in the 1981 dryland sunflower treatment.

$$\text{Seed wt. } (g\ m^{-2}) = \ln(-79.0 - 2.24X -).02X^2 + 0.00006X^3)$$

Source	df	Mean square
Total	5	
Regression	3	2.82
Error	2	0.02

$R^2 = 0.99$

Days after emergence	Observed dry wt. ($g\ m^{-2}\ day^{-1}$)	C.V. (%)	Predicted dry wt. ($g\ m^{-2}\ day^{-1}$)
75	10.1	6.8	10.5
84	71.9	12.2	64.0
96	179.2	9.7	201.9
106	265.3	11.3	261.0
116	271.9	10.6	258.1
126	270.2	8.5	276.5

Table 80. Cubic polynomial exponential equation describing the relationship of leaf area index (LAI) and days after emergence in the 1981 dryland sunflower treatment.

$$LAI = \ln(-7.58 + 0.27X - 0.003X^2 + 0.0001X^3)$$

Source	df	Mean square
Total	7	
Regression	3	0.425
Error	4	0.017

$R^2 = 0.98$

Days after emergence	Observed LAI†	C.V. (%)	Predicted LAI
40	0.48	8.2	0.50
52	1.27	9.6	1.11
63	1.40	7.5	1.64
75	1.84	14.3	1.87
84	2.06	8.2	1.79
96	1.40	9.7	1.52
106	1.31	5.6	1.30
116	1.15	9.2	1.15

† average of 4 replications.

Table 81. Relative growth rate (RGR), leaf area ratio (LAR), leaf weight ratio (LWR), specific leaf weight (SLW), and relative leaf growth rate (RLGR).

Days after emergence	RGR ($g\ g^{-1}\ day^{-1}$)	LAR ($cm^2\ g^{-1}$)	LWR ($g\ g^{-1}$)	SLA ($cm^2\ g^{-1}$)	RLGR ($cm^2\ cm^{-2}\ day^{-1}$)
40	0.12	106	0.55	191	0.09
52	0.08	69	0.36	190	0.05
63	0.06	47	0.25	193	0.02
75	0.03	32	0.18	182	0.01
84	0.02	25	0.15	171	0.00
96	0.00	19	0.13	152	-0.02
106	-0.01	16	0.13	120	-0.02
116	-0.01	15	0.15	100	-0.01
126	0.00	7	0.10	56	0.00

Table 82. Cubic polynomial exponential equation describing the relationship of cumulative ET and days after emergence in in the 1981 optimum sunflower treatment.

$$ET(cm) = \ln(-2.97 + 0.123X - 0.0008X^2 + 0.000002X^3)$$

Source	df	Mean square
Total	9	
Regression	3	3.47
Error	6	0.01

$R^2 = 0.99$

Days after emergence	Observed ET†	C.V. (%)	Predicted ET
30	1.0	6.9	1.1
42	2.5	11.3	2.2
53	4.7	9.1	4.7
65	7.7	7.3	8.0
75	11.7	10.2	12.6
84	16.2	9.5	16.4
96	22.3	11.1	21.3
106	25.6	6.6	24.9
116	27.6	8.3	27.6
126	28.9	7.0	29.6

† average of 4 replicaions.

Table 83. Cubic polynomial exponential equation describing the relationship of total dry matter production and days after emergence in the 1981 optimum sunflower treatment.

$$\text{Total dry wt. } (g\ m^{-2}) = \ln(-6.29 + 0.37X - 0.0034X^2 + 0.00001X^3)$$

Source	df	Mean square
Total	8	
Regression	3	3.66
Error	3	0.02

$R^2 = 0.99$

Days after emergence	Observed total dry wt. ($g\ m^{-2}$)	C.V. (%)	Predicted total dry wt. ($g\ m^{-2}$)
40	40.8	6.5	45.7
52	253.1	9.6	203.3
63	553.5	11.2	505.7
75	772.8	8.7	918.0
84	1037.2	14.3	1165.0
96	1383.0	9.1	1322.4
106	1488.7	7.6	1366.3
116	1382.8	11.2	1324.7
126	1285.4	9.6	1272.8

† average of 4 replications.

Table 84. Cubic polynomial exponential equation describing the relationship of leaf weight and days after emergence in the 1981 optimum sunflower treatment.

$$\text{Leaf wt. } (g\ m^{-2}) = \ln(-7.05 + 0.41X - 0.004X^2 + 0.00001X^3)$$

Source	df	Mean square
Total	7	
Regression	3	1.40
Error	4	0.01

$R^2 = 0.99$

Days after emergence	Observed dry wt. ($g\ m^{-2}$)†	C.V. (%)	Predicted dry wt. ($g\ m^{-2}$)
40	26.3	6.3	26.9
52	96.8	18.2	96.3
63	212.5	5.7	186.1
75	225.4	11.3	252.2
84	235.2	9.6	260.4
96	258.9	10.2	236.3
106	225.4	11.3	212.9
116	197.1	6.7	206.5

† average of 4 replications

Table 85. Cubic polynomial exponential equation describing the relationship of stem weight and days after emergence in the 1981 optimum sunflower treatment.

$$\text{Stem wt. } (\text{g m}^{-2}) = \ln(-10.85 + 0.52X - 0.005X^2 + 0.00002X^3)$$

Source	df	Mean square
Total	8	
Regression	3	3.951
Error	5	0.006

$R^2 = 1.00$

Days after emergence	Observed dry wt. (g m^{-2})†	C.V. (%)	Predicted dry wt. (g m^{-2})
40	15.3	8.7	16.0
52	95.8	11.2	93.7
63	274.1	9.6	239.0
75	339.2	15.1	376.8
84	378.6	12.7	403.4
96	347.6	9.3	359.2
106	328.8	8.9	309.5
116	311.8	7.3	287.2
126	301.8	12.0	321.0

† average of 4 replications.

Table 86. Cubic polynomial exponential equation describing the relationship between head weight and days after emergence in the 1981 optimum sunflower treatment.

$$\text{Head wt. (g m}^{-2}) = \ln(-18.7 + 0.63X - 0.005X^2 + 0.00002X^3)$$

Source	df	Mean square
Total	6	
Regression	3	1.48
Error	3	0.02

$R^2 = 0.99$

Days after emergence	Observed dry wt. (g m-2)†	C.V. (%)	Predicted dry wt. (g m-2)
63	34.2	10.8	33.7
75	120.4	9.6	119.2
84	185.7	11.3	210.6
96	362.0	9.1	309.0
106	346.6	8.8	340.3
116	297.3	12.6	337.9
126	349.5	10.1	331.7

† average of 4 replications.

Table 87. Cubic polynomial exponential equation describing the relationship of seed weight and days after emergence in the 1981 optimum sunflower treatment.

$$\text{Seed wt. } (g\ m^{-2}) = \ln(-90.5 + 2.48X - 0.02X^2 + 0.00006X^3)$$

Source	df	Mean square
Total	5	
Regression	3	5.36
Error	2	0.03

$R^2 = 1.00$

Days after emergence	Observed dry wt. ($g\ m^{-2}$)†	C.V. (%)	Predicted dry wt. ($g\ m^{-2}$)
75	5.0	8.8	5.0
84	49.7	11.3	49.5
96	250.0	14.0	244.1
106	370.3	9.2	391.5
116	443.9	8.7	424.7
126	443.0	11.3	448.4

† average of 4 replications.

Table 88. Cubic polynomial exponential equation describing the relationship of leaf area index (LAI) and days after emergence in the 1981 optimum sunflower treatment.

$$LAI = \ln(-8.92 + 0.32X - 0.003X^2 + 0.00001X^3)$$

Source	df	Mean square
Total	7	
Regression	3	1.221
Error	4	0.007

$R^2 = 0.99$

Days after emergence	Observed LAI[†]	C.V. (%)	Predicted LAI
40	0.53	8.2	0.56
52	1.89	10.3	1.70
63	3.11	9.6	3.15
75	4.06	11.4	4.36
84	4.50	10.2	4.66
96	4.55	6.8	4.36
106	4.06	7.3	3.84
116	3.24	6.8	3.37

[†] average of 4 replications.

Table 89. Relative growth rate (RGR), leaf area ratio (LAR), leaf weight ratio (LWR), specific leaf weight (SLW), and relative leaf growth rate (RLGR).

Days after emergence	RGR ($g\ g^{-1}\ day^{-1}$)	LAR ($cm^2\ g^{-1}$)	LWR ($g\ g^{-1}$)	SLA ($cm^2\ g^{-1}$)	RLGR ($cm^2\ cm^{-2}\ day^{-1}$)
40	0.15	123	0.59	209	0.12
52	0.10	84	0.47	177	0.07
63	0.07	62	0.37	168	0.04
75	0.04	48	0.27	175	0.01
84	0.02	40	0.22	179	0.00
96	0.00	33	0.18	185	-0.01
106	0.00	29	0.16	182	-0.02
116	0.00	0	0.16	0	-0.02

Table 90. Cubic polynomial exponential equation describing the relationship of cumulative ET and days after emergence in the 1981 dryland soybean treatment.

$$ET(cm) = \ln(-3.15 + 0.14X - 0.001X^2 + 0.000004X^3)$$

Source	df	Mean square
Total	10	
Regression	3	3.522
Error	7	0.004

$R^2 = 1.00$

Days after emergence	Observed ET†	C.V. (%)	Predicted ET
20	0.4	3.9	0.4
30	1.0	11.7	0.9
42	2.0	17.6	2.0
53	3.5	15.8	3.3
65	4.5	16.3	4.7
74	5.3	14.6	5.7
86	6.9	11.8	6.8
96	7.3	9.7	7.5
106	8.6	13.2	8.1
116	9.3	12.8	8.9
126	9.4	15.0	10.1

† average of 4 replications

Table 91. Cubic polynomial exponential equation describing the relationship of total dry weight and days after emergence in the 1981 dryland soybean treatment.

$$\text{Total dry wt. } (g\ m^{-2}) = \ln(-0.94 + 0.168X = 0.0013X^2 + 0.000003X^3)$$

Source	df	Mean square
Total	9	
Regression	3	3.20
Error	6	0.01

$R^2 = 0.99$

Days after emergence	Observed total dry wt. $(g\ m^{-2})$†	C.V. (%)	Predicted total dry wt. $(g\ m^{-2})$
30	20.1	8.4	21.5
42	70.3	9.9	63.0
53	134.6	7.8	133.8
65	257.3	10.2	243.9
74	295.3	11.3	330.9
86	391.4	6.9	425.5
96	464.8	9.6	464.2
106	505.7	7.8	461.1
116	455.0	10.2	423.9
126	340.9	8.5	366.6

† average of 4 replications.

Table 92. Cubic polynomial exponential equation describing the relationship of leaf weight and days after emergence in the 1981 dryland soybean treatment.

$$\text{Leaf wt. } (g\ m^{-2}) = \ln(-0.70 + 0.10X - 0.0005X^2 - 0.00001X^3)$$

Source	df	Mean square
Total	8	
Regression	3	2.832
Error	5	0.007

$R^2 = 0.99$

Days after emergence	Observed leaf wt. $(g\ m^{-2})$†	C.V. (%)	Predicted leaf wt. $(g\ m^{-2})$
30	14.3	12.3	15.8
42	46.0	9.7	37.3
53	70.8	14.0	73.3
65	127.8	6.8	128.7
74	150.0	7.5	168.9
86	177.6	6.9	190.4
96	172.5	13.6	164.1
106	132.5	8.7	109.1
116	48.1	9.4	54.3

† average of 4 replications.

Table 93. Cubic polynomial exponential equation describing the relationship of stem weight and days after emergence in the 1981 dryland soybean treatment.

$$\text{Stem wt. } (g\ m^{-2}) = \ln(-4.40 + 0.273X - 0.0025X^2 + 0.000007X^3)$$

Source	df	Mean square
Total	10	
Regression	3	3.494
Error	7	0.007

$R^2 = 0.99$

Days after emergence	Observed stem wt. ($g\ m^{-2}$)†	C.V. (%)	Predicted stem wt. ($g\ m^{-2}$)
30	5.8	16.1	5.9
42	24.3	12.0	24.8
53	63.6	8.7	62.1
65	128.6	13.3	116.1
74	137.2	9.1	150.5
86	165.6	8.5	170.2
96	166.4	9.3	163.5
106	131.8	11.2	144.3
116	138.7	10.6	122.4
126	104.1	15.0	104.2
136	90.2	6.6	92.9

† average of 4 replications.

Table 94. Cubic polynomial exponential equation describing the relationship of pod weight and days after emergence in the 1981 dryland soybean treatment.

$$\text{pod wt. } (g\ m^{-2}) = \ln(-37.1 + 0.96X - 0.007X^2 + 0.00002X^3)$$

Source	df	Mean square
Total	7	
Regression	3	8.39
Error	4	0.03

$R^2 = 1.00$

Days after emergence	Observed pod wt. ($g\ m^{-2}$)†	C.V. (%)	Predicted pod wt. ($g\ m^{-2}$)
65	0.9	11.0	0.9
74	7.6	8.7	6.8
86	39.6	6.8	40.3
96	87.9	11.3	97.6
106	148.5	8.7	153.7
116	220.3	10.2	174.7
126	133.8	9.1	159.2
136	134.5	13.0	129.3

† average of 4 replications.

Table 95. Cubic polynomial exponential equation describing the relationship of seed weight and days after emergence in the 1981 dryland soybean treatment.

$$\text{Seed wt. } (g\ m^{-2}) = \ln(-90.3 + 2.31X - 0.0187X^2 + 0.00005X^3)$$

Source	df	Mean square
Total	6	
Regression	3	14.57
Error	3	0.18

$R^2 = 1.00$

Days after emergence	Observed seed wt. ($g\ m^{-2}$)†	C.V. (%)	Predicted seed wt. ($g\ m^{-2}$)
74	0.3	6.0	0.3
86	8.7	8.8	8.4
96	38.0	11.3	41.0
106	92.9	10.2	86.1
116	101.9	11.7	105.6
126	102.9	6.9	102.4
136	106.4	14.1	106.3

† average of 4 replications.

Table 96. Cubic polynomial exponential equation describing the relationship of leaf area index (LAI) and days after emergence in the 1981 dryland soybean treatment.

$$LAI = \ln(-3.48 + 0.07X + 0.0003X^2 - 0.000006X^3)$$

Source	df	Mean square
Total	8	
Regression	3	1.69
Error	5	0.03

$R^2 = 0.98$

Days after emergence	Observed LAI†	C.V. (%)	Predicted LAI
30	0.26	8.6	0.29
42	0.77	10.3	0.66
53	1.31	9.1	1.25
65	2.12	9.0	2.11
74	2.20	11.2	2.65
86	2.49	7.6	2.74
96	2.39	8.4	2.13
106	1.49	9.3	1.24
116	0.46	15.6	0.52

† average of 4 replications.

Table 97. Relative growth rate (RGR), leaf area ratio (LAR), leaf weight ratio (LWR), specific leaf weight (SLW), and relative leaf growth rate (RLGR) in the 1981 dryland soybean treatment.

Days after emergence	RGR ($g\ g^{-1}$ day-1)	LAR ($cm^2\ g^{-1}$)	LWR ($g\ g^{-1}$)	SLA ($cm^2\ g^{-1}$)	RLGR ($cm^2\ cm^{-2}\ g^{-1}$)
30	0.10	135	0.73	185	0.07
42	0.08	105	0.59	178	0.07
53	0.06	94	0.55	171	0.05
65	0.04	87	0.53	164	0.03
74	0.03	80	0.51	157	0.02
86	0.01	64	0.45	142	-0.01
96	0.00	46	0.35	131	-0.04
106	-0.01	27	0.24	112	-0.07
116	-0.01	12	0.13	92	-0.10
126	-0.02	0	0.0	0	0.00

Table 98. Cubic polynomial exponential equation describint the relationship of cumulative ET and days after emergence in the 1981 optimum soybean treatment.

$$ET(cm) = \ln(-3.24 + 0.14X - 0.001X^2 + 0.000003X^3)$$

Source	df	Mean square
Total	10	
Regression	3	6.150
Error	7	0.005

$R^2 = 1.00$

Days after emergence	Observed ET†	C.V. (%)	Predicted ET
20	0.4	6.9	0.4
30	1.2	13.2	1.1
42	3.0	12.6	2.8
53	5.4	14.3	5.3
65	8.0	6.9	8.9
74	11.2	8.7	11.9
86	16.0	10.2	15.9
96	10.4	9.7	19.0
106	23.0	11.6	21.9
116	25.8	8.5	24.7
126	26.8	7.3	28.0

† average of 4 replications.

Table 99. Cubic polynomial exponential equation describing the relationship of total dry weight and days after emergence in the 1981 optimum soybean treatment.

$$\text{Total dry wt. } (\text{g m}^{-2}) = \ln(-2.09 + 0.22X - 0.0018X^2 + 0.000006X^3)$$

Source	df	Mean square
Total	9	
Regression	3	6.08
Error	6	0.01

$R^2 = 1.00$

Days after emergence	Observed total dry wt. (g m^{-2})†	C.V. (%)	Predicted total dry wt. (g m^{-2})
30	21.4	5.2	20.8
42	72.4	6.8	77.1
53	182.4	11.5	191.1
65	468.4	13.1	393.1
74	574.2	7.9	580.9
86	750.9	20.3	837.7
96	977.1	8.2	1031.3
106	1300.2	14.7	1203.6
116	1424.6	9.6	1377.5
126	1550.9	11.3	1598.1

† average of 4 replications

Table 100. Cubic polynomial exponential equation describing the relationship of leaf weight and days after emergence in the 1981 optimum soybean treatment.

$$\text{Leaf wt. (g m}^{-2}) = \ln(-1.15 + 0.15X - 0.008X^2 - 0.000002X^3)$$

Source	df	Mean square
Total	8	
Regression	3	3.241
Error	5	0.005

$R^2 = 1.00$

Days after emergence	Observed leaf wt. (g m^{-2})†	C.V. (%)	Predicted leaf wt. (g m^{-2})
30	14.8	13.0	14.8
42	45.5	10.5	45.4
53	97.8	8.7	103.3
65	220.9	6.9	201.2
74	282.8	11.8	283.1
86	337.1	9.3	360.9
96	357.9	12.4	366.6
106	339.8	10.1	313.8
116	219.4	9.7	226.2

† average of 4 replications.

Table 101. Cubic polynomial exponential equation describing the relationship of stem weight and days after emergence in the 1981 optimum soybean treatment.

$$\text{Stem wt. } (\text{g m}^{-2}) = \ln(-4.73 + 0.287X - 0.003X^2 + 0.000007X^3)$$

Source	df	Mean square
Total	10	
Regression	3	6.64
Error	7	0.02

$R^2 = 0.99$

Days after emergence	Observed stem wt. (g m^{-2})†	C.V. (%)	Predicted stem wt. (g m^{-2})
30	6.5	6.0	6.1
42	26.9	12.7	30.7
53	84.6	13.1	89.0
65	246.6	8.7	196.3
74	284.4	9.6	288.0
86	366.2	11.3	386.4
96	398.9	10.2	429.6
106	432.8	9.8	441.5
116	429.1	8.5	438.6
126	511.7	11.1	440.6
136	435.1	11.0	467.9

† average of 4 replications.

Table 102. Cubic polynomical exponential equation describing the relationship of pod weight and days after emergence in the 1981 optimum soybean treatment.

$$\text{Pod wt. } (g\ m^{-2}) = \ln(-22.1 + 0.47X - 0.002X^2 + 0.000006X^3)$$

Source	df	Mean square
Total	7	
Regression	3	11.63
Error	4	0.03

$R^2 = 1.00$

Days after emergence	Observed pod wt. ($g\ m^{-2}$)†	C.V. (%)	Predicted pod wt. ($g\ m^{-2}$)
65	1.2	9.4	1.0
74	5.1	10.3	6.4
86	42.2	11.1	42.3
96	167.7	8.7	133.9
106	287.4	10.1	291.2
116	387.7	9.3	436.6
126	445.4	10.5	453.1
136	339.4	6.5	326.4

† average of 4 replications.

Table 103. Cubic polynomial exponential equation describing the relationship of seed weight and days after emergence in the 1981 optimum soybean treatment.

$$\text{Seed wt. } (g\ m^{-2}) = \ln(-43.7 + 0.87X - 0.004X^2 + 0.000005X^3)$$

Source	df	Mean square
Total	6	
Regression	3	15.71
Error	3	0.05

$R^2 = 1.00$

Days after emergence	Observed seed wt. $(g\ m^{-2})$†	C.V. (%)	Predicted seed wt. $(g\ m^{-2})$
74	0.3	11.8	0.2
86	5.4	10.1	6.8
96	52.4	13.5	48.6
106	240.3	8.7	190.3
116	388.4	7.8	420.5
126	463.1	9.5	538.6
136	445.4	9.8	411.1

† average of 4 replications.

Table 104. Cubic polynomial exponential equation describing the relationship of leaf area index (LAI) and days after emergence in the 1981 optimum soybean treatment.

$$LAI = \ln(-6.15 + 0.194X - 0.0012X^2 + 0.0000008X^3)$$

Source	df	Mean square
Total	8	
Regression	3	3.71
Error	5	0.02

$R^2 = 0.99$

Days after emergence	Observed LAI†	C.V. (%)	Predicted LAI
30	0.25	12.0	0.25
42	0.87	7.0	0.92
53	2.18	8.6	2.34
65	5.76	14.9	4.81
74	6.81	5.7	6.77
86	7.21	6.3	8.07
96	7.49	11.1	7.84
106	7.02	9.2	6.21
116	3.76	14.7	3.94

† average of 4 replications.

Table 105. Relative growth rate (RGR), leaf area ratio (LAR), specific leaf weight (SLW), specific leaf area (SLA), and relative leaf growth rate (RLGR).

Days after emergence	RGR ($g\ g^{-1}\ day^{-1}$)	LAR ($cm^2\ g^{-1}$)	SLW ($g\ g^{-1}$)	SLA ($cm^2\ g^{-1}$)	RLGR ($cm^2\ cm^{-2}\ g^{-1}$)
30	0.13	118	0.71	166	0.09
42	0.09	119	0.59	202	0.09
53	0.07	122	0.54	226	0.07
65	0.05	122	0.51	239	0.05
74	0.04	117	0.49	239	0.03
86	0.02	98	0.43	229	0.00
96	0.02	76	0.36	214	-0.02
106	0.01	51	0.26	195	-0.04
116	0.01	28	0.16	175	-0.06
126	0.01	0	0.04	0	0.00

Table 106. Canopy light interception and leaf area index at flowering in the 1981 sunglower treatments and at pod fill in the 1981 soybean treatment.

	Canopy light interception (C.V.)	LAI (C.V.)
SUNFLOWER		
Dryland	0.73 (11.3%)	1.84 (14.7%)
Severe deficit	0.76 (5.8%)	2.00 (6.6%)
Deficit	0.89 (14.6%)	2.30 (19.4%)
Optimum	0.98 (5.7%)	3.86 (13.8%)
Over-irrigated	0.98 (2.9%)	3.33 (5.7%)
SOYBEAN		
Dryland	0.60 (8.5%)	2.22 (11.3%)
Severe deficit	0.77 (10.3%)	2.44 (8.6%)
Deficit	0.98 (11.4%)	4.59 (9.4%)
Optimum	0.99 (4.2%)	5.12 (8.2%)
Over-irrigated	1.0 (4.1%)	6.48 (12.6)

DELIBERATE BLANK PAGE

Table 107. Diurnal patterns of crop water status and associated measurements of the 1980 dryland and optimum sunflower treatments for July 15.†

DRYLAND

Time (Hour)	Leaf Ψ(MPa)	π(MPa)	P(MPa)	r_s(s cm^{-1})	Leaf T (°C)
6:30	-0.14	-0.94	0.80	0.	15.2
9:00	-0.33	-0.98	0.65	0.62	17.8
12:00	-0.72	-1.28	0.56	1.11	20.5
14:30	-1.00	-1.41	0.41	1.20	23.6
17:00	-0.59	-1.29	0.70	1.21	22.0
19:30	-0.38	-1.20	0.82	3.20	20.1
Average C.V. (%)	15.0	11.5	16.2	7.2	5.6

OPTIMUM

Time (Hour)	Leaf Ψ(MPa)	π(MPa)	P(MPa)	r_s(s cm^{-1})	Leaf T (°C)
6:30	-0.12	-0.95	0.83	0.47	15.6
9:00	-0.30	-0.98	0.68	0.69	17.5
12:00	-0.73	-1.20	0.47	0.94	20.3
14:30	-0.89	-1.39	0.50	0.56	24.0
17:00	-0.55	-1.31	0.76	0.88	23.7
19:30	-0.40	-1.25	0.85	2.51	20.5
Average C.V. (%)	13.8	11.7	15.1	6.5	5.0

† average of 4 replications.

Table 108. Diurnal patterns of crop water status and assocaited measurements of the 1980 dryland and optimum soybean treatments for July 15.†

DRYLAND

Time (Hour)	Leaf Ψ(MPa)	π(MPa)	P(MPa)	r_s(s cm^{-1})	Leaf T (°C)
6:30	-0.18	-1.19	1.01	0.60	15.3
9:00	-0.40	-1.23	0.83	1.17	18.3
12:00	-1.00	-1.30	0.30	1.31	22.8
14:30	-1.20	-1.44	0.24	1.28	25.3
17:00	-1.00	-1.48	0.48	1.53	23.3
19:30	-0.65	-1.30	0.65	3.17	20.6
Average C.V. (%)	12.7	11.3	10.9	6.8	9.2

OPTIMUM

Time (Hour)	Leaf Ψ(MPa)	π(MPa)	P(MPa)	r_s(s cm^{-1})	Leaf T (°C)
6:30	-0.08	-1.05	0.97	0.35	15.2
9:00	-3.00	-1.20	0.90	0.88	19.1
12:00	-0.78	-1.25	0.43	0.72	21.9
14:30	-0.91	-1.31	0.40	0.67	23.0
17:00	-0.70	-1.26	0.56	1.19	21.8
19:30	-0.40	-1.23	0.93	3.00	20.0
Average C.V. (%)	10.8	12.2	12.0	5.7	6.8

† average of 4 replications.

Table 109. Diurnal patterns of crop water status and associated measurements of the 1980 dryland optimum sunflower treatments for July 22.†

DRYLAND

Time (Hour)	Leaf Ψ(MPa)	π (MPa)	P(MPa)	r_s(s cm^{-1})	Leaf T (°C)
6:30	-0.25	-1.12	0.87	0.56	18.5
9:00	-0.60	-1.35	0.75	0.91	23.5
12:00	-1.12	-1.52	0.40	0.96	28.0
14:30	-1.26	-1.54	0.28	1.37	32.5
17:00	-0.98	-1.45	0.47	1.16	29.7
19:30	-0.54	-1.25	0.71	3.17	27.1
Average C.V. (%)	12.3	11.6	16.1	5.9	4.3

OPTIMUM

Time (Hour)	Leaf Ψ(MPa)	π (MPa)	P(MPa)	r_s(s cm^{-1})	Leaf T (°C)
6:30	-0.17	-1.01	0.84	0.35	18.0
9:00	-0.42	-1.26	0.74	0.62	23.0
12:00	-0.88	-1.35	0.47	0.49	26.5
14:30	-0.92	-1.39	0.47	0.56	29.0
17:00	-0.65	-1.20	0.55	0.57	26.0
19:30	-0.36	-1.23	0.87	2.31	25.7
Average C.V. (%)	8.7	12.6	14.1	5.0	4.2

† average of 4 replicaions.

Table 110. Diurnal patterns of crop water status and associated measurements of the 1980 dryland and optimum soybean treatments for July 22.†

DRYLAND

Time (Hour)	Leaf Ψ(MPa)	π(MPa)	P(MPa)	r_s(s cm^{-1})	Leaf T (°C)
6:30	-0.30	-1.23	0.93	1.01	19.3
9:00	-0.85	-1.40	0.55	1.63	23.7
12:00	-1.05	-1.43	0.38	2.01	28.9
14:30	-1.41	-1.50	0.09	3.17	34.8
17:00	-1.25	-1.45	0.20	2.52	30.0
19:30	-0.69	-1.46	0.75	4.61	27.5
Average C.V. (%)	11.5	-9.60	13.3	2.8	4.7

OPTIMUM

Time (Hour)	Leaf Ψ(MPa)	π(MPa)	P(MPa)	r_s(s cm^{-1})	Leaf T (°C)
6:30	-0.13	-1.09	0.96	0.71	19.0
9:00	-0.34	-1.17	0.83	0.75	22.9
12:00	-0.94	-1.29	0.35	0.97	28.2
14:30	-0.92	-1.35	0.43	0.88	32.9
17:00	-0.70	-1.30	0.60	0.78	28.2
19:30	-0.38	-1.22	0.84	2.26	26.1
Average C.V. (%)	14.6	12.0	13.9	3.8	6.2

† Average of 4 replications.

Table 111. Diurnal patterns of crop water status and associated measurements in the 1980 dryland and optimum sunflower treatments for July 29.†

DRYLAND

Time (Hour)	Leaf Ψ (MPa)	π(MPa)	P(MPa)	r_s(s cm^{-1})	Leaf T (°C)	CER(mg m^{-2} s^{-1})	PAR(μE m^{-2} s^{-1})
6:30	-0.26	-1.17	0.91	1.13	18.9	*	400
9:00	-0.85	-1.31	0.46	0.68	25.0	1.38	1200
12:00	-1.38	-1.58	0.20	0.87	31.5	1.15	1590
14:30	-1.40	-1.55	0.15	1.12	32.5	0.52	1640
17:00	-0.93	-1.46	0.43	0.87	28.1	*	1200
19:30	-0.65	-1.35	0.70	1.92	24.0	*	525
Average C.V. (%)	9.2	14.1	12.9	4.7	5.2	16.7	

OPTIMUM

Time (Hour)	Leaf Ψ (MPa)	π(MPa)	P(MPa)	r_s(s cm^{-1})	Leaf T (°C)	CER(mg m^{-2} s^{-1})	PAR(μE m^{-2} s^{-1})
6:30	-0.13	-1.02	0.94	0.56	18.3	*	400
9:00	-0.60	-1.25	0.65	0.61	24.0	1.63	1200
12:00	-0.99	-1.38	0.39	0.55	29.5	1.53	1590
14:30	-1.08	-1.45	0.37	0.88	31.0	1.38	1640
17:00	-0.62	-1.30	0.68	0.57	25.8	*	1200
19:30	-0.50	-1.30	0.80	2.28	23.1	*	525
Average C.V. (%)	12.0	15.5	7.9	3.8	5.6	18.2	

† average of 4 replications.

* no measurement taken.

Table 112. Diurnal patterns of crop water status and associated measurements in the 1980 dryland and optimum soybean treatments for July 29.†

Time (Hour)	Leaf Ψ (MPa)	π (MPa)	P (MPa)	r_s (s cm^{-1})	Leaf T (°C)	CER (mg m^{-2} s^{-1})	PAR (μE m^{-2} s^{-1})
DRYLAND							
6:30	-0.53	-1.43	0.90	1.28	19.1	*	400
9:00	-1.20	-1.56	0.36	2.17	25.5	0.53	1200
12:00	-1.60	-1.67	0.07	3.12	32.0	0.13	1590
14:30	-1.64	-1.65	-0.01	4.25	37.5	0.07	1640
17:00	-1.37	-1.57	0.20	2.63	31.4	*	1200
19:30	-0.90	-1.40	0.50	9.26	28.0	*	525
Average C.V. (%)	10.7	15.1	12.7	7.2	6.3	19.1	
OPTIMUM							
6:30	-0.17	-1.15	0.98	0.50	18.5	*	400
9:00	-0.58	-1.20	0.62	0.71	23.5	1.02	1200
12:00	-1.00	-1.32	0.32	0.80	29.0	0.95	1590
14:30	-1.14	-1.40	0.36	1.01	35.0	0.83	1640
17:00	-0.90	-1.30	0.40	0.88	29.2	*	1200
19:00	-0.63	-1.35	0.72	4.16	27.5	*	525
Average C.V. (%)	11.8	14.6	13.9	3.8	5.1	19.2	

† average of 4 replications.

* no measurement taken

Table 113. Diurnal patterns of crop water status and associated measurements in the 1980 dryland and optimum sunflower treatments for August 4.†

DRYLAND

Time (Hour)	Leaf Ψ (MPa)	π(MPa)	P(MPa)	r_s(s cm^{-1})	Leaf T (°C)	CER(mg m^{-2} s^{-1})	PAR(μE m^{-2} s^{-1})
6:30	-0.40	-1.25	0.85	5.21	15.7	*	220
9:00	-0.87	-1.50	0.63	0.51	20.0	1.15	1000
12:00	-1.24	-1.56	0.32	0.96	26.0	1.07	1400
14:30	-1.30	-1.60	0.30	0.82	28.5	1.20	1420
17:00	-0.95	-1.45	0.50	0.76	22.2	*	930
19:30	-0.62	-1.28	0.64	3.16	18.3	*	300
Average C.V. (%)	8.7	11.2	15.5	6.9	6.7	13.1	

OPTIMUM

Time (Hour)	Leaf Ψ (MPa)	π(MPa)	P(MPa)	r_s(s cm^{-1})	Leaf T (°C)	CER(mg m^{-2} s^{-1})	PAR(μE m^{-2} s^{-1})
6:30	-0.10	-1.10	0.10	2.63	15.0	*	220
9:00	-0.42	-1.21	0.79	0.33	19.1	1.56	1000
12:00	-0.80	-1.30	0.50	0.35	24.0	1.61	1400
14:30	-0.88	-1.35	0.47	0.50	26.2	1.53	1420
17:00	-0.60	-1.29	0.69	0.55	20.1	*	930
19:30	-0.41	-1.25	0.84	3.78	17.0	*	300
Average C.V. (%)	10.0	8.5	11.3	6.9	7.2	15.6	

† average of 4 replications.

* no measurements taken.

Table 114. Diurnal patterns of crop water status and associated measurements in the 1980 dryland and optimum soybean treatments for August 4.[†]

Time (Hour)	Leaf Ψ (MPa)	π (MPa)	P (MPa)	r_s (s cm^{-1})	Leaf T (°C)	CER (mg m^{-2} s^{-1})	PAR (μE m^{-2} s^{-1})
DRYLAND							
6:30	-0.60	-1.35	0.75	4.63	16.0	*	220
9:00	-1.13	-1.48	0.35	2.10	21.2	0.59	1000
12:00	-1.50	-1.59	0.09	4.63	28.5	0.15	1400
14:30	-1.55	-1.55	0.00	6.21	28.2	0.08	1420
17:00	-1.07	-1.61	0.54	3.20	24.6	*	930
19:30	-0.93	-1.51	0.58	8.87	20.0	*	300
Average C.V. (%)	12.0	12.6	15.1	6.2	7.9	11.8	
OPTIMUM							
6:30	-0.08	-1.17	1.09	2.53	15.5	*	220
9:00	-0.46	-1.23	0.77	0.87	20.6	1.00	1000
12:00	-0.78	-1.30	0.52	0.56	24.9	0.98	1400
14:30	-0.95	-1.41	0.46	0.69	26.1	0.93	1420
17:00	-0.63	-1.25	0.92	1.13	22.3	*	930
19:30	-0.39	-1.19	0.80	4.62	18.5	*	300
Average C.V. (%)	11.1	16.6	18.3	6.2	7.0	12.1	

† average of 4 replications.

* no measurements taken.

Table 115. Diurnal patterns of crop water status and associated measurements in the 1980 dryland and optimum sunflower treatments for August 11.†

Time (Hour)	Leaf Ψ (MPa)	π(MPa)	P(MPa)	r_s(s cm^{-1})	Leaf T (°C)	CER(mg m^{-2} s^{-1})	PAR(μE m^{-2} s^{-1})
			DRYLAND				
6:30	-0.40	-1.20	0.80	0.91	18.2	*	375
9:00	-0.95	-1.32	0.37	1.88	23.1	0.84	1050
12:00	-1.40	-1.60	0.20	1.16	30.0	0.55	1475
14:30	-1.51	-1.58	0.07	1.57	31.5	0.52	1580
17:00	-1.08	-1.46	0.38	1.89	28.7	*	940
19:30	-0.88	-1.38	0.50	3.63	25.9	*	360
Average C.V. (%)	15.1	6.7	11.9	4.6	5.9	17.1	
			OPTIMUM				
6:30	-0.12	-1.06	0.94	0.39	18.0	*	375
9:00	-0.45	-1.19	0.74	0.56	21.6	1.60	1050
12:00	-0.82	-1.35	0.53	0.82	27.3	1.73	1475
14:30	-0.93	-1.42	0.49	0.61	29.0	1.58	1580
17:00	-0.65	-1.35	0.70	0.91	26.2	*	940
19:30	-0.38	-1.28	0.90	3.16	24.0	*	360
Average C.V. (%)	11.6	9.7	14.3	8.2	5.1	16.6	

† average of 4 replications.

* no measurements taken.

Table 116. Diurnal patterns of crop water status and associated measurements in the 9180 dryland and optimum soybean treatments for August 11.†

DRYLAND

Time (Hour)	Leaf Ψ (MPa)	π (MPa)	P (MPa)	r_s (s cm^{-1})	Leaf T (°C)	CER (mg m^{-2} s^{-1})	PAR (μE m^{-2} s^{-1})
6:30	-0.73	-1.50	0.76	0.90	19.2	*	375
9:00	-1.18	-1.58	0.40	1.63	24.2	0.53	1050
12:00	-1.60	-1.52	-0.08	3.87	32.3	0.20	1475
14:30	-1.63	-1.63	0.00	4.13	35.0	0.13	1580
17:00	-1.45	-1.53	0.08	6.21	30.3	*	940
19:30	-1.05	-1.28	0.23	11.73	26.7	*	360
Average C.V. (%)	6.9	14.7	13.3	10.0	5.3	11.6	

OPTIMUM

Time (Hour)	Leaf Ψ (MPa)	π (MPa)	P (MPa)	r_s (s cm^{-1})	Leaf T (°C)	CER (mg m^{-2} s^{-1})	PAR (μE m^{-2} s^{-1})
6:30	-0.10	-1.19	1.09	0.51	18.0	*	375
9:00	-3.75	-1.31	0.56	0.85	23.6	0.86	1050
12:00	-0.82	-1.30	0.48	0.76	30.1	0.98	1475
14:30	-0.94	-1.34	0.40	0.92	31.7	1.00	1580
17:00	-0.75	-1.28	0.53	1.16	27.8		940
19:30	0.48	-1.21	0.73	3.17	25.2		360
Average C.V.	14.2	12.1	9.6	11.3	2.9	8.7	

† average of 4 replications.

* no measurements taken.

Table 117. Diurnal patterns of crop water status and associated measurements in the 1980 dryland and optimum sunflower treatments for August 26.†

DRYLAND

Time (Hour)	Leaf Ψ(MPa)	π (MPa)	P(MPa)	r_s(s cm^{-1})	Leaf T (°C)
6:30	-0.53	-1.28	0.75	0.62	17.2
9:00	-0.86	-1.46	0.60	0.91	23.7
12:00	-1.23	-1.55	0.32	1.06	27.0
14:30	-1.51	-1.69	0.15	1.13	32.5
17:00	-1.09	-1.52	0.43	1.87	26.7
19:30	-0.75	-1.32	0.67	3.52	21.3
Average C.V. (%)	11.3	10.6	8.7	9.3	6.8

OPTIMUM

Time (Hour)	Leaf Ψ(MPa)	π (MPa)	P(MPa)	r_s(s cm^{-1})	Leaf T (°C)
6:30	-0.19	-1.10	0.91	0.82	17.0
9:00	-0.55	-1.21	0.66	0.63	23.0
12:00	-0.81	-1.32	0.52	0.57	25.8
14:30	-0.91	-1.41	0.50	1.03	28.9
17:00	-0.68	-1.35	0.67	1.42	24.7
19:30	-0.40	-1.20	0.80	3.16	19.5
Average C.V. (%)	12.9	13.6	16.3	7.5	5.7

† average of 4 replications.

Table 118. Diurnal patterns of crop water status and associated measurements in the 1980 dryland and optimum soybean treatments for August 26.†

DRYLAND

Time (Hour)	Leaf Ψ(MPa)	π(MPa)	P(MPa)	r_s(s cm^{-1})	Leaf T (°C)
6:30	-0.74	-1.45	0.71	2.16	19.7
9:00	-1.25	-1.73	0.48	5.62	25.2
12:00	-1.80	-1.88	0.08	8.85	29.8
14:30	-2.02	-1.99	-0.03	9.18	35.0
17:00	-1.68	-1.80	0.12	11.36	27.0
19:30	-1.32	-1.85	0.53	16.20	22.0
Average C.V. (%)	11.3	16.2	12.5	8.8	9.1

OPTIMUM

Time (Hour)	Leaf Ψ(MPa)	π(MPa)	P(MPa)	r_s(s cm^{-1})	Leaf T (°C)
6:30	-0.13	-1.15	1.02	0.45	18.5
9:00	-0.42	-1.23	0.81	0.81	23.7
12:00	-0.86	-1.37	0.51	0.67	26.8
14:30	-0.95	-1.43	0.48	1.63	31.6
17:00	-0.61	-1.33	0.72	1.16	25.7
19:30	-0.52	-1.35	0.83	4.21	20.1
Average C.V. (%)	13.5	11.1	8.7	6.5	3.2

† average of 4 replications.

Table 119. Diurnal patterns of leaf elongation rates (LER) in the dryland and optimum sunflower treatments on 2 dates in 1980.†

JULY 24-25

Time (Hour)	Dryland LER (cm)	Optimum LER (cm)
21:00 (7/24) to 6:00 (7/25)	0.25	0.93
6:00 - 9:00	0.05	0.20
9:00 - 12:00	0.00	0.00
12:00 - 14:30	0.00	0.00
14:30 - 17:00	0.00	0.00
17:00 - 19:30	0.00	0.10
Average C.V. (%)	9.1	14.2

JULY 29-30

Time (Hour)	Dryland LER (cm)	Optimum LER (cm)
21:00 (7/29) to 6:00 (7/30)	0.10	0.40
6:00 - 9:00	0.05	0.15
9:00 - 12:00	0.00	0.00
12:00 - 14:30	0.00	0.00
14:30 - 17:00	0.00	0.00
17:00 - 19:30	0.00	0.10
Average C.V. (%)	12.0	6.5

† average of 4 replications.

Table 120. Diurnal patterns of leaf elongation rates (LER) in the dryland and optimum soybean treatments on 2 dates in 1980.†

Time (Hour)	Dryland LER (cm)	Optimum LER (cm)
JULY 24-25		
21:00 (7/45) to 6:00 (7/25)	0.20	0.40
6:00 - 9:00	0.05	0.20
9:00 - 12:00	0.05	0.10
12:00 - 14:30	0.00	0.00
14:30 - 17:00	0.00	0.00
17:00 - 19:30	0.10	0.30
Average C.V. (%)	5.6	4.9
JULY 29-30		
21:00 (7/29) to 6:00 (7/30)	0.04	0.35
6:00 - 9:00	0.02	0.10
9:00 - 12:00	0.00	0.10
12:00 - 14:30	0.00	0.00
14:30 - 17:00	0.00	0.00
17:00 - 19:30	0.01	0.20
Average C.V. (%)	6.2	7.3

† average of 4 replications.

Table 121. Diurnal patterns of crop water status and associated measurements in the 1981 dryland and optimum sunflower treatments for July 8.†

Time (Hour)	Leaf Ψ (MPa)	π(MPa)	P(MPa)	r_s(s cm^{-1})	Leaf T (°C)	Transpir. (μ g cm^{-2} s^{-1})	CER (mg m^{-2} s^{-1})
DRYLAND							
7:00	-0.16	-1.10	0.94	0.87	17.4	6.3	0.71
9:30	-0.77	-1.28	0.51	0.42	22.0	15.8	1.34
12:00	-1.23	-1.51	0.28	0.53	23.9	19.0	1.18
14:30	-1.18	-1.42	0.24	0.47	27.8	22.6	1.13
17:00	-1.10	-1.36	0.26	0.62	25.2	20.0	0.86
19:30	-0.69	-1.15	0.46	2.17	24.1	3.98	0.20
Average C.V. (%)	7.2	11.3	14.1	6.2	3.7	14.2	19.3
OPTIMUM							
7:00	-0.12	-0.10	0.91	0.62	18.3	8.2	9.82
9:30	-0.50	-1.11	0.61	0.31	21.9	16.0	1.57
12:00	-0.82	-1.38	0.56	0.35	25.8	22.3	1.60
14:30	-0.92	-1.30	0.38	0.47	26.9	21.5	1.52
17:00	-0.91	-1.31	0.40	0.51	24.3	18.5	1.36
19:30	-0.50	-0.23	0.73	1.10	24.0	6.25	0.41
Average C.V. (%)	9.6	14.7	13.2	5.0	2.9	11.6	23.2

† average of 4 replications.

Table 122. Diurnal patterns of crop water status and associated measurements in the 1981 dryland and optimum soybean treatments for July 8.†

Time (Hour)	Leaf Ψ (MPa)	π(MPa)	P(MPa)	r_s(s cm^{-1})	Leaf T (°C)	Transpir. (μ g cm^{-2} s^{-1})	CER (mg m^{-2} s^{-1})
			DRYLAND				
7:00	-0.20	-1.13	0.93	0.42	19.7	5.2	0.40
9:30	-0.50	-1.29	0.79	0.64	22.6	6.2	0.75
12:00	-1.01	-1.35	0.34	2.36	31.1	7.7	0.62
14:30	-1.21	-1.33	0.12	2.13	33.8	10.4	0.50
17:00	-0.99	-1.25	0.26	2.59	30.8	4.3	0.29
19:30	-0.68	-1.18	0.50	1.34	27.4	2.2	0.22
Average C.V. (%)	11.3	9.7	14.6	7.1	2.9	8.2	15.0
			OPTIMUM				
7:00	-0.09	-1.04	0.95	0.27	20.1	6.1	0.71
9:30	-0.32	-1.12	0.80	0.42	23.5	9.0	0.98
12:00	-0.87	-1.34	0.47	0.49	28.1	11.5	0.97
14:30	-0.93	-1.33	0.40	0.71	29.8	14.6	0.86
17:00	-0.76	-1.11	0.35	0.68	27.9	10.2	0.74
19:30	-0.46	-1.06	0.60	1.34	26.5	3.3	0.23
Average C.V. (%)	9.6	11.1	19.2	7.5	6.2	13.1	12.8

† average of 4 replications.

Table 123. Diurnal patterns of crop water status and associated measurements in the 1981 dryland and optimum sunflower treatments for August 17.[†]

DRYLAND

Time (Hour)	Leaf Ψ (MPa)	π(MPa)	P(MPa)	r_s(s cm^{-1})	Leaf T (°C)	Transpir. (μ g cm^{-2} s^{-1})	CER (mg m^{-2} s^{-1})
7:00	-0.30	-1.18	0.88	0.79	21.2	4.3	0.58
9:30	-0.85	-1.41	0.56	0.63	25.2	6.8	0.81
12:00	-1.21	-1.45	0.24	0.42	28.2	15.1	0.94
14:30	-1.36	-1.54	0.18	0.87	30.8	10.4	0.56
17:00	-1.12	-1.43	0.31	2.00	33.1	7.4	0.26
19:30	-0.77	-1.42	0.65	1.18	31.3	10.2	0.34
Average C.V. (%)	9.2	14.7	13.8	5.1	6.2	26.3	28.2

OPTIMUM

Time (Hour)	Leaf Ψ (MPa)	π(MPa)	P(MPa)	r_s(s cm^{-1})	Leaf T (°C)	Transpir. (μ g cm^{-2} s^{-1})	CER (mg m^{-2} s^{-1})
7:00	-0.16	-1.03	0.87	0.90	20.7	5.1	0.67
9:30	-0.63	-1.26	0.63	0.55	26.5	8.0	1.08
12:00	-0.94	-1.44	0.50	0.39	28.2	15.8	0.90
14:30	-0.84	-1.21	0.37	0.31	28.3	22.1	0.79
17:00	-0.78	-1.36	0.58	0.39	30.9	20.2	1.16
19:30	-0.59	-1.33	0.74	0.58	28.2	18.1	0.35
Average C.V. (%)	6.8	9.7	10.1	4.6	6.3	31.3	27.0

[†] average of 4 replications.

Table 124. Diurnal patterns of crop water status and associated measurements in the 1981 dryland and optimum soybean treatments for August 17.†

Time (Hour)	Leaf Ψ (MPa)	π(MPa)	P(MPa)	r_s(s cm^{-1})	Leaf T (°C)	Transpir. (μ g cm^{-2} s^{-1})	CER_2 (mg m^{-2} s^{-1})
DRYLAND							
7:00	-0.40	-1.26	0.86	2.52	21.0	1.1	0.66
9:30	-0.76	-1.29	0.63	1.48	23.7	2.8	0.73
12:00	-1.11	-1.35	0.24	3.32	29.8	2.6	0.41
14:30	-1.31	-1.33	0.02	2.63	33.4	4.4	0.13
17:00	-1.20	-1.35	1.15	2.91	34.8	5.3	0.28
19:30	-0.99	-1.36	0.37	3.46	31.3	3.7	0.27
Average C.V. (%)	14.7	11.1	9.9	8.2	5.6	12.0	22.5
OPTIMUM							
7:00	-0.16	-1.04	0.88	0.89	20.9	3.0	0.87
9:30	-0.48	-1.19	0.71	0.66	24.1	5.9	0.87
12:00	-0.96	-1.24	0.28	0.76	28.6	9.3	0.77
14:30	-1.00	-1.37	0.37	1.32	33.2	8.7	0.57
17:00	-0.86	-1.23	0.37	1.18	31.2	9.9	0.52
19:30	-0.50	-1.23	0.73	3.05	31.2	4.3	0.34
Average C.V. (%)	15.6	11.3	17.1	6.9	5.0	18.2	20.5

† average of 4 replications.

Table 125. Relationships between crop water measurements and associated parameters in the 1981 dryland and optimum sunflower treatments for July 16.

n	y	x	b_0	b_1	b_{11}	R^2
			DRYLAND			
20	Leaf T†	Leaf Ψ ‡	11.29	-12.54		0.96
16	r_s*	"	- 1.44	- 4.26	-1.99	0.56
16	CER**	"	- 1.64	- 7.26	-4.28	0.45
20	Leaf T	P‡	28.50	-17.77		0.86
16	r_s	"	1.49	- 3.41	2.58	0.86
16	CER	"	0.95	1.76	-2.02	0.16
16	CER	r_s	1.31	- 0.10		0.03
			OPTIMUM			
20	Leaf T	Leaf Ψ	13.12	-12.27		0.87
16	r_s	"	0.61	1.04	1.02	0.51
16	CER	"	1.83	0.78	0.43	0.23
20	Leaf T	P	30.66	-17.78		0.71
16	r_s	"	0.56	0.18	-0.46	0.72
16	CER	"	1.16	1.01	-0.57	0.25
16	CER	r_s	1.50	- 0.07		0.06

† = °C

‡ = MPa

* = $s\ cm^{-1}$

** = $mg\ m^{-2}\ s^{-1}$

Table 126. Relationships between crop water measurements and associated parameters in the 1981 dryland optimum soybean treatments for July 16.

n	y	x	b_0	b_1	b_{11}	R^2
			DRYLAND			
20	Leaf T†	Leaf Ψ ‡	10.83	-16.31		0.93
16	r_s *	"	- 2.46	- 7.04	-3.33	0.46
16	CER **	"	0.78	- 0.32	-0.57	0.22
20	Leaf T	P ‡	32.52	-19.52		0.87
16	r_s	"	2.77	- 6.33	4.33	0.80
16	CER	"	0.41	0.476	0.001	0.21
16	CER	r_s	0.78	- 0.15		0.07
			OPTIMUM			
20	Leaf T	Leaf Ψ	11.72	-18.90		0.97
16	r_s	"	1.28	3.43	3.19	0.64
16	CER	"	0.29	- 2.59	-2.33	0.29
20	Leaf T	P	41.41	-29.31		0.97
16	r_s	"	2.20	- 4.50	2.78	0.87
16	CER	"	- 0.29	3.35	-2.26	0.40
16	CER	r_s	0.80	- 0.09		0.03

† = °C

‡ = MPa

* = s cm^{-1}

** = mg m^{-2} s^{-1}

Table 127. Relationships between crop water measurements and associated parameters in the 1981 dryland and optimum sunflower treatments for July 27.

DRYLAND

n	y	x	b_0	b_1	b_{11}	R^2
20	Leaf T†	Leaf Ψ‡	13.67	-16.12		0.94
16	r_s *	"	0.51	1.77	2.77	0.19
16	CER **	"	-0.67	- 3.36	-1.68	0.17
20	Leaf T	P‡	41.49	-32.45		0.78
16	r_s	"	1.32	- 2.91	2.35	0.49
16	CER	"	-0.36	7.92	-11.30	0.57
16	CER	r_s	1.15	- 0.33		0.12

OPTIMUM

n	y	x	b_0	b_1	b_{11}	R^2
20	Leaf T	Leaf Ψ	19.46	-10.39		0.84
16	r_s	"	0.39	- 7.16	6.84	0.03
16	CER	"	2.07	1.79	0.81	0.32
20	Leaf T	P	36.11	-19.63		0.80
16	r_s	"	1.39	- 3.62	3.20	0.53
16	CER	"	0.51	1.97	-0.72	0.37
16	CER	r_s	1.61	- 0.22		0.18

† = °C

‡ = MPa

* = s cm^{-1}

** = mg m^{-2} s^{-1}

Table 128. Relationships between crop water measurements and associated parameters in the 1981 dryland and optimum soybean treatments for July 27.

n	y	x	b_0	b_1	b_{11}	R^2
			DRYLAND			
20	Leaf T†	Leaf ψ‡	12.33	-21.74		0.93
16	r_s*	"	- 0.156	- 2.82	1.50	0.56
16	CER**	"	- 0.26	- 2.25	-1.47	0.59
20	Leaf T	P‡	41.99	-26.50		0.94
16	r_s	"	3.34	- 9.25	0.83	0.82
16	CER	"	0.075	2.07	-2.10	0.64
16	CER	r_s	0.77	- 0.204		0.72
			OPTIMUM			
20	Leaf T	Leaf ψ	18.22	-14.80		0.93
16	r_s	"	0.33	0.36	0.44	0.36
16	CER	"	0.76	0.24	1.71	0.00
20	Leaf T	P	37.22	-19.20		0.89
16	r_s	"	1.29	- 2.81	2.16	0.45
16	CER	"	0.70	- 0.11	0.19	0.00
16	CER	r_s	0.88	- 0.08		0.11

† = °C

‡ = MPa

* = $s\ cm^{-1}$

** = $mg\ m^{-2}\ s^{-1}$

Table 129. Relationships between crop water measurements and associated parameters in the 1981 adryland and optimum treatments for August 7.

n	y	x	b_0	b_1	b_{11}	R^2
			DRYLAND			
20	Leaf T†	Leaf Ψ‡	15.96	-13.13		0.81
16	r_s*	"	- 0.72	- 1.95	-0.51	0.30
16	CER**	"	3.81	4.71	1.78	0.50
20	Leaf T	P‡	37.16	-19.73		0.80
16	r_s	"	1.86	- 5.58	5.81	0.75
16	CER	"	0.55	0.347	1.58	0.61
16	CER	r_s	1.12	- 0.39		0.24
			OPTIMUM			
20	Leaf T	Leaf Ψ	20.06	-12.15		0.93
16	r_s	"	0.70	0.92	-0.73	0.30
16	CER	"	0.38	- 2.74	-2.10	0.53
20	Leaf T	P	42.19	-22.47		0.88
16	r_s	"	1.01	- 1.58	1.06	0.43
16	CER	"	- 0.09	3.58	-2.44	0.39
16	CER	r_s	1.32	- 0.16		0.08

† = °C

‡ = MPa

* = $s\ cm^{-1}$

** = $mg\ m^{-2}\ s^{-1}$

Table 130. Relationships between crop water measurements and associated parameters in the 1981 dryland and optimum soybean treatments for August 7.

DRYLAND

n	y	x	b_0	b_1	b_{11}	R^2
20	Leaf T†	Leaf Ψ‡	14.66	-17.70		0.90
16	r_s*	"	- 0.37	- 9.44	15.26	0.55
16	CER**	"	0.13	- 0.70	- 0.55	0.61
20	Leaf T	P‡	40.89	-23.11		0.93
16	r_s*	"	5.47	-16.71	15.52	0.80
16	CER	"	0.16	1.44	- 1.37	0.80
16	CER	r_s	0.43	- 0.07		0.70

OPTIMUM

n	y	x	b_0	b_1	b_{11}	R^2
20	Leaf T	Leaf Ψ	16.91	-15.04		0.89
16	r_s	"	- 0.11	- 1.57	- 0.36	0.48
16	CER	"	1.04	- 0.08	- 0.39	0.52
20	Leaf T	P	40.29	-21.99		0.84
16	r_s	"	1.57	- 0.03	- 0.60	0.61
16	CER	"	0.41	0.72	0.96	0.81
16	CER	r_s	0.82	- 0.12		0.16

† = °C

‡ = MPa

* = $s\ cm^{-1}$

** = $mg\ m^{-2}\ s^{-1}$

Table 131. Relationships between crop water measurements and associated parameters across 3 dates in the 1981 dryland and optimum sunflower treatments.

n	y	x	b_o	b_1	b_{11}	R^2
			DRYLAND			
60	Leaf T†	Leaf Ψ‡	12.12	-15.64		0.78
48	r_s*	"	- 0.30	- 1.37	-0.36	0.32
48	CER**	"	0.44	- 2.00	-1.32	0.42
60	Leaf T	P‡	35.34	-22.07		0.55
48	r_s	"	1.62	- 4.22	3.72	0.72
48	CER	"	0.48	2.40	-2.01	0.24
48	CER	r_s	1.29	- 0.40		0.14
			OPTIMUM			
60	Leaf T	Leaf Ψ	16.73	-12.76		0.63
48	r_s	"	0.44	0.23	0.31	0.23
48	CER	"	1.03	- 1.75	-1.67	0.34
60	Leaf T	P	35.36	-18.27		0.42
48	r_s	"	0.93	- 1.44	0.95	0.39
48	CER	"	0.58	2.21	-1.40	0.13
48	CER	r_s	1.83	- 1.19		0.21

† = °C

‡ = MPa

* = $s\ cm^{-1}$

** = $mg\ m^{-2}\ s^{-1}$

Table 132. Relationships between crop water measurements and associated parameters across 3 dates in the 1981 dryland and optimum soybean treatments.

DRYLAND

n	y	x	b_0	b_1	b_{11}	R^2
60	Leaf T†	Leaf Ψ‡	10.93	-20.63		0.85
48	r_s*	"	3.21	7.53	5.81	0.66
48	CER**	"	0.08	- 1.52	-2.63	0.58
60	Leaf T	P‡	39.73	-25.77		0.82
48	r_s	"	4.33	-12.86	11.21	0.71
48	CER	"	0.05	1.95	- 1.65	0.54
48	CER	r_s	0.68	- 0.14		0.58

OPTIMUM

n	y	x	b_0	b_1	b_{11}	R^2
60	Leaf T	Leaf Ψ	14.96	-16.96		0.87
48	r_s	"	0.85	1.74	1.80	0.56
48	CER	"	1.02	0.18	-1.37	0.22
60	Leaf T	P	39.28	-23.45		0.82
48	r_s	"	1.11	- 0.64	-0.37	0.30
48	CER	"	0.50	0.16	0.54	0.40
48	CER	r_s	0.93	- 0.23		0.14

† = °C

‡ = MPa

* = $s\ cm^{-1}$

** = $mg\ m^{-2}\ s^{-1}$

Table 133. Pressure-volume data for the 1981 dryland sunflower treatment on 3 dates.

JULY 17

Balance Pressure (MPa)	1/P (MPa)	Leaf wt. (g)
0.0	0.0000	6.0000
0.2	3.3333	5.6493
0.6	1.6667	5.4507
0.10	1.0000	5.1879
1.2	0.8333	5.0202
1.4	0.7143	4.8339
1.6	0.6250	4.6811
1.8	0.5556	4.4999
2.0	0.5000	4.2578
2.5	0.4000	3.8339

JULY 28

0.0	0.0000	5.2301
0.3	3.3333	5.0862
0.6	1.6667	4.9611
1.0	1.0000	4.7620
1.2	0.8333	4.6100
1.4	0.7143	4.3892
1.6	0.6250	4.0821
1.8	0.5556	3.7119
2.0	0.5000	3.5500
2.5	0.4000	3.4093

AUGUST 8

0.0	0.0000	6.4500
0.3	3.3333	6.1399
0.6	1.6667	6.0020
1.1	0.9091	5.8601
1.2	0.8333	5.7587
1.4	0.7143	5.6669
1.6	0.6250	5.5503
1.8	0.5556	5.2589
2.0	0.5000	4.8593
2.5	0.4000	4.4440

Table 134. Pressure-volume data for the 1981 dryland soybean treatment on 3 dates.

JULY 17

Balance Pressure (MPa)	1/P (MPa)	Leaf wt. (g)
0.0	0.0000	1.7238
0.3	3.3333	1.6840
0.6	1.6667	1.6564
1.0	1.0000	1.5984
1.2	0.8333	1.5600
1.5	0.6667	1.4691
1.8	0.5556	1.4203
2.0	0.5000	1.3883
2.5	0.4000	1.3479

JULY 28

0.0	0.0000	2.4001
0.3	3.3333	2.3410
0.6	1.6667	2.3088
1.0	1.0000	2.2020
1.2	0.8333	2.1592
1.4	0.7143	2.1280
1.6	0.6250	2.0703
1.8	0.5556	2.0100
2.0	0.5000	1.9118
2.25	0.4444	1.8693
2.5	0.4000	1.8300

AUGUST 8

0.0	0.0000	2.5000
0.3	3.3333	2.4577
0.6	1.6667	2.4380
1.0	1.0000	2.4100
1.2	0.8333	2.2019
1.5	0.6667	2.1299
1.8	0.5556	2.0200
2.0	0.5000	1.9388
2.25	0.4444	1.8906
2.5	0.4000	1.8300