STOMATAL RESISTANCE, LEAF WATER POTENTIAL, AND YIELD IN IRRIGATED AND NONIRRIGATED SOYBEANS

by

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INTRODUCTION

Water is the major limiting factor for crop production in many agricultural areas. With increasing demands for agricultural products the use of supplemental water (irrigation) becomes increasingly important. Geraghty, Miller, and van der Leeden (1973) project surface water supplies in many areas will not be adequate to meet demands by the year 2000. Many areas are currently experiencing dropping water tables and limited availability of irrigation water. These facts indicate that irrigation water should be applied only when significant increases in yield can be attained. An evaluation is necessary to determine what stages of growth are most susceptible to water deficits, and to determine by some means when critical soil moisture levels are, or will be reached.

Application of irrigation water should be based upon a scientific interpretation of the soil-plant-water system. Taylor and Ashcroft (1972) state that plant response to water is more closely related to the soil water potential than any other soil factor. The variability that exists in soil physical characteristics and root density in the soil profile make soil water potential as sensed by a plant difficult, if not impossible to determine.

Kramer (1969) stated the only true reflection of the availability of soil water to a plant is a plant's water status. Many approaches are available for measuring plant water status. Two of the most obvious approaches are: 1) water vapor diffusion from the leaf to the atmosphere and 2) plant water potentials.

Stomata play a key role in controlling plant water status. The resistance to water vapor diffusion from the leaf can be measured with a diffusion porometer (Kanemasu, Thurtell, and Tanner, 1969). Chapter I shows the relationship determined between stomatal resistance and soil water potential.

Plant water potential indicates the effect of soil water potential and the daily decrease in potential caused by transpiration. Plant water potentials can be estimated from xylem pressure potential measurements taken with a pressure chamber (Scholander et al., 1965). Chapter II discusses the relationships determined between maximum and minimum leaf water potentials and soil water potential.

Chapter III is an evaluation of soybean yield response to irrigations initiated at various stages of growth and soil-moisture-depletion levels. The Appendix contains soil water characteristics and bulk density for the research site.

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CHAPTER I

THE RELATION OF SOIL WATER POTENTIAL TO STOMATAL RESISTANCE OF SOYBEAN

Agronomy Journal (to be submitted)

R. A. Brady, S. M. Goltz, W. L. Powers, and E. T. Kanemasu

THE RELATION OF SOIL WATER POTENTIAL TO STOMATAL RESISTANCE OF SOYBEAN[1]

R. A. Brady, S. M. Goltz, W. L. Powers, and E. T. Kanemasu[2]

ABSTRACT

Stomatal resistance and soil water potential were compared and a definite relationship determined in two consecutive growing seasons. Adaxial stomatal resistance increased rapidly when soil water potential decreased to near -4 bars. Abaxial stomatal resistance was not noticeably affected until the soil water potential reached -6 bars.

Factors affecting stomatal resistance in the field were examined and it was found that stomatal resistance of upper canopy leaves was not affected by the physiological stage of growth. The differences in adaxial stomatal resistance of well-irrigated and nonirrigated soybeans were distinct and indicate that stomatal resistance may be useful in determining irrigation schedules.

Additional Index Words: Evapotranspiration, Water stress

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INTRODUCTION

Soil moisture content and soil water potential have long been used as criteria to schedule irrigation (Stanhill, 1957; Taylor, 1965). Since water moves in response to a potential energy gradient, soil water potential unlike soil moisture content, is a more representative method of determining a plant's ability or inability to obtain adequate amounts of soil water.

A plant's response to water apparently is more closely related to soil water potential than any other single soil factor (Taylor and Ashcroft, 1972); however, determining a representative soil water potential for a plant is difficult. Determinations are subject to errors in measuring root distribution and especially water extraction patterns. It has been suggested that plant water status (in this study, stomatal resistance) is the simplest and most direct approach to measuring the availability of water to a plant as it is affected by the soil water potential (Kramer, 1969).

Stomatal resistance is affected by a plant's ability to extract water from the soil. Kanemasu et al. (1973) showed that as soil water potentials decrease below -5 or -6 bars, stomatal resistance in grain sorghum increased rapidly. Differences in stomatal resistances of soybeans under various soil water potentials have been noted (Stevenson, 1971). Changes in stomatal aperture have been used by Alvim (1966), Oppenheimer and Elze (1941), and Schmueli (1964) on a variety of plants to indicate water need.

Before stomatal resistance can be used as a measure of a plant's need for water, a relationship between stomatal resistance and soil water potential must be determined. The purpose of this study was to determine this relationship using irrigated and nonirrigated soybeans.

METHODS AND MATERIALS

Measurements were taken from an irrigated field on the Ashland Agronomy Farm 14 km south of Manhattan, Kansas. The soil is a Muir silt loam developed from alluvium. In 1972 soybeans (*Glycine max* L. cv. Calland) were planted May 18 and final plant density was 269,000 plants/ha. In 1973 the planting date was May 14; final plant density was 259,000 plants/ha. Leaf area index (LAI) was determined at various times during both growing seasons.

In 1972, the experimental design was a split plot with the main treatments being three soil-moisture-depletion levels plus nonirrigated control plots and the subtreatments were three stages of growth at which irrigation was initiated. These 12 treatments were replicated four times. In 1973 the 12 treatments were completely randomized in each of four replications.

Irrigation was initiated at three stages of growth (vegetative, flowering, and podding), when predetermined soil-moisture-depletion levels were reached. Table 1 shows the physiological calander for soybeans (Hanway and Thompson, 1971). Depletion levels in 1972 were 20, 40, and 60 percent of available water in the root zone. In 1973 depletion levels were changed to 40, 55 and 65 percent.

Plot width was changed in 1973 from 8 rows 60 cm apart to 10 rows 75 cm apart. Criterion for changing row and plot dimensions was to prevent damage to plants during sampling after full cover, and reduce the effect of horizontal movement of water. Plot length for both years was 13 meters.

Irrigation requirements were determined from soil moisture measurements taken weekly with a neutron probe in a 165 cm soil profile at 15 cm intervals. Access tubes were located in the row and centered in each plot. Gravimetric samples, or a special calibration of the neutron probe was used to determine soil moisture in the top 15 cm increment. Available water was assumed to be the amount held in the root zone between -1/3 and -15 bars pressure. The moisture release curves were determined in a constant temperature room for each 15 cm increment of soil. The depth of the root zone was determined from soil moisture measurements. The lowest depth of water removal was used as the bottom of the root zone. Average soil water potential was determined by averaging the soil water potential of the increments in the effective root zone.

Stomatal resistance measurements were taken with a diffusion porometer (Kanemasu, Thurtell, and Tanner, 1969). Measurements were taken on the topmost, unrolled trifoliate leaves to reduce mutual shading and seniscence effects in the lower leaves. Abaxial and adaxial measurements were taken on the same leaflet. A minimum of three measurements from each plot were averaged to determine plot resistance.

The sampling period (1300-1500 hours), as used in this study, was also used by Kanemasu et al. (1973) and Stevenson (1969) in relating stomatal resistance to soil water potential. Stomatal resistance in soybeans changes through the day and seems to reach near maximum values under high soil water potentials at 1300 hours (Stevenson, 1971). Under low soil water potentials, resistance may continue to increase through the late afternoon (Stevenson, 1971; Teare and Kanemasu, 1972; and Teare et al., 1973).

Daily solar radiation was measured using an Eppley pyranometer. Daily wind run was obtained using a 3-cup anemometer. Maximum and minimum air temperatures and relative humidity were recorded by hygrothermograph. These data were used to calculate potential evapotranspiration (Penman, 1948).

Water was applied with a furrow irrigation system and each plot was irrigated with an individual plastic pipe fitted with a constant flow valve to insure accurate measurements of applied water. Water was delivered to the plots in 15 cm diameter aluminum pipe in which pressure was controlled with a standpipe. Aluminum edging along plot borders reduced lateral movement of surface water between plots.

Because the soil moisture and the stomatal resistance could not be measured in all 48 plots between 1300 and 1500 hours on a given day, only data from a few representative plots were used to develop the relationships in this paper. The plot design described earlier was used primarily for statistical analysis of yield and lodging to be reported in a later paper.

Table 1. Stage of soybean development according to Hanway and Thompson (1972).

Stage No.	Stage	1972 Month	1972 Day	1973 Month	1973 Day
	Planting	May	18	May	14
	Germination and emergence		19 - 28		15 - 30
V2	Four nodes	June	20	June	16
V3	Six nodes		29		26
R4	Beginning bloom	July	5	July	3
R5	Full bloom		18		15
R5.5	Beginning of pod development		24		20
R6	Rapid pod growth	Aug.	2		30
R7	Pods growing in size and pods beginning to fill		8	Aug.	6

RESULTS AND DISCUSSION

Figures 1 and 2 show relationships between stomatal resistance and soil water potential. Because both adaxial and abaxial leaflet surfaces have stomata, stomatal resistance measurements were made on both surfaces. These figures show an increase in the stomatal resistance with decreasing potential for both the adaxial and abaxial surface. However, the adaxial stomatal resistance apparently is more sensitive to water potential as suggested by the steeper curve (Fig. 2). The adaxial surface has a higher resistance than the abaxial surface because of the difference in stomatal densities of the two sides (Teare and Kanemasu, 1972).

The solid lines in Figs. 1 and 2 are curves of second-order polynomials fitted to the data by a least square method. The correlation coefficients are significant at the 0.01 probability level in both figures. The curves in Fig. 2 indicate that the soil moisture becomes limiting as the soil water potential approaches -4 bars. This relationship in soybeans is similar to that shown by Kanemasu et al. (1973) for grain sorghum. In this soil, a soil water potential of -4 bars occurs when 70 to 80 percent of the available water in the root zone is depleted.

Although the development of the curves in Figs. 1 and 2 seems simple and straight-forward, there are several factors that influence the measured values of stomatal resistance. Meidner and Mansfield (1968) discussed environmental factors affecting stomatal response. Some factors we found necessary to consider when relating

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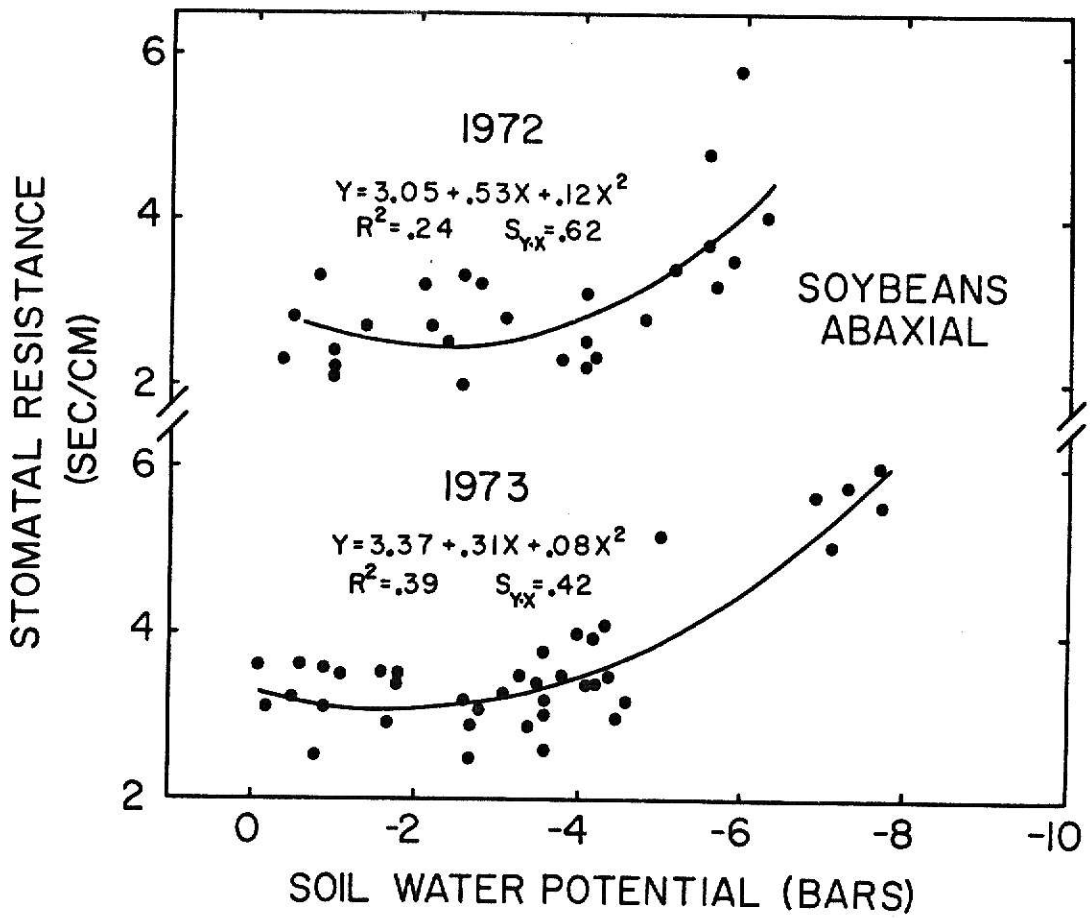

Figure 1. Relation of abaxial stomatal resistance (1300-1500 CDT) to soil water potential, June 26 to July 14, 1972 and June 21 to July 12, 1973.

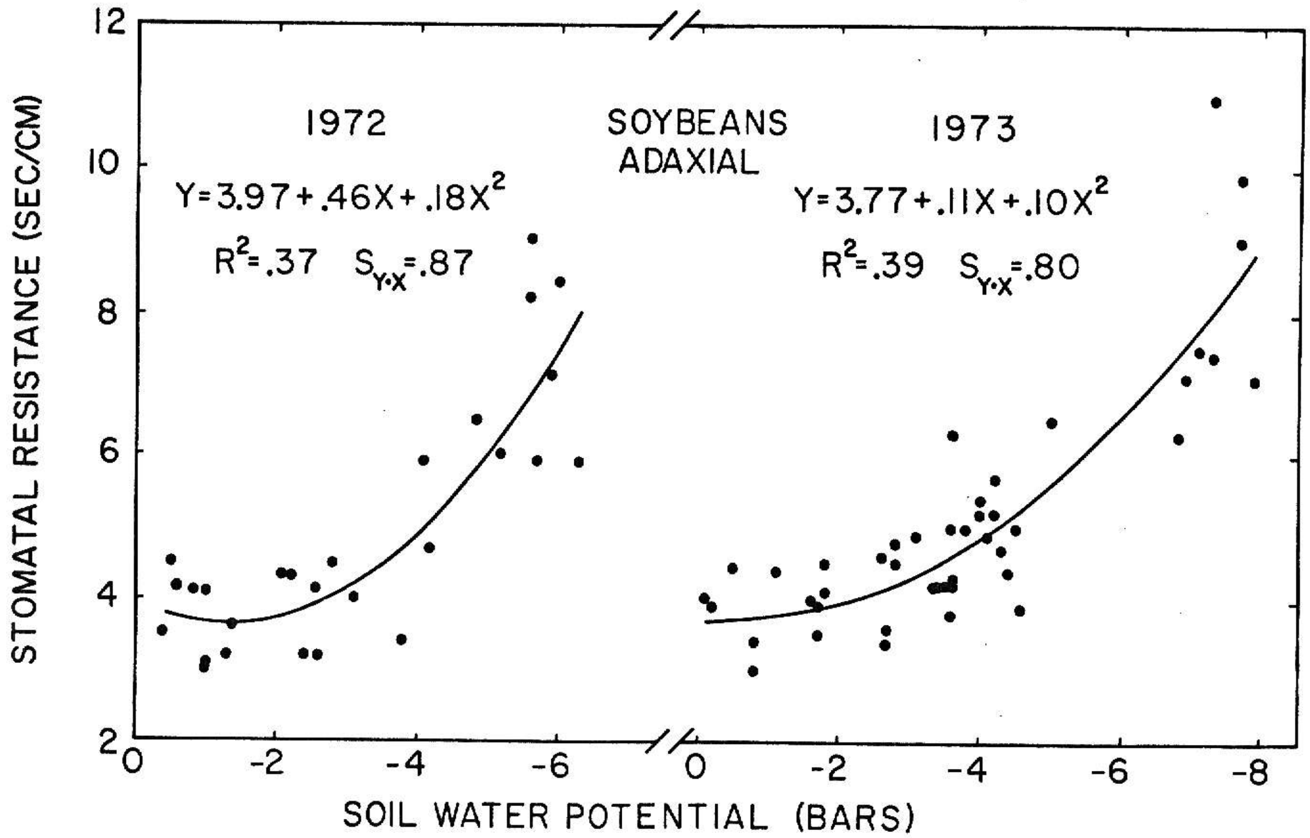

Figure 2. Relation of adaxial stomatal resistance (1300-1500 CDT) to soil water potential, June 26 to July 14, 1972 and June 21 to July 12, 1973.

field measurements of stomatal resistance to soil water potential are: 1) the location of the measurement, 2) the physiological stage of growth, 3) wet leaves and recent irrigations, and 4) the evaporative demand.

The location of the measurement within the canopy and on the leaf surface both affect resistance readings. As was mentioned under the methods section the effect of shading and seniscence are reduced by sampling from the upper canopy. Also as seen earlier in Figs. 1 and 2 the resistance readings from the adaxial surface of the leaf are more sensitive to changes in soil water potential. Stevenson (1969), Kanemasu and Tanner (1969), and Teare and Kanemasu (1972) noted similar responses and attributed the less sensitive abaxial surface to the greater number of stomata per unit area. Stomatal resistance measurements on the adaxial surface of the upper leaves were used in Figs. 3 and 4. The resistance values of the abaxial surface were lower; however, the seasonal trend was similar to the adaxial surface.

The physiological stage of growth seemed to have little influence on the stomatal resistance readings measured during this study. This is shown in Figs. 3 and 4 in which the stomatal resistance and the soil water potential have been plotted throughout the growing season of 1972 and 1973. In 1972 the stomatal resistance of the well-irrigated plots (those plots irrigated at 40 percent depletion throughout the growing season) ranged from 2 to 4.5 sec/cm while in 1973 it ranged from 1.0 to 3.5 sec/cm. However, it is noted that in both figures

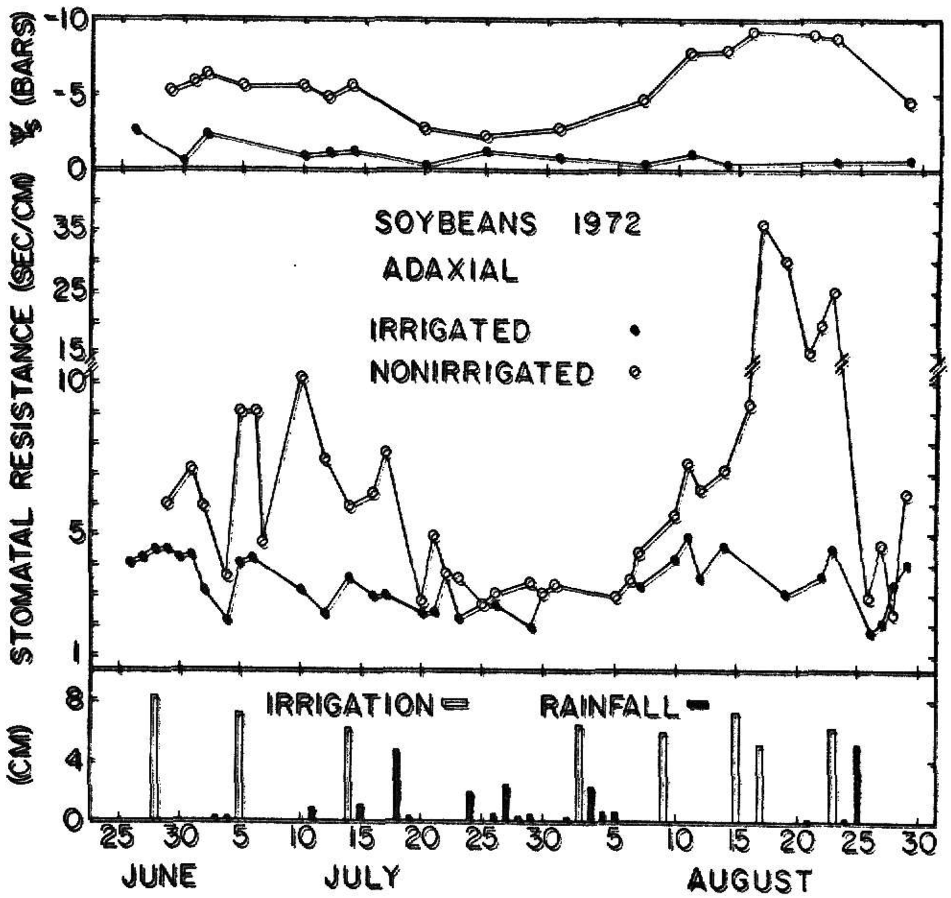

Figure 3. Seasonal variation in stomatal resistance (1300-1500 CDT) between nonirrigated and irrigated at 40 percent depletion throughout 1972.

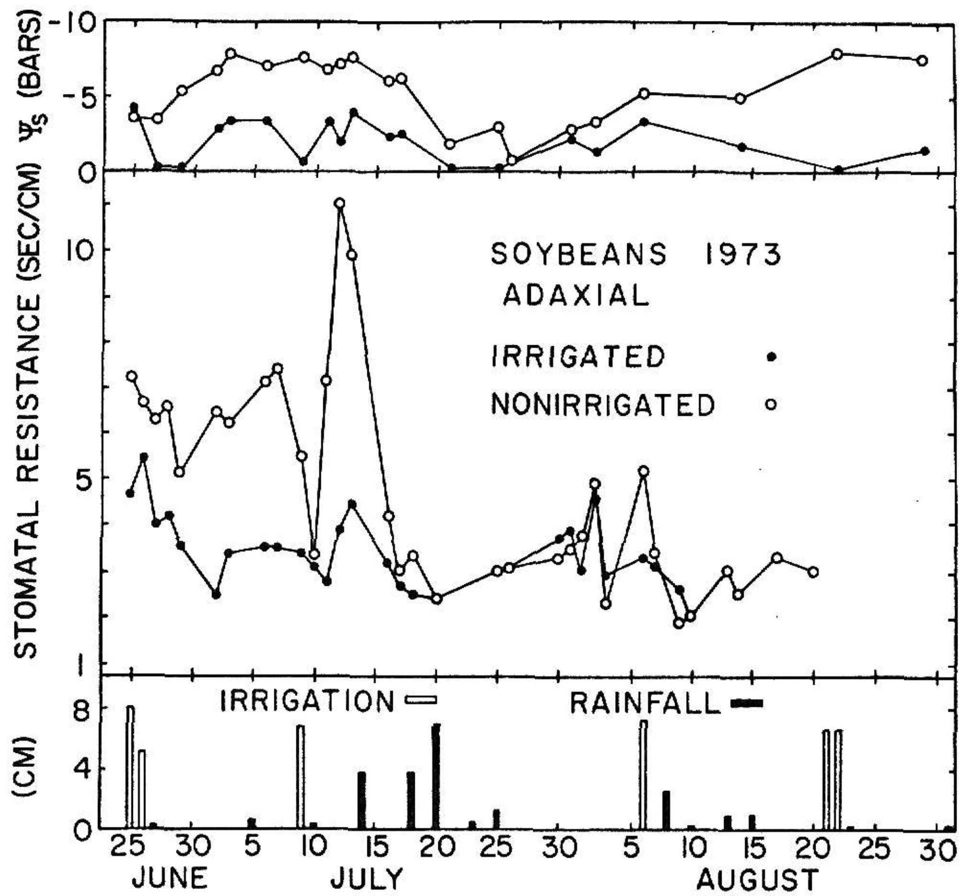

Figure 4. Seasonal variation in stomatal resistance (1300-1500 CDT) between nonirrigated and irrigated at 40 percent depletion throughout 1973.

there is no apparent trend in resistance as a result of a particular growth stage. The difference between the two years can be partially explained by the greater LAI (leaf area index) in 1972 as shown in Table 2. Patterns of stomatal resistance of the plots that were irrigated at flowering and podding stages followed the nonirrigated plots until irrigation was initiated. After irrigation stomatal resistance in these plots then closely followed resistances in previously irrigated plots with comparable depletion levels.

Small amounts of precipitation before sampling allow soybeans to temporarily escape midday water deficits. This can be seen in Figs. 3 and 4 when measurements were taken on days when rainfall occurred during the night. Also, as seen in these figures, stomatal resistances may not recover immediately after a plot is irrigated. Measurements seem to be most reliable on days during extended dry periods. Thus, in some cases stomatal resistance will reflect plant water status, but may not reflect the soil water potential.

The apparent recovery of stomatal resistance values in nonirrigated plots to values found in the plots irrigated at 40 percent depletion (well-irrigated plots) is contrary to the findings of other investigators (Clark and Levitt, 1956). The conflicting results may be partially attributed to the use of new leaves in the upper canopy for resistance measurements in this study.

Finally we consider the effects of evaporative demand on the resistance values. Fig. 5 shows adaxial stomatal resistance of the soybeans irrigated at 40 percent depletion for various daily potential evapotranspiration (ET). Even during the highest ET days the resist-

Table 2. Leaf area index (LAI) for soybeans 1972-1973.

	Irrigated LAI		Nonirrigated LAI	
Date	1972	1973	1972	1973
June 19	.44		.33	
30	1.79		1.54	
July 17	7.75	3.70	6.02	2.68
31	8.95	5.95	7.69	3.84
Aug 9		4.46		3.74
14	7.13		6.46	
Sept 9	5.25		4.84	

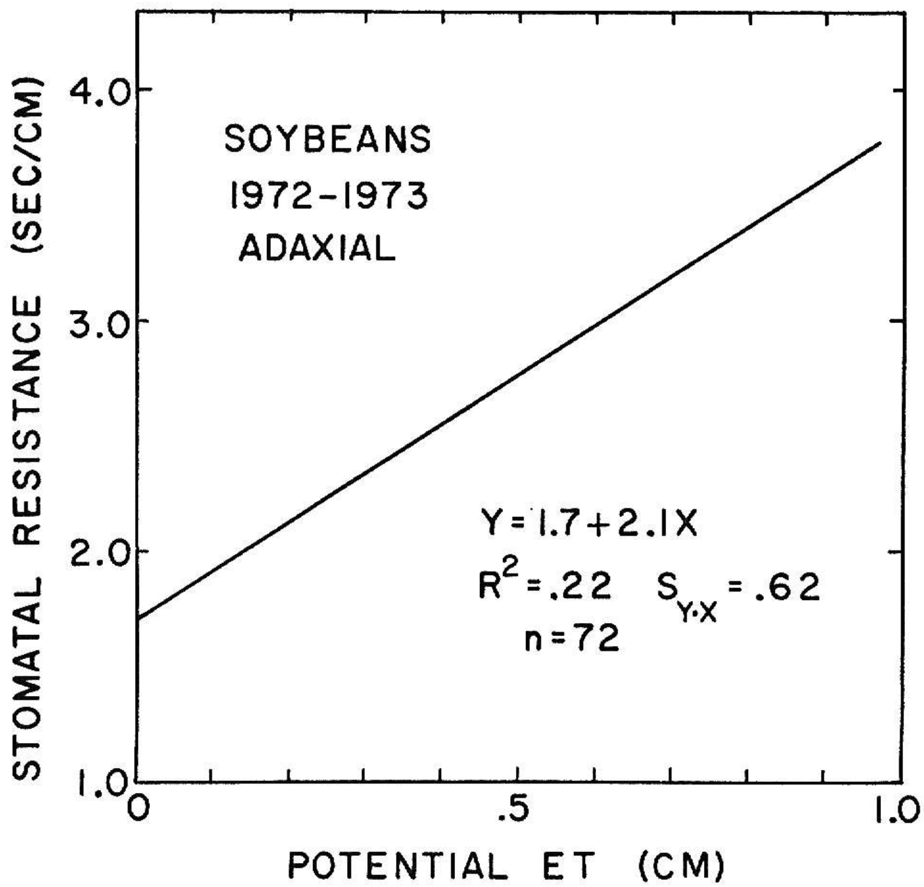

Figure 5. The influence of potential ET (Penman, 1948) on stomatal resistance values for soybeans irrigated at 40 percent depletion, 1972 and 1973.

ance values in the well-irrigated plots did not increase above 4 sec/cm. The relationship shown in Fig. 5 helps explain some of the data variation at high soil water potentials in Figs. 1 and 2. Because high potential ET should not produce resistance readings greater than 4 sec/cm on well-irrigated plots, resistance values greater than 4 or 5 sec/cm should primarily result from low soil water potential. Further, it should be expected that a high potential ET should increase the differences in resistance readings between well-irrigated and nonirrigated soybeans.

This study shows that stomatal resistance measurements can be used to determine when soil water is limiting, and that a definite relationship can be developed between stomatal resistance and soil water potential. Stomatal resistance measurements eliminate the need for a determination of root depth and extraction patterns needed with soil moisture data to properly estimate the soil water potential. Although care must be taken when making stomatal resistance measurements in the field, diffusion porometers may be used for irrigation scheduling.

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CHAPTER II

THE RELATION OF SOIL WATER POTENTIAL TO LEAF WATER POTENTIAL OF SOYBEAN

Agronomy Journal (to be submitted)

R. A. Brady, W. L. Powers, L. R. Stone, and S. M. Goltz

THE RELATION OF SOIL WATER POTENTIAL TO LEAF WATER POTENTIAL OF SOYBEAN [1]

R. A. Brady, W. L. Powers, L. R. Stone, and S. M. Goltz [2]

ABSTRACT

The relation of maximum and minimum leaf water potential to soil water potential was determined for soybeans under a wide range of soil water potentials. Leaf water potentials were measured with a pressure chamber and soil water potentials determined from moisture release curves by using volumetric soil moisture measurements made with a nuetron probe. Minimum leaf water potentials decreased an average of 9 to 10 bars due to the evaporative demand during the vegetative stage. In the podding stage, leaf water potentials were approximately 4 bars lower than minimum values in the vegetative stage. The response of leaf water potential was equally sensitive to change in soil water potential during both the vegetative and podding stages.

Additional Index Words: Irrigation, Root zone, Xylem osmotic potential

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INTRODUCTION

The only reliable soil property indicative of water availability for plant growth is the soil water potential; however, the best indicator of irrigation need is the plant itself (Kramer, 1969). One problem encountered in using the measured soil water potential as an indication of water availability to a plant is the uncertainty of locating the proper soil depth affecting the plant. Plant roots are the ideally located sensors for determining the soil water potential that affects the plant. Plant water potential is affected directly by the soil water potential encountered by the plant roots and by the atmospheric demand. Therefore, measurements of plant water potential eliminate any theoretical interpretation of root densities and soil water potentials measured at various depths in the soil profile.

Clark and Hiler (1973) evaluated several plant measurements as indicators of crop water deficits and found leaf water potentials to be more sensitive to change in plant water status than either leaf diffusion resistance or leaf-air temperature differences. Cary and Wright (1971) used a portable freezing meter to measure leaf water potentials in several crops under irrigated conditions. The development of pressure chamber techniques (Scholander et al., 1965; and Boyer, 1967) for measuring plant water potentials has aroused interest in the use of this technique for determining water potentials in the field. DeRoo (1969) found that corn leaf water potentials measured with a pressure chamber agreed well with thermocouple psychrometer measurements. Boyer and Ghorashy (1971) found that in moist soybean tissue the xylem osmotic component was negligible, and leaf water potential measured with a pressure chamber is a useful means of estimating soybean water potential.

The pressure chamber technique for determining plant water potential suggests its possible use for scheduling irrigation. Boyer (1972) outlined a procedure for using leaf water potential measurements for irrigation scheduling during the vegetative stage of growth. The purpose of this work was to examine the relationship of leaf water potentials to soil water potentials in irrigated and nonirrigated soybeans.

METHODS AND MATERIALS

Measurements were taken from an irrigated field on the Ashland Agronomy Farm 14 km south of Manhattan, Kansas. The soil is a Muir silt loam developed from alluvium. In 1972 soybeans (*Glycine max* L. cv. Calland) were planted May 18 and final plant density was 269,000 plants/ha. In 1973 the planting date was May 14; final plant density, 259,000 plants/ha. Leaf area index was determined at various times during both growing seasons (Brady et al.[3]).

In 1972 the experimental design was a split plot with the main treatments being three soil-moisture-depletion levels plus nonirrigated

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[3] Brady, R. A., S. M. Goltz, W. L. Powers, and E. T. Kanemasu. 1974. The relation of soil water potential to stomatal resistance of soybean. Chapter 1 (in this thesis).

control plots and the subtreatments were three stages of growth at which irrigation was initiated. These 12 treatments were replicated four times. In 1973 the 12 treatments were completely randomized in each of four replications.

Irrigation was initiated at three stages of growth (vegetative, flowering, and podding) when predetermined soil moisture depletion levels were reached. Developmental stages were reported by Brady et al.[3] Depletion levels in 1972 were 20, 40, and 60 percent of the available water in the root zone. In 1973 depletion levels were changed to 40, 55 and 65 percent.

Plot width was changed in 1973 from 8 rows 60 cm apart to 10 rows 75 cm apart. Criterion for changing row and plot dimensions was to prevent damaging plants during sampling after full cover, and reduce the affect of horizontal movement of water. Plot length both years was 13 meters.

Irrigation requirements were determined from soil moisture determinations taken weekly with a neutron probe in a 165 cm soil profile at 15 cm intervals. Access tubes were located in the row and centered in each plot. Gravimetric samples or a special calibration of the neutron probe was used to dètermine soil moisture in the top 15 cm increment. Available water was assumed to be the amount held in the root zone between -1/3 and -15 bars pressure. Moisture release curves were determined in a constant temperature room for each 15 cm increment of soil. The depth of the root zone was determined from soil moisture measurements. The lowest depth of water removal was used as the bottom of the root zone. Average soil water potential was determined by averaging the soil water potential of the increments in the effective root zone.

Leaf water potentials were measured with a pressure chamber (Scholander et al., 1965). Method used was similar to Boyer (1972). The center leaflet of the topmost unrolled trifoliate, in full sunlight, was cut and then placed in the chamber with the petiole protruding from the chamber. Pressure (compressed air) was then applied to the chamber until liquid appeared on the cut surface. The pressure was then released slowly until the liquid disappeared on the cut surface of the petiole. An average of these two pressures was used as the leaf water potential. Minimum values of leaf water potential were measured between 1300-1500 hours CDT. Maximum values of leaf water potential were measured prior to sunrise. A minimum of three measurements were made to establish a plot average.

Daily solar radiation was measured using an Eppley pyranometer. Daily wind run was obtained using a 3-cup anemometer. Maximum and minimum air temperatures and relative humidity were recorded by hygrothermograph. These data were used to calculate potential evapotranspiration (Penman, 1948).

Water was applied with a furrow irrigation system using individual plastic pipes fitted with constant flow valves to insure accurate measurement of applied water. Water was delivered to the plots in 15 cm diameter aluminum pipes in which pressure was controlled with a standpipe. Aluminum edging along plot borders reduced lateral movement of surface water between plots.

Because the soil moisture and leaf water potential could not be measured in all 48 plots between 1300 and 1500 hours on a given day, only data from a few representative plots were used to develop the relationships in this paper. The plot design described earlier was primarily for statistical analysis of yield and lodging data to be reported in a later paper.

RESULTS AND DISCUSSION

In order to relate leaf water potential to soil water potential it is essential to understand the diurnal changes of leaf water potential. Figure 1 shows the range of leaf water potentials that occurred during the daylight hours on July 11, 1973. Maximum values of leaf water potential occurred prior to sunrise, then decreased during the day, reaching a minimum at approximately 1600 hours CDT. Slatyer (1967) indicated that during the night, equilibrium occurs between the plant and soil water systems. Maximum values of leaf water potential should therefore reflect the soil water potential directly.

The differences between leaf water potential of irrigated and nonirrigated soybeans appears to be fairly constant throughout the day (Fig. 1). This would indicate that the evaporative demand decreases leaf water potential by equal amounts, independent of the soil water potential. Estimation of soil water potential from leaf water potential measurements could thus be made knowing the magnitude of the evaporative demand even if early morning values of leaf water potential were not taken.

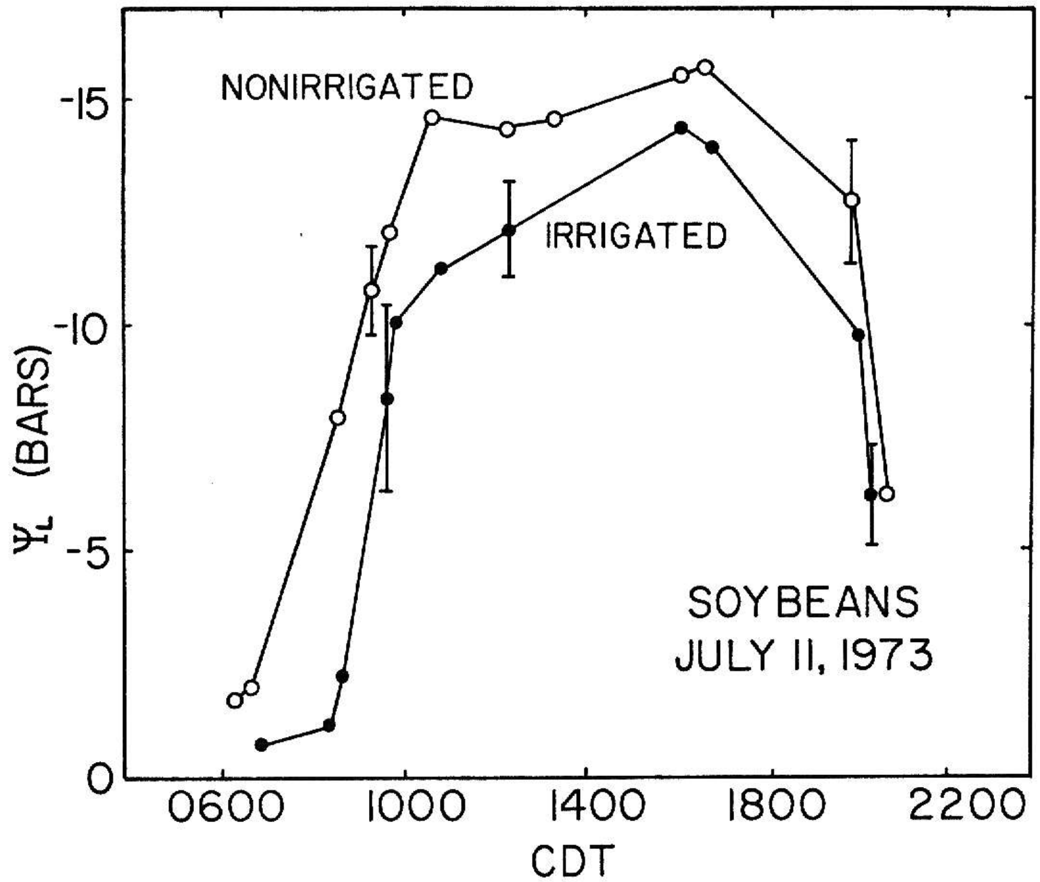

Figure 1. Diurnal changes of leaf water potential (Ψ_L) in nonirrigated and irrigated when 40 percent of the available water in the effective root zone is depleted on July 11, 1973.

Minimum values of leaf water potential reflect the maximum influence of the evaporative demand and the maximum water deficit imposed upon the plant. Data shown in Fig. 1 and data not reported, do indicate that minimum leaf water potentials occur between approximately 1200-1600 hours CDT. Figure 2 presents the relationships determined between maximum and minimum leaf water potentials and soil water potentials during the vegetative stage of growth. Leaf water potentials presented in Fig. 2 taken from 1300-1500 hours are referred to as minimum values. Data collected during 1300-1500 hours when rainfall occurred the previous night are not included. Early morning measurements of leaf water potential presented in Fig. 2 are referred to as maximum values or the base level of leaf water potential as determined by the soil water potential.

Simple linear regression and correlation analyses were conducted on both sets of data. The determined curves were similar, indicating the combined effects of soil water potential and evaporative demand are additive. Correlation coefficients in both cases are significant at the 0.01 level. Maximum values of leaf water potential in Fig. 2 do not reflect a 1:1 ratio with soil water potential, which should be the case if the soil-plant-water system returns to equilibrium during the night. There are three possible reasons: 1) leaf water potential measurements, with a pressure chamber, do not account for the xylem osmotic potential, 2) a representative determination of soil water potential as it affects the plant is extremely difficult from soil water measurements, and 3) water may have been absorbed

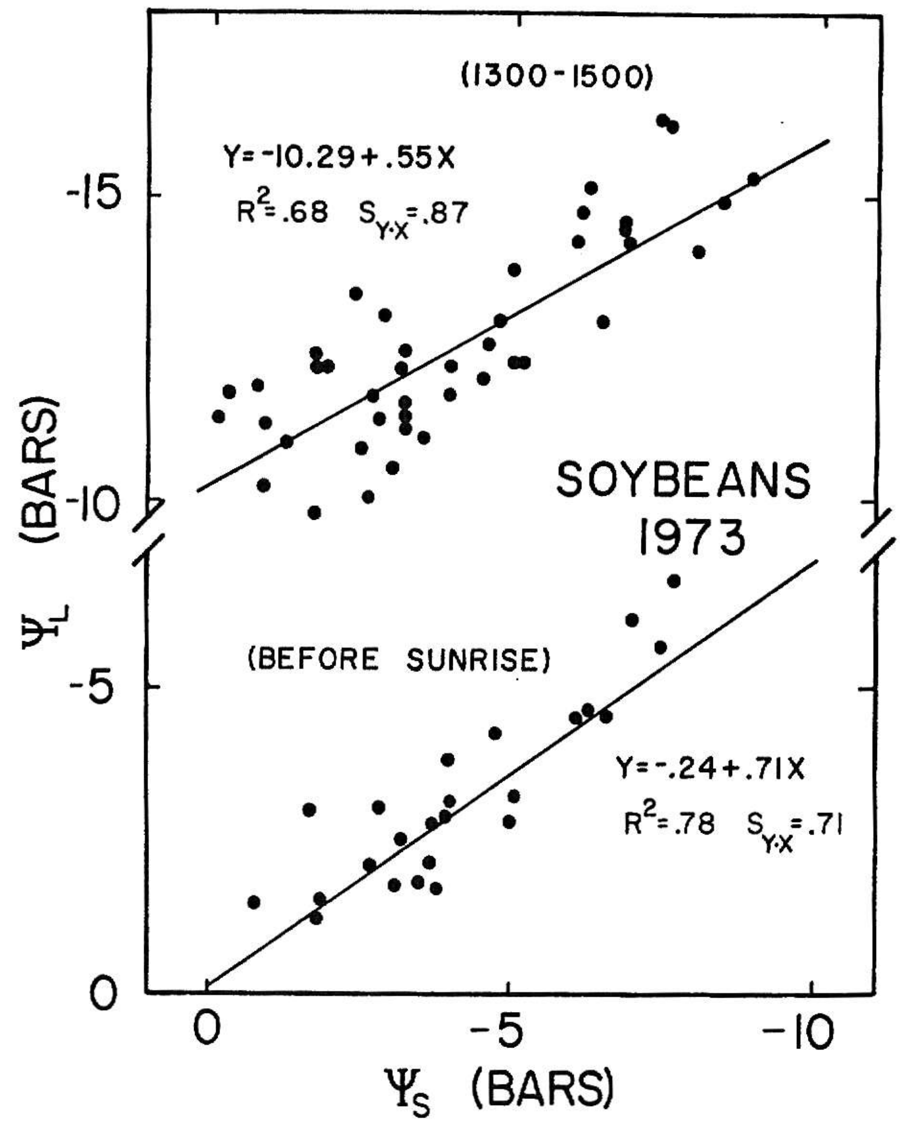

Figure 2. The relationship of maximum and minimum soybean leaf water potentials (Ψ_L) to soil water potential (Ψ_S) in the vegetative stage, 1973.

from the atmosphere by the plant tissue. Boyer and Ghorashy (1971) showed that xylem osmotic potential in soybeans was negligible in moist tissue; however, at leaf water potentials (pressure potentials) of -8 bars xylem osmotic potential can be as much as -1 bar. It was also noted on mornings when leaves were wet, that leaf water potentials from nonirrigated soybeans were similar to those from irrigated soybeans under drastically different soil water potentials. Maximum values of leaf water potential in Fig. 2 include only measurements taken on mornings when leaflets were dry. It is suggested that as the leaves become drier (lower leaf water potentials) their ability to absorb moisture from the atmosphere increases, thus possibly accounting for maximum values of leaf water potential not reflecting soil water potential in an exact 1:1 ratio.

Clark and Hiler (1973) determined a nonlinear relation between leaf water potentials, taken at solar noon, and soil water potentials in the tensiometer range. They projected the midday relationship to zero leaf water potential at zero soil water potential. Data in Fig. 2 indicate that the average atmospheric demand caused a decrease in minimum leaf water potential (1300-1500 CDT) of -9 to -10 bars. This agrees well with information shown by Gardner and Ehlig (1963). Minimum values in Fig. 2 reflect only days when measurements could be taken in full sunlight. Measurements taken during extremely high evaporative demand conditions caused an increase in leaf water potential as compared to those taken on medium to high evaporative demand days. Cary and Wright (1971) illustrated a similar response of leaf water potential to high evaporative demand in beans.

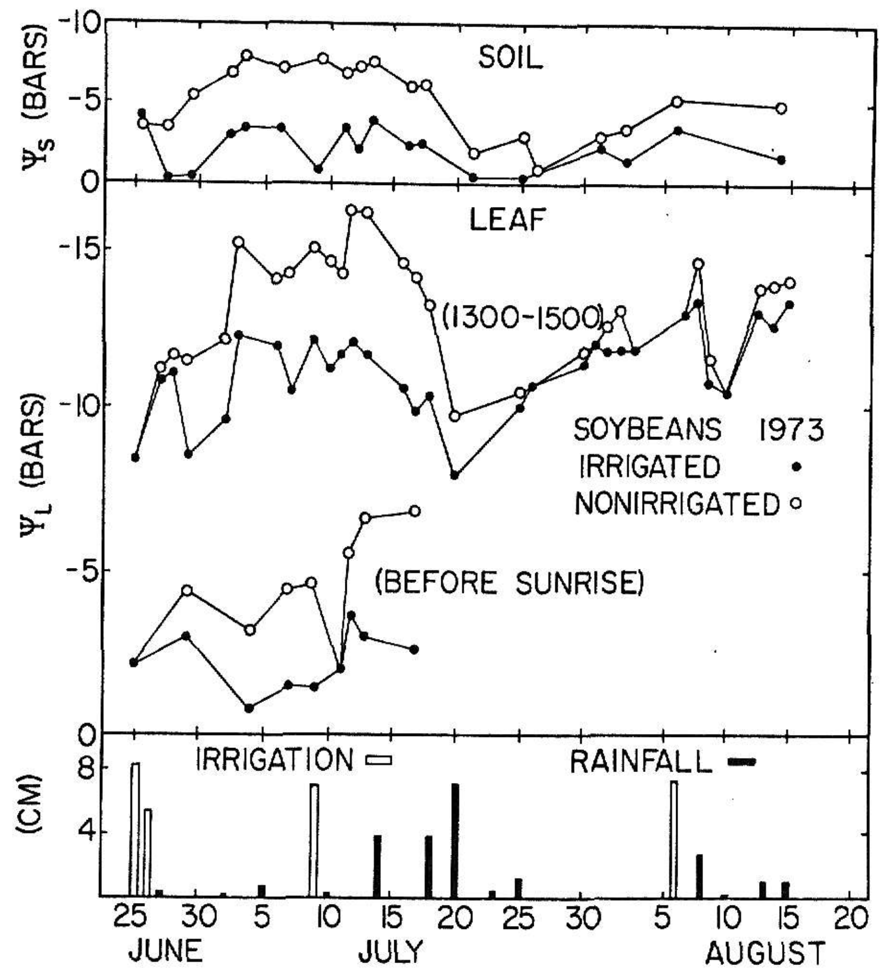

Figure 3. Seasonal changes of maximum and minimum leaf water potential (Ψ_L), soil water potential (Ψ_S), and amounts of rainfall and irrigation for non-irrigated and irrigated at 40 percent depletion, 1973.

The relationships between leaf water potential and soil water potential shown in Fig. 2 were determined during the vegetative stage. Figure 3 presents leaf water potentials taken during 1973. The upper set of curves represents the midday measurements and the lower set represents the early morning measurements. Differences in leaf water potential between irrigated and nonirrigated soybeans can be readily seen and are an indication of soil water potential during the vegetative and flowering stages. Boyer (1972) and Clark and Hiler (1973) noted that during the reproductive stage, leaf water potentials were less responsive than in the vegetative stage. An evaluation of leaf water potential in the podding stage from data collected in 1973 was not possible because of severe leaf damage from bacterial pustule late in the season. Figure 4 presents measurements of leaf water potential taken in 1972 during the podding stage as well as soil water potential and rainfall. The values of leaf water potential presented in Fig. 4 appear to be as responsive to changes in soil water potential as those presented for the vegetative and flowering stages (Fig. 3).

Figure 5 shows the relationship between the minimum values of leaf water potential in the podding stage of the 1972 season and the soil water potential. Measurements were taken from August 17 to September 11. A regression analysis indicated a similar slope to those determined during the vegetative stage of the 1973 season (Fig. 2). The coefficient of determination indicates similar explained variation as in the two previous relations in the vegetative stage (Fig. 2). The analyses presented in Fig. 2 and Fig. 5 indicate

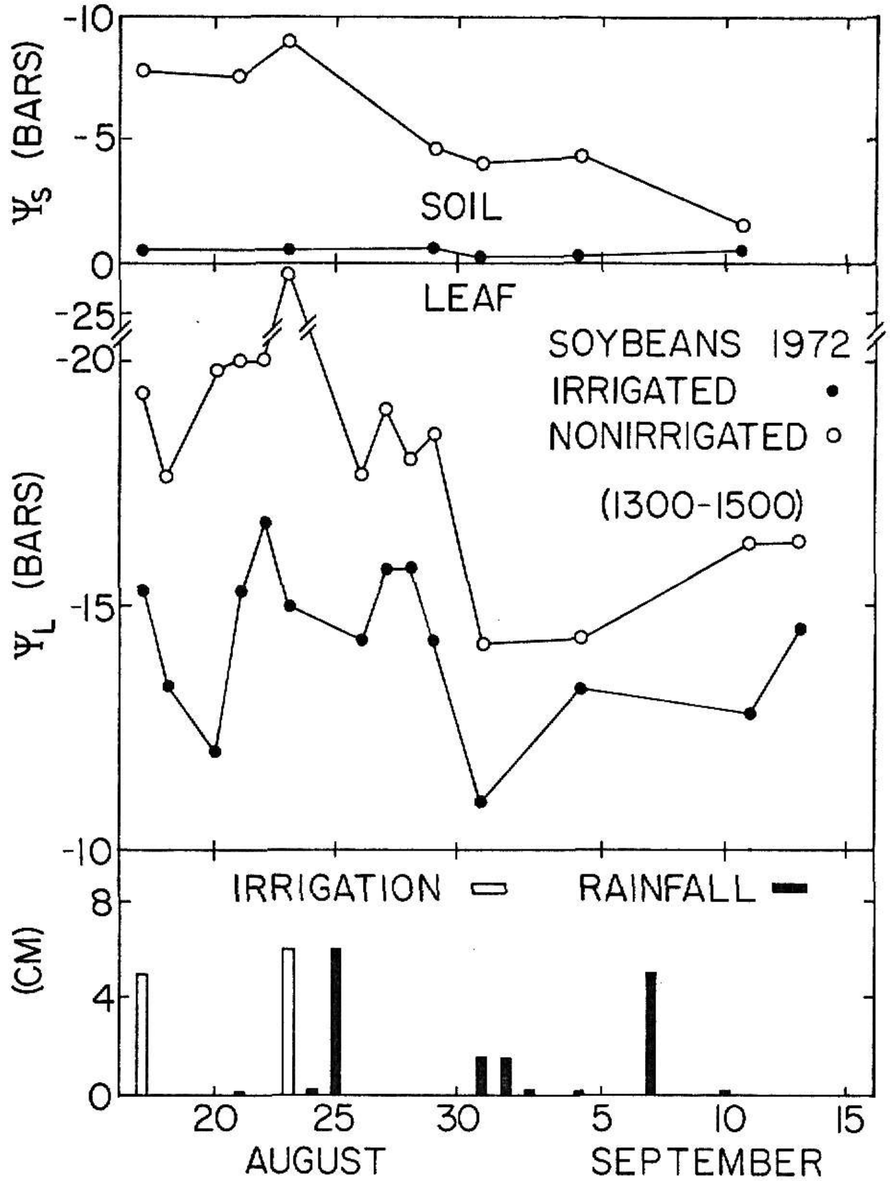

Figure 4. Changes in minimum leaf water potentials (Ψ_L) and soil water potentials (Ψ_S) for nonirrigated and irrigated at 40 percent depleted during the podding stage, 1972.

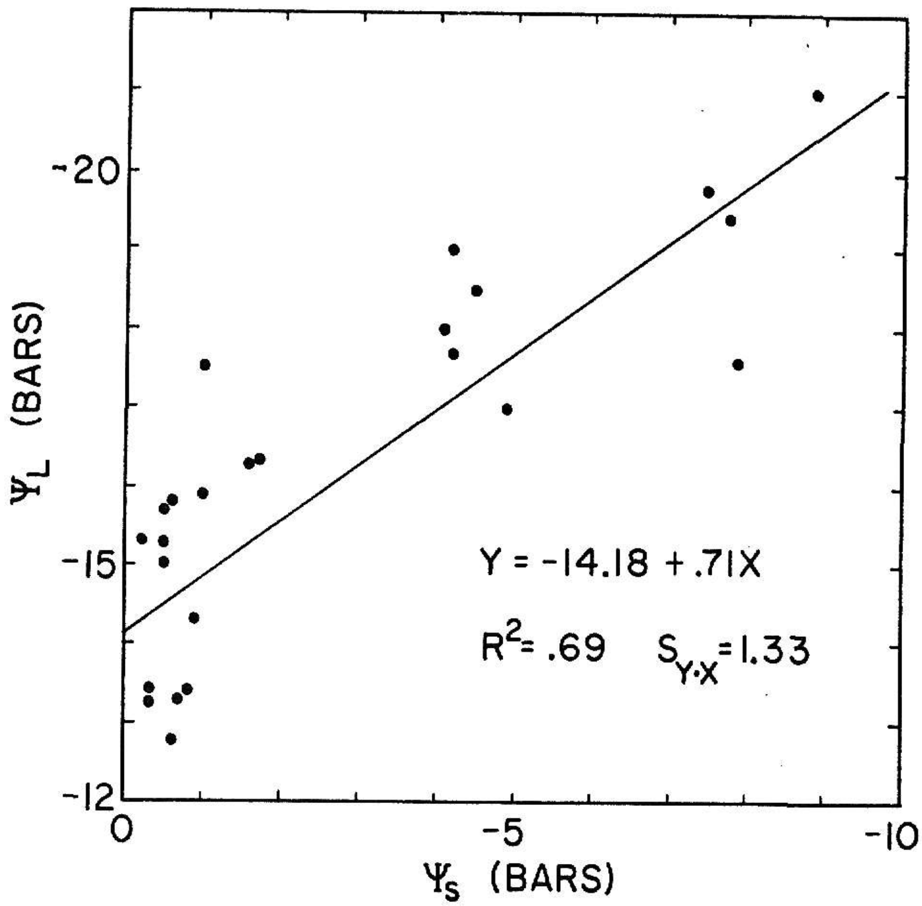

Figure 5. The relationship of minimum leaf water potentials (Ψ_L) to soil water potentials (Ψ_S) in the podding stage, 1972.

that soybean leaf water potential is as responsive to soil water potential in the reproductive stage as in the vegetative stage with minimum values being approximately 4 bars less (see y intercept values).

This study shows that a definite relation exists between soil water potential and leaf water potential. Leaf water potentials, measured with a pressure chamber, can be used to determine the integrated soil water potential sensed by a plant's roots. It is suggested that accurate measurement of leaf water potentials may be applied to determining irrigation schedules.

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CHAPTER III

SOYBEAN YIELD RESPONSE TO IRRIGATION INITIATED AT STAGES OF GROWTH AND SOIL-MOISTURE-DEPLETION LEVELS

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SOYBEAN YIELD RESPONSE TO IRRIGATION INITIATED AT STAGES OF GROWTH AND SOIL-MOISTURE-DEPLETION LEVELS [1]

R. A. Brady, W. L. Powers, C. D. Nickell, and L. R. Stone [2]

ABSTRACT

Yield response of soybeans to irrigations initiated at various stages of growth when predetermined soil-moisture-depletion levels were reached was evaluated in a two-year study. Yields were significantly reduced only in nonirrigated treatments. Soybeans which received approximately 15 cm of irrigation yielded as well, and had less lodging, than soybeans which received 25-35 cm of irrigation. Soybean yields were not increased by irrigating in the vegetative and flowering stages. Soil-moisture-depletion levels of 60 to 65 percent of the available water in the active root zone during the podding stage did not decrease yields. These data clearly indicate the potential water savings that can result from timely irrigation.

Additional Index Words: Seed weight, Rainfall

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INTRODUCTION

Many researchers have reported soybeans to be most sensitive to moisture stress during the reproductive stage. Laing (1966) found soybean yields most suceptible to moisture stress in the bean filling period. Runge and Odell (1960) noted that above normal rainfall during the late vegetative and bean filling period increased soybean yields. Matson (1964) showed irrigation from bloom to one month before harvest as effective as irrigation throughout the season. Similarly, Somerholder and Schluesener (1960) showed irrigation at late bloom to be comparable to irrigation throughout the growing season.

Knowledge of soybean yield response to irrigation in various stages of growth is essential in making optimum use of water resources. This study has evaluated the seed yield, lodging, and seed weight of soybeans where irrigation was initiated at the vegetative, flowering, and podding stages of growth when predetermined soil-moisture-depletion levels were reached.

METHODS AND MATERIALS

Measurements were taken from an irrigated field on the Ashland Agronomy Farm 14 km south of Manhattan, Kansas. The soil is a Muir silt loam developed from alluvium. In 1972 soybeans (<u>Glycine max</u> L. cv. Calland) were planted May 18 and final plant density was 269,000 plants/ha. In 1973 the planting date was May 14; final plant density, 259,000 plants/ha.

THIS BOOK CONTAINS NUMEROUS PAGES THAT ARE BLURRY DUE TO DOUBLE PRINTING IN THE TEXT.

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In 1972 the experimental design was a split plot with the main treatments being three soil-moisture-depletion levels plus nonirrigated control plots and the subtreatments were three stages of growth at which irrigation was initiated. These 12 treatments were replicated four times. In 1973 the 12 treatments were completely randomized in each of four replications.

Irrigation was initiated at three stages of growth (vegetative, flowering, and podding) when predetermined soil-moisture-depletion levels were reached. Developmental stages are reported by Brady et al.[3] Depletion levels in 1972 were 20, 40, and 60 percent of the available water in the root zone. In 1973 depletion levels were changed to 40, 55, and 65 percent.

Plot width was changed in 1973 from 8 rows 60 cm apart to 10 rows 75 cm apart. Criterion for changing row and plot dimensions was to prevent damage to plants during sampling after full cover, and reduce the affect of horizontal movement of water. Plot length both years was 13 meters.

Irrigation requirements were determined from soil moisture determinations taken weekly with a neutron probe in a 165 cm soil profile at 15 cm intervals. Access tubes were located in the plant row and centered in each plot. Gravimetric samples or a special calibration of the neutron probe was used to determine soil moisture

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[3] Brady, R. A., S. M. Goltz, W. L. Powers, and E. T. Kanemasu. 1974. The relation of soil water potential to stomatal resistance of soybean. Chapter I (in this thesis).

in the top 15 cm increment. Available water was assumed to be the amount held in the root zone between -1/3 and -15 bars pressure. Moisture release curves were determined in a constant temperature room for each 15 cm increment of soil. The depth of the root zone was determined from soil moisture measurements. The lowest depth of water removal was used as the bottom of the root zone.

Water was applied with a furrow irrigation system using individual plastic pipes fitted with constant flow valves to insure accurate measurement of applied water. Water was delivered to the plots in 15 cm diameter aluminum pipes in which pressure was controlled with a standpipe. Aluminum edging along plot borders reduced lateral movement of surface water between plots.

Seed yield, lodging, and weight per 100 seeds was determined from soybeans harvested from 2.4 m of the two center rows in each plot.

RESULTS AND DISCUSSION

Yield of soybeans when irrigation was initiated at various stages of growth is shown in Table 1. Yields were significantly increased, approximately 20 percent, by irrigation in both years. No significant difference in yield existed due to depletion level or growth stage when irrigation was initiated. Although not significantly different, yields were higher when depletion levels were 60 percent in 1972 and 65 percent in 1973.

Lodging information collected in 1972 and 1973 is also shown in Table 1. A lodging score of 1 to 5 was used; where 1 corresponds

Table 1. Agronomic performance of irrigated and nonirrigated soybeans, 1972 and 1973.

Treatment		Yield (kg/ha)		Lodging*		Seed Weight per 100 seeds (gms)	
Beginning of irrigation		1972	1973	1972	1973	1972	1973
No water		3069	2731	1.3	1.4	17.0	14.7
Vegetative		3685	3300	2.8	2.6	17.4	17.5
Flowering		3591	3405	2.4	2.8	17.6	17.5
Podding		3799	3392	2.0	1.8	17.0	16.9
$LSD_{.05}$		277	227	.3	.4	NS	.6
Soil Depletion							
1972	1973						
20	40	3564	3167	2.5	2.4	16.7	16.5
40	55	3427	3202	2.0	2.3	17.6	16.8
60	65	3625	3251	1.9	1.9	17.5	16.5
$LSD_{.05}$		NS	NS	.3	.3	NS	NS

* Lodging score (1 to 5); where 1 represents 100 percent of plants standing erect, and 5 represents no plants standing erect.

to all plants standing erect, and 5 corresponds to no plants standing erect. Significant differences in lodging did exist within both stage of growth and depletion treatments. Plots were hand harvested, so yield reduction due to lodging was minimal. It is possible that combine harvesting could have decreased yield differences between irrigated and nonirrigated treatments when lodging was significant in the irrigated treatments. Lodging might possibly cause significant harvestable differences within stages of growth and depletion treatments of the irrigated soybeans.

Seed weight per 100 seeds is shown in Table 1. No significant differences existed in 1972 in either the stage of growth or depletion treatments. Seed number, and not seed weight was primarily responsible for reduction in yield in the nonirrigated treatments of 1972. In 1973, seed weight was significantly reduced in the nonirrigated treatments. This indicates reduced yield in nonirrigated treatments, in 1973, was primarily due to seed weight and not seed number. Seed weight in the depletion levels did not significantly differ in 1973.

The greatest yields were produced by the 60 and 65 percent depletion levels and irrigations initiated in the podding stage (Table 1). In each year, the soil profile was near field capacity at planting time. Rainfall during the growing season was 27.6 and 34.3 cm in 1972 and 1973, respectively. Table 2 shows the amount of irrigation and the seed yield per cm of water applied for each irrigation treatment. In 1972, 123 kg/ha were harvested for each

Table 2. Amount of irrigation applied and seed yield per cm of irrigation, by stage of growth and depletion level, 1972 and 1973.

Stage of Growth	Depletion Level (%)		Irrigation (cm)		Seed Yield per cm of Irrigation Applied (kg/ha cm)	
	1972	1973	1972	1973	1972	1973
Vegetative	20	40	55.1	40.7	67	81
	40	55	48.9	24.9	71	133
	60	65	36.1	13.1	103	252
Flowering	20	40	52.1	33.8	67	99
	40	55	44.5	26.5	73	127
	60	65	37.7	13.1	102	267
Podding	20	40	31.6	19.5	120	168
	40	55	31.2	13.1	120	259
	60	65	30.0	13.1	123	267

cm of irrigation water applied to the soybeans irrigated only during the podding stage when 60 percent depletion occurred. Minimum efficiency in 1972 was 67 kg/ha harvested per cm of irrigation water applied to the soybeans irrigated throughout the season (vegetative stage) when 20 percent depletion occurred. In 1973 the results were more pronounced and showed similar trends.

In summary, this yield analysis indicates that: 1) irrigation increased soybean yields approximately 20 percent, 2) neither the stage nor soil-moisture-depletion level at which irrigation was initiated had a significant effect on seed yields even though the amount of water applied ranged from 13 to 40 cm, 3) most efficient use of water occurred when irrigation was initiated in the podding stage of growth at 60 to 65 percent soil-moisture-depletion level, and 4) low efficiencies corresponded to high lodging scores, which could result in reduced yields if machine harvested.

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APPENDIX I

Table 1. Values of soil water content, soil water potential, and bulk density of Muir silt loam.

Soil Water Potential (bars)	Depth (cm) 0-15	15-30	30-45	45-60	60-75	75-90	90-105	105-120	120-135	135-150
	Soil water content cm^3/cm^3									
-.10	.391	.377	.405	.404	.379	.377	.377	.386	.411	.410
-.20	.359	.361	.392	.395	.304	.258	.223	.275	.327	.286
-.80	.329	.345	.375	.375	.194	.141	.141	.122	.206	.192
-1.40	.316	.336	.366	.368	.179	.133	.130	.112	.174	.161
-2.00	.301	.328	.357	.362	.171	.127	.125	.104	.160	.153
-5.00	.204	.237	.269	.266	.089	.065	.085	.056	.093	.059
-10.00	.189	.207	.235	.236	.081	.058	.078	.053	.085	.052
-15.00	.173	.193	.196	.223	.076	.057	.073	.049	.078	.051
	Soil Bulk Density g/cm^3									
	1.37	1.29	1.38	1.30	1.28	1.28	1.30	1.37	1.32	1.38

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STOMATAL RESISTANCE, LEAF WATER POTENTIAL, AND YIELD IN IRRIGATED AND NONIRRIGATED SOYBEANS

by

RANDALL A. BRADY

B. S., KANSAS STATE UNIVERSITY, 1972

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Soybean yield response to irrigations initiated at various stages of growth and soil-moisture-depletion levels was evaluated in a two-year study. Plant measurements (stomatal resistance and leaf water potential) were taken to determine their ability to indicate water need.

Irrigation requirements were determined from soil moisture measurements made with a neutron probe. Soil water potentials were determined from the soil moisture measurements using a moisture release curve. Stomatal resistance was measured with a diffusion porometer; leaf water potentials with a pressure chamber. Seed yield, lodging, and seed weight information was determined in both years.

Stomatal resistance and soil water potential was compared and a definite relationship determined. Adaxial stomatal resistance of upper canopy leaves increased rapidly when soil water potentials decreased to near -4 bars. Abaxial resistances were less sensitive, and were not affected until soil water potentials reached -6 bars.

Soil water potentials were compared to maximum and minimum leaf water potentials and linear relationships determined. Maximum values of leaf water potential in the vegetative and flowering stages were found to closely correspond to soil water potential. Minimum leaf water potentials reflected an average decrease of 9 to 10 bars due to the evaporative demand. Minimum values of leaf water potential decreased approximately 4 bars during the podding stage.

Yields were significantly lower only in nonirrigated treatments. Soybeans which received approximately 15 cm of irrigation yielded as well, and had less lodging, than soybeans which received 25-35 cm of irrigation. Depletion levels of 60 to 65 percent of the available water in the active root zone during the podding stage did not decrease yields. Information clearly shows the potential water savings that can result from timely irrigation of soybeans.