SOYBEAN ROOT SYSTEMS AS INFLUENCED BY CULTIVAR, NITROGEN FERTILITY, AND WATER LEVEL

by

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B. S., Kansas State University, 1975

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas
1981

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ABSTRACT

Knowledge of the relation between root development and soil water extraction is necessary to evaluate genetic potential of parent soybean lives for water-use efficiency and conservation of irrigation water. This study was conducted to examine root development and to measure the corresponding water depletion patterns of five soybean [Glycine max (L.) Merr.] cultivars: 'Bonus', 'Calland', 'Clark 63', 'Williams', and 'Woodworth'. Soil cores were collected for root determination with a tractor mounted coring machine on three dates during the growing season. Roots were washed free of soil using a 35 mesh screen. Soil water was determined in the 15 cm to 150 cm soil profile at 15cm intervals using neutron moderation, and in the 0 cm to 15 cm depth by gravimetric sampling. Two mercury manometer tensiometers were installed in the crop row in each plot for determination of hydraulic potential, one at 130 cm depth and one at the 150 cm depth.

Results showed the five soybean cultivars did not vary significantly in either root dry matter or root depth, or in soil water use. Additionally, soybean yields of the five cultivars were not significantly different.

Because of the suggested need of soybeans for nitrogen, a study was conducted to measure the influence of preplant applied nitrogen on soybean [Glycine max (L.) Merrill cv. 'Williams'] root growth under

watered and unwatered field conditions. A rhizotron was used for obtaining the root depth and density measurements, which were taken twice a week from 15 June to 1 July once a week until 28 August, and the final measurement taken on 15 September.

Statistical analysis of the root counts (root density) showed significant nitrogen and irrigation interaction effects. The influence of irrigation on total root density at the 0 kg N and 112 kg N per hectare treatments was variable and no consistent trends over the sampling period were established. However, the 56 kg of N per hectare treatment showed a significantly higher total root density as a response to irrigation. Root depth, physiological stage development and soybean dry matter yields showed no significant differences between each N-treatment and accompanying water level.

Additional index words: Soil water depletion, nuetron moderation, hydraulic potential, tensiometer, nitrogen, root growth, rhizotron.

INTRODUCTION

Knowledge of root depth and distribution is important in designing irrigation systems and in determining proper time and amount of water application. However, the root systems of plants have received less attention than the above ground parts because of the difficulty in making periodic examinations of roots growing in the soil. As a result, knowledge of root systems is relatively scarce.

The objectives of this study were to investigate root development and soil water depletion of five soybean cultivars and to investigate effects of preplant-N on soybean root growth under watered and unwatered field conditions.

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Chapter I

ROOT SYSTEMS AND SOIL WATER DEPLETION OF FIVE SOYBEAN CULTIVARS

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ABSTRACT

Knowledge of the relation between root development and soil water extraction is necessary to evaluate genetic potential of parent soybean lines for water-use efficiency and conservation of irrigation water. This study was conducted to examine root development and to measure the corresponding water depletion patterns of five soybean [*Glycine max* (L.) Merr.] cultivars: 'Bonus', 'Calland', 'Clark 63', 'Williams', and 'Woodworth'. Soil cores were collected for root determination with a tractor mounted coring machine on three dates during the growing season. Roots were washed free of soil using a 35 mesh screen. Soil water was determined in the 15 to 150 cm soil profile at 15 cm intervals using neutron moderation, and in the 0 to 15 cm depth by gravimetric sampling. Two mercury manometer tensiometers were installed in the crop row in each plot for determination of hydraulic potential, one at the 130 cm depth and one at the 150 cm depth.

Results showed the five soybean cultivars did not vary significantly in either root dry matter or root depth, or in soil water use. Additionally, soybean yields of the five cultivars were not significantly different.

Additional index words: Soil water depletion, neutron moderation, hydraulic potential, tensiometer.

INTRODUCTION

Irrigation acreage is ever increasing, while water resources become more and more limited, forcing correct and efficient use of irrigation water. Knowledge of the factors which effect the amount of subsoil water used is essential. These factors include atmospheric demand, the plant's ability to regulate the flow of water through the plant system, exploitation of the subsoil water reservoir by the root system, and hydraulic properties of the soil (Teare et al., 1973). Root ramification which includes root density and depth is important in the determination of the quantity of water which may be depleted before irrigation is required. More efficient use of irrigation water can be attained through knowledge of root growth patterns combined with evapotranspiration and available soil water data. Workers using estimates of rooting depth have analyzed the performance of irrigation systems using simulation models (Godwin, Lembke, and Jones, 1971; Morey and Gilley, 1973).

Study of soybean [*Glycine max* (L.) Merr.] root development has been limited due to sampling difficulty and the large amounts of manual labor required. Borst and Thatcher (1934) found that the soybean primary root reached a depth of 152 cm under favorable field conditions. More lateral roots were present and the primary root less prominent under less favorable conditions. Dittmer (1940) suggested that the primary lateral roots of soybeans, although less numerous than the other roots, nevertheless exposed more surface area and occupied more volume than any other root division. Raper and Barber (1970) found variation in root morphology (differential adsorption capacities) and root density among different soybean cultivars. Mitchell and Russell (1971) sampled systems of eight soybean cultivars on four dates and found root growth and development to occur in three phases, each phase corresponding to a specific vegetative or reproductive stage. Stone et al., (1976) examined root depth and distribution in the field with irrigated and nonirrigated soybeans. They found root depths reaching 160 cm in both treatments. During the first half of their study, maximum root and water depletion depths were nearly equal. Later, water depletion depths tended to be 15 cm deeper than root growth (possibly as a result of upward water movement into the water-depleted root zone). Allmaras et al., (1975) found maximum soybean rooting depths coinciding with maximum depth of water uptake.

The objective of this study was to examine root development of five soybean cultivars and to measure the corresponding soil water depletion patterns.

METHODS AND MATERIALS

The study was conducted on the Ashland Agronomy Research Farm, 14 km south of Manhattan, Kansas. The soil is a Muir silt loam (fine silt, mixed, mesic, Pachic Haplustoll) which has developed from alluvial deposits. The surface silt loam extends to the 14 cm depth; silty clay loam from 14 cm through 50 cm; silty clay from 50 cm through 81 cm; and silty loam below 81 cm. The soil profile has slight plowpan features in the 14 cm to 22 cm layer, but is relativey free from root restricting features.

Five cultivars of soybeans [Glycine max (L.) Merr. cv. 'Bonus', 'Calland', 'Clark 63', 'Williams', and 'Woodworth'] were planted 35 plants per meter 19 May 1975, in rows 76 cm apart. The plot area was organized into fifteen plots, with the five cultivars being randomized in each of three blocks. Treatment and block significance levels were determined using the SAS procedure ANOVA (Goodnight, 1979). Each plot was ten rows wide by 12.2 m long. Physiological stages were recorded as described by Hanway and Thompson (1971). Slight differences were observed up to stage V2; after stage V2 Calland was five to seven days earlier than the other varieties, however, Woodworth reached stage R9 (beans at full size) at the same time as Calland.

All plots received 11 cm of irrigation water near stage R6 (21 July 1975). Water was metered into the furrowed basins using gated pipe. Soil water was determined in the 15 to 150 cm soil profile at 15 cm depth intervals using neutron moderation and in the 0 to 15 cm layer by gravimetric sampling. One access tube was placed in the center of each of the fifteen plots. Two mercury manometer tensiometers were installed in the crop row in each plot for determination of hydraulic potential; one at the 130 cm depth and one at the 150 cm depth. Hydraulic potential is listed with the ground surface as the reference level.

Soil cores used for root determination were collected using a tractor mounted coring machine (The Giddings Model B.S. Soil Sampling Machine by the Giddings Machine Company, Fort Collins, Colorado). The coring tube had an internal diameter of 8.3 cm. Each sample consisted of a composite of two cores, one centered on a soybean plant in the row (in-row) and another 25 cm perpendicular from the crop row (one-third row) giving four cores per plot. The soil cores were partitioned with depth into 15 cm increments. The top 15 cm increment was further partitioned into two 7.5 cm sections. Samples were taken three times during the growing season, 28 June, 28 July, and 20 August. Roots were washed free from soil using a 35 mesh screen. Roots were then oven dried at 100° C. Maximum rooting depth was taken to be the maximum depth at which roots were observed at the time of sampling.

RESULTS AND DISCUSSION

Yields for the five soybean cultivars ranged from 1875 to 2410 kg/ha and were not significantly different (Appendix:Table 3).

Total root dry matter and mean root depth in relation to sampling data are shown in Table 1-1. On 28 June all cultivars except Calland were at stage V3 (Calland was at stage R4). Total root dry matter varied significantly at this stage from 0.4 g/1.08 dm^2 soil surface for Calland to 0.9 g/1.08 dm^2 soil surface for Woodworth, while the differences in total root dry matter among the remaining cultivars were not significant. On 28 July, Calland was at stage R7, and the remaining cultivars were at stage R6. Total root dry matter at this time varied from 4.3 g/1.08 dm^2 soil surface for Woodworth to 6.6 g/1.08 dm^2 soil surface for Williams, however, none of the total root dry matter amounts among the cultivars were significantly different. By 20 August, all cultivars had reached stage R9 (beans at full size). Total root dry matter varied significantly from 4.3 g/1.08 dm^2 soil surface for Williams, 4.8 g/1.08 dm^2 for Woodworth, and 7.6 g/1.08 dm^2 for Bonus. Total root dry matter amounts among the remaining cultivars were not significantly different. No one cultivar was consistently highest or lowest in total root dry matter throughout the sampling period.

Root depth for the five cultivars on the three sampling dates is also given in Table 1-1. On 28 June, Clark 63 was significantly deeper rooted than Woodworth. No other significant differences in root depth among the cultivars existed on 28 June. On 28 July, as well as 20 August, no significant difference in root depth among the cultivars existed. No cultivar was consistently deeper rooted throughout the sampling period.

There were no significant differences in hydraulic potential among the cultivars at either the 130 or 150 cm depths except Clark 63 had a significantly higher hydraulic potential value than Williams at the 150 cm depth on 20 August (Appendix:Table 9).

Throughout the measuring period there were only three periods during which there were significant differences in water use among the cultivars (Table 1-2). Total water use was approximately 55 cm and no significant differences existed among the cultivars.

Over the entire measurement period significant differences in total water content in the 150 cm soil profile nor in three separate depth intervals among the cultivars existed (Appendix:Tables 11 and 12).

Results show the five soybean cultivars did not vary significantly in either root dry matter or root depth, or in soil water use. Soybean yields of the five cultivars were not significantly different.

Table 1-1. Total root dry matter + and mean root depth as a function of date under five soybean cultivars.

Cultivar	Total root dry matter, Sampling date: 28 June	28 July	20 August	Mean root depth, Sampling date: 28 June	28 July	20 August
	$g/1.08\ dm^2$ ground surface area			cm		
Bonus	0.717ab‡	5.670a	7.624a	49.8ab	126.3a	131.0a
Calland	0.444b	5.383a	5.268ab	61.4ab	128.8a	137.5a
Clark 63	0.750ab	6.427a	5.793ab	71.8a	125.0a	135.0a
Williams	0.767ab	6.618a	4.345b	53.7ab	121.3a	138.8a
Woodworth	0.923a	4.313a	4.785b	48.6b	117.5a	141.3a
	Treatment significance level§					
	0.1714	0.6598	0.1209	0.1677	0.7974	0.8937
	Block significance level§					
	0.3733	0.1882	0.9552	0.5385	0.1656	0.8368

+ Mean combined values of cores taken in-row and one-third row.

‡ Treatment means within a column followed by the same letter are not different at the 0.05 level of significance according to Duncan's multiple range test.

§ Treatment and block significance levels were determined using the SAS procedure ANOVA.

Table 1-2. Mean water use for designated time intervals under five soybean cultivars.

Cultivar	Mean water use		
	Time interval		
	30 Jun-7 Jul	7-17 Jul	20 Aug-2 Sept
	cm of H_2O/day		
Bonus	0.56 ab	0.80 a	0.59 ab
Calland	0.72 a	0.52 b	0.56 b
Clark 63	0.60 a	0.66 ab	0.49 b
Williams	0.38 b	0.70 ab	0.71 a
Woodworth	0.63 a	0.66 ab	0.52 b
	Treatment significance level‡		
	0.0370	0.2581	0.0318
	Block significance level‡		
	0.4178	0.9104	0.0058

† Treatment means within a column followed by the same letter are not different at the 0.05 level of significance according to DMRT.

‡ Treatment and block significance levels were determined using the SAS procedure ANOVA.

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Chapter II

SOYBEAN ROOT SYSTEMS AS INFLUENCED BY WATER LEVEL AND NITROGEN FERTILITY

SOYBEAN ROOT SYSTEMS AS INFLUENCED BY WATER LEVEL AND NITROGEN FERTILITY

ABSTRACT

Because of soybean's questioned need for nitrogen, this study was conducted to measure the influence of preplant applied nitrogen on soybean [Glycine max (L.) Merrill cv. 'Williams'] root growth under irrigated and nonirrigated field conditions. A rhizotron was used in obtaining the root depth and density measurements, which were taken twice a week from June 15 to July 1, once a week until August 28, and the final measurement taken on September 15.

Statistical analysis of the root counts (root density) showed significant nitrogen and irrigation interaction effects. The influence of irrigation on total root density at the 0 kg N and 112 kg N per hectare treatments was variable and no consistent trends over the sampling period were established. However, the 56 kg of N per hectare treatment showed a significantly higher total root density as a response to irrigation. Root depth, physiological stage development and soybean dry matter yields showed no significant differences between each N-treatment and accompanying water level.

Additional index words: nitrogen, root growth, rhizotron.

INTRODUCTION

Because of the cost and availability situation, correct timing and rate of application of N-fertilizer is even more essential today than in the past. High rates of N-fertilization of leguminous crops such as soybeans may be unfeasible because of cost and supply of N-fertilizer. However, the merits of low rates of N-fertilization on soybeans applied during the planting or pre-plant period should be considered.

Work in mineral nutrition of soybeans has shown an inverse relationship between high rates of mineral N and symbiotic N produced (Caldwell et al., 1973). High rates of supplemental N taken by the plant from the soil, or from fertilizer sources, diverts a certain amount of nodule-bound photosynthate for increased growth (in both plant tops and roots) and overall protein synthesis. Conversely, low rates of supplemental N have been shown to be beneficial on soybeans (Caldwell et al., 1973); lower rates of N applied both before and after soybean emergence (at vegetative stages only) increased dry matter of both tops and roots, 23-71% and 91-93%, respectively.

The most critical period of soybean need for N is just before flowering; and work has shown that N supplied prior to bloom stimulated better growth and yields, resulting in a 70% increase in dry matter yield at maturity in soybeans from $Ca\ (NO_3)_2$ fertilization applied prior to planting (Caldwell et al., 1973).

Nodule formation can be seen in field grown soybeans six days after emergence and depending on growing conditions, N-fixation can be detected anywhere from two to four weeks after emergence (Weber et al., 1971). Therefore, a low preplant N-application may be useful during the period of time before the nodules begin effective N-fixation.

Certain environmental conditions contribute to the N-response in soybeans. Although results obtained from N-fertilization have been highly variable, substantial evidence has been established indicating that in years of adequate rainfall or irrigation, yield responses and profitable economic responses occurred due to N-fertilization (Mederski et al., 1958). Irrigated soybeans have been shown to have increased root dry matter in the deeper soil depths (Mayaki et al., 1975) as compared to nonirrigated soybeans; part of the N-response under better soil moisture conditions can be attributed to the increased absorbing effectiveness for soil N that has been leached downward in the soil profile.

The objective of this study was to determine the influence of preplant-N on soybean root growth using a rhizotron under nonirrigated and irrigated field conditions.

METHODS AND MATERIALS

The research area was located on the Ashland Agronomy Research Farm, 14 km south of Manhattan, Kansas. The soil used in the rhizotron is Muir silt loam (fine silty, mixed, mesic, Pachic Haplustoll). The soil was taken from the 30-180 cm depth (silt loam), and then sifted through a wire screen having 0.6 by 0.6 cm square openings. This sifted soil was then put into the rhizotron boxes and packed to an approximate bulk density of 1.3 gm/cm^3.

The rhizotron boxes are constructed of steel. Dimensions of the boxes are 182 cm long by 75.2 cm wide by 39.5 cm across (at the top). The front faces of the boxes are slanted at approximately 10°, making the bottom of the box 9.5 cm across. This front face is fitted with one sheet of wire-reinforced glass, 182 cm long by 75.5 cm wide by 0.6 cm thick. Increment root counts were taken by the line transect method (Canfield, 1941). The transect line (0.45 mm in width) was 120.5 cm long for each depth increment (15 cm) and consisted of the combined root counts on a horizontal line 75.5 cm long, and three vertical lines each 15 cm long. One vertical line was located in-row bordered by two vertical lines at 1/2-row (18.5 cm).

Soybean [*Glycine max* (L.) Merr. cv. 'Williams'] was planted 28 May 1976. A single row was planted down the middle of the rhizotron, and plant spacing thinned to 5.6 cm. Three rates of N-fertilizer (30-0-0) were applied as liquid at 0, 56, and 112 kg of N per hectare. Soil tests made on the soil in the rhizotron boxes showed a phosphorus deficiency, so 28 kg P per hectare (0-45-0) as liquid was also applied to each box. Both fertilizer applications occurred on the same day, before planting. Treatments (3 N-fertilizer rates x 2 watering levels) replicated 3 times were applied to the 18 rhizotron boxes in a completely randomized design. Treatment significance levels were determined using the SAS procedures ANOVA (Goodnight, 1979). The code used to describe each corresponding nitrogen and water treatment is given by the kg of nitrogen per hectare (0, 56, and 112) followed by no irrigation (NI) or irrigation (I). Irrigated rhizotrons were watered every two weeks with 5.1 cm of water from 1 July to 1 September (Figure 2-1). Root counts were taken two times a week until stage V2.5 (1 July), once a week until stage R9 (28 August), and the final measurement taken at harvest maturity (15 September). No measurements were taken from 29 July to 17 August due to a breakdown in the winch used to raise and lower the rhizotron boxes. Physiological growth stages were recorded each week (Table 2-1).

RESULTS AND DISCUSSION

Throughout the measurement period (15 June to 15 September) no differences in physiological growth stages among the treatments were observed (Appendix:Table 2).

Soybean root density (measured in root counts) in the rhizotron root boxes receiving nitrogen fertilization and irrigation is shown versus date in Table 2-1. On 15 June (growth stage V1), in decreasing order of total root density, the 0-I treatment had 45 counts, the 0-NI treatment had 37 counts, both 56-NI and 112-I treatments had 34 counts, 112-NI had 31 counts, and the 56-I treatment had 30 counts. Similarly, total root density among the treatments differed significantly in the following decreasing order according to Duncan's multiple range test: 0-I, 0-NI, 56-NI and 112-I, then 112-NI and 56-I. Both 0 kg of N per hectare treatments were significantly higher in total root density than either the 56 or 112 kg of N per hectare treatments.

On 28 July (growth stage R5.5), total root density ranged from 309 counts for the 112-I treatment, 278 counts for the 56-I treatment, 277 counts for the 112-NI treatment, 228 counts for the 0-I treatment, 224 counts for the 0-NI treatment, to 208 counts for the 56-NI treatment. Total root density among the treatments differed significantly in the following decreasing order according to Duncan's multiple range test: 112-I, 56-I and 112-NI, 0-I and 0-NI, then 56-NI.

On 28 September, 13 days after harvest maturity, the decreasing order of total root density was 288 counts for 112-NI, 281 counts for 56-I, 220 counts for 112-I, 187 counts for 56-NI, 172 counts for 0-I, and 153 counts for 0-NI. Total root density among the treatments differed significantly in the following decreasing order according to Duncan's multiple range test: 112-NI, 56-I, 112-I, 56-NI, 0-I, then 0-NI. Both 0 kg of N per hectare treatments were significantly the lowest in total root density.

Statistical anaysis on the root count (root density) data in Table 2-2 showed significant nitrogen and irrigation interaction effects. Discussion of only nitrogen or irrigation effects on root density would not accurately interpret the root count data.

The influence of irrigation on total root density at each level of N-treatment varied. After 30 June, rainfall was limited until 15 September (Fig. 2-1). During that time the only N-treatment that showed consistently significant higher total root density as a response to irrigation was the 56 kg of N per hectare treatment.

Generally, no significant differences in root depth among the N-treatments and accompanying water levels was evident (Appendix:Table 15).

No significant differences among the treatments existed in stem, bean, pod, or leaf dry matter (Appendix:Table 4).

Statistical analysis of the root counts (root density) showed significant nitrogen and irrigation interaction effects. The influence of irrigation on total root density at the 0 kg N and 112 kg N per hectare treatments was variable and no consistent trends over the sampling period were established. However, the 56 kg of N per hectare treatment showed a significantly higher total root density as a response to irrigation. Root depth, physiological stage development and soybean dry matter yields showed no significant differences between each N-treatment and accompanying water level.

Table 2-1. Total soybean root density + as a function of date, nitrogen fertilization, and water treatment.

	Total soybean root density												
	Jun				Jul							Aug	Sept
Treatment	15	19	22	29	1	6	8	13	15	21	28	28	28
	counts												
0-NI	37b ‡	50b	57cd	85c	70f	90d	123bc	118f	191c	129f	224c	181e	153f
0-I	45a	47c	58c	71e	83d	117b	119d	124e	173e	150e	228c	177e	172e
56-NI	34c	50b	69a	83d	94b	120b	111e	182c	188d	189d	208d	224d	187d
56-I	30d	51a	63b	87b	99a	107c	125b	185b	195b	234a	278b	282a	281b
112-NI	31d	45e	54d	82d	90c	121b	122c	220a	231a	208b	277b	234c	288a
112-I	34c	46d	61b	93a	77e	149a	180a	169d	233a	195c	309a	241b	220c
	Treatment significance level§												
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

+ Mean combined counts of horizontal and vertical lines transect in the 0-165cm rhizotron soil column.

‡ Treatment means within a column followed by the same letter are not different at the 0.05 significance level according to Duncan's multiple range test.

§ Treatment significance level was determined using the SAS procedure ANOVA.

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Appendices

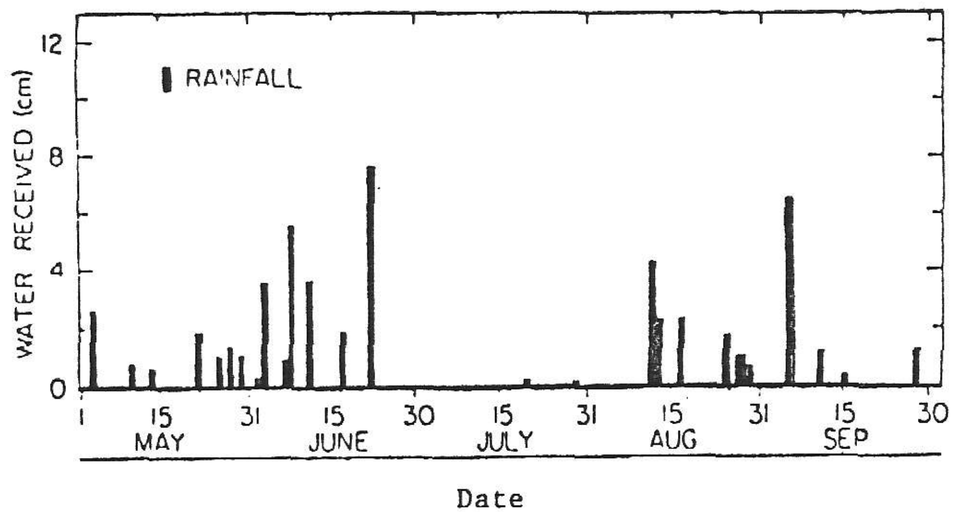

Fig 1 Rainfall received in relation to date, 1975.

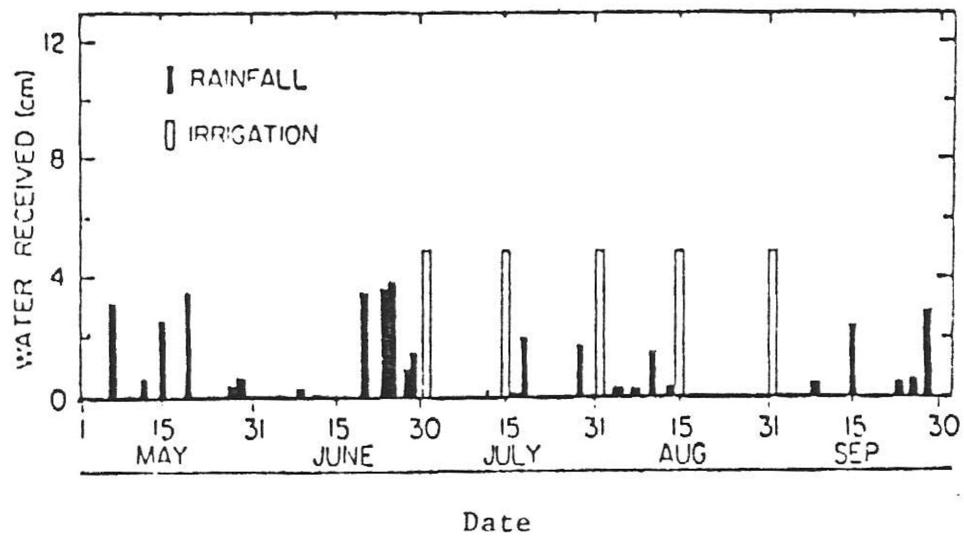

Fig 2 Water received (irrigation and rainfall) in relation to date, 1976.

Table 1. Soybean physiological stages of development during the 1975 season.

	Stages													
Cultivar	Emergence	V0*	V1	V2	V3	R4	R5	R5.5	R6	R7	R8	R9	R10	R11
	date													
Bonus	5-27**	6-2	6-8	6-15	6-27	7-2	7-7	7-14	7-22	7-29	8-4	8-23	9-20	9-29
Calland	5-27	6-2	6-8	6-15	6-20	6-27	7-2	7-9	7-24	7-27	8-1	8-18	9-8	9-26
Clark 63	5-27	6-2	6-8	6-15	6-27	7-2	7-11	7-18	7-24	8-4	8-11	8-23	9-20	9-30
Williams	5-27	6-2	6-8	6-15	6-27	7-2	7-7	7-14	7-30	8-4	8-11	8-23	9-15	9-26
Woodworth	5-27	6-2	6-8	6-15	6-27	7-2	7-7	7-14	7-24	7-30	8-11	8-18	9-3	9-23

* Hanway, J. J. and H. E. Thompson. 1971. How a soybean plant develops. SR53 (Rev.), Iowa State University. 17 p.

**Month and day of year.

Table 2. Williams soybean physiological stages of development during the 1976 season.

Treatment**	Emergence	V0	V1	V2	V3	R4	R5	R5.5	R6	R7	R8	R9	R10	R11
0-NI	4 June	7 June	12 June	29 June	4 July	13 July	18 July	25 July	1 Aug	11 Aug	16 Aug	26 Aug	2 Sept	15 Sept
0-I	4 June	7 June	12 June	29 June	4 July	13 July	20 July	25 July	1 Aug	10 Aug	15 Aug	25 Aug	2 Sept	15 Sept
56-NI	4 June	7 June	12 June	26 June	3 July	12 July	19 July	26 July	31 July	10 Aug	16 Aug	25 Aug	1 Sept	15 Sept
56-I	4 June	7 June	12 June	27 June	4 July	12 July	19 July	24 July	2 July	8 Aug	14 Aug	25 Aug	1 Sept	15 Sept
112-NI	4 June	7 June	12 June	25 June	3 July	12 July	18 July	24 July	31 July	11 Aug	16 Aug	26 Aug	2 Sept	15 Sept
112-I	4 June	7 June	12 June	28 June	3 July	11 July	19 July	24 July	31 July	11 Aug	16 Aug	27 Aug	3 Sept	15 Sept

Stages*: column heading spanning all stage columns.

* Hanway, J. J. and H. E. Thompson. 1971. How a soybean plant develops. SR53 (Rev.), Iowa State University, 17 p.

** Treatment code: I= irrigated; NI= nonirrigated; 0, 56, 112 kg nitrogen per hectare.

Table 3. Mean soybean yield of the five soybean cultivars.

Cultivar	Mean soybean yield
	------kg/ha-------
Bonus	2,328 a[+]
Calland	2,334 a
Clark 63	1,875 a
Williams	2,410 a
Woodworth	1,969 a
	Treatment significance level[‡]
	0.1624
	Block significance level[‡]
	0.6242

+ Treatment means within a column followed by the same letter are not different at the 0.05 significance level according to Duncan's multiple range test.

‡ Treatment and block significance levels were determined using the SAS procedure ANOVA.

Table 4. Mean above ground soybean dry matter yields (cv. Williams).

Treatment	Dry matter plant yield			
	Stems	Beans	Pods	Leaves
	---------- $g/2970cm^2$ soil surface ----------			
0-NI	79.20 b +	4.74 a	7.39 a	25.91 a
0-I	90.62 ab	7.61 a	10.48 a	20.06 a
56-NI	82.84 ab	4.34 a	8.32 a	23.58 a
56-I	90.72 ab	6.96 a	11.32 a	21.35 a
112-NI	79.49 b	3.05 a	4.96 a	26.23 a
112-I	98.84 a	3.82 a	7.13 a	26.75 a
	Treatment significance level ++			
	0.1249	0.5226	0.2627	0.6652

\+ Treatment means within a column followed by the same letter are not different at the 0.05 level of significance according to Duncan's multiple range test.

++ Treatment significance level was determined using the SAS procedure ANOVA.

Table 5. Soybean yield for summer of 1976*

0-NI — g/2970 cm^2 soil surface — rhizotron

5	13	17	
74.11	75.68	87.80	stems
4.97	2.16	7.10	beans
8.43	3.50	10.25	pods
23.25	24.93	29.55	leaves

0-I — g/2970 cm^2 soil surface — rhizotron

	2	9	18
stems	103.86	83.10	84.91
beans	5.01	14.92	2.90
pods	12.45	12.90	6.09
leaves	23.35	10.69	26.24

56-NI — g/2970 cm^2 soil surface — rhizotron

4	8	12	
90.33	81.14	77.05	stems
4.16	5.98	2.87	beans
7.63	12.06	5.28	pods
22.97	24.95	22.81	leaves

56-I — g/2970 cm^2 soil surface — rhizotron

	3	6	10
stems	97.65	78.41	96.09
beans	5.15	6.85	8.88
pods	11.98	9.01	12.96
leaves	34.06	14.95	15.03

112-NI — g/2970 cm^2 soil surface — rhizotron

1	7	15	
82.37	87.80	68.31	stems
1.55	7.10	0.50	beans
3.38	10.25	1.24	pods
25.26	29.55	23.87	leaves

112-I — g/2970 cm^2 soil surface — rhizotron

	11	14	16
stems	102.10	90.88	103.54
beans	3.85	4.87	2.75
pods	7.23	7.70	6.46
leaves	24.37	26.20	29.69

*Yields taken on 15 September, 1976.

Table 6. Root dry matter, mean combined values of cores taken in row and one-third row, as a function of depth and time under five soybean cultivars. Ground surface area per sample is 1.08 dm^2.

	Cultivar														
	Bonus			Calland			Clark 63			Williams			Woodworth		
Depth	June 28	July 28	Aug. 20	June 28	July 28	Aug. 20	June 28	July 28	Aug. 20	June 28	July 28	Aug. 20	June 28	July 28	Aug. 20
cm	g/1.08 dm^2														
0-7.5	.640	4.112	5.441	.395	3.879	3.490	.680	4.382	4.062	.694	5.156	2.597	.778	3.160	2.773
7.5-15	.039	.477	.584	.036	.424	.500	.032	.433	.433	.055	.955	.539	.131	.225	.731
15-30	.024	.388	.316	.006	.173	.290	.018	.225	.152	.008	.776	.293	.011	.175	.252
30-45	.015	.205	.141	.003	.119	.121	.013	.107	.101	.009	.134	.121	.001	.118	.118
45-60	T*	.216	.431	.002	.195	.115	.003	.145	.354	.001	.125	.146	T	.133	.156
60-75	T	.130	.138	.002	.118	.158	T	.624	.262	T	.279	.093		.230	.113
75-90		.065	.174		.119	.095	.001	.122	.093	T	.080	.132		.113	.202
90-105		.043	.145		.128	.121	.002	.096	.084	T	.066	.064		.091	.110
105-120		.024	.169		.192	.211		.118	.170		.023	.171		.058	.136
120-135		.009	.027		.034	.115		.162	.061		.020	.149		.003	.105
135-150		.001	.010		.002	.048		.011	.009		.003	.019		.005	.075
150-165		.001	.005			.003		.002	.008			.015			.011
165-180			.004						.002						.003
Total	.717	5.670	7.624	.444	5.383	5.268	.750	6.427	5.793	.767	7.618	4.345	.923	4.313	4.785

* T = Trace

Table 7. In-row and 1/3-row maximum root depth as a function of date under five soybean cultivars.

	Bonus														
	Plot														
	3				37				42						
Date	R1	R2	1/3R1	1/3R2	R1	R2	1/3R1	1/3R2	R1	R2	1/3R1	1/3R2	$\bar{X}$	S	S/ n
	cm														
28 June	46.5	22.5	37.5	37.5	62.0	62.0	46.0	64.0	61.5	61.0	47.5	50.0	49.8	12.9	3.73
28 July	142.5	127.5	157.5	157.5	127.5	127.5	127.5	127.5	112.5	112.5	82.7	112.5	126.3	23.4	6.76
20 Aug.	127.5	142.5	127.5	157.5	97.5	127.5	127.5	127.5	127.5	184.5	112.5	112.5	131.0	22.5	6.50
	Calland														
	Plot														
	19				23				44						
Date	R1	R2	1/3R1	1/3R2	R1	R2	1/3R1	1/3R2	R1	R2	1/3R1	1/3R2	$\bar{X}$	S	S/ n
	cm														
28 June	42.5	61.5	36.0	82.5	78.0	63.5	49.5	52.5	78.0	67.5	63.0	62.0	61.4	14.3	4.13
28 July	142.5	127.5	127.5	112.5	127.5	142.5	127.5	127.5	112.5	127.5	127.5	142.5	128.8	10.0	2.89
20 Aug.	157.5	142.5	157.5	112.5	142.5	127.5	127.5	127.5	127.5	172.5	112.5	142.5	137.5	18.5	5.35
	Clark 63														
	Plot														
	17				22				38						
Date	R1	R2	1/3R1	1/3R2	R1	R2	1/3R1	1/3R2	R1	R2	1/3R1	1/3R2	$\bar{X}$	S	S/ n
	cm														
28 June	92.0	92.0	92.5	33.5	92.0	93.5	81.5	67.5	52.0	65.5	50.0	49.0	71.8	21.6	6.24
28 July	157.5	142.5	127.5	112.5	112.5	97.5	127.5	112.5	127.5	112.5	142.5	127.5	125.0	16.7	4.83
20 Aug.	172.5	157.5	157.5	127.5	127.5	142.5	112.5	127.5	142.5	127.5	127.5	127.5	135.0	16.3	4.71

Table 7. (continued)

	Williams														
	Plot														
	4				18				39						
Date	R1	R2	1/3R1	1/3R2	R1	R2	1/3R1	1/3R2	R1	R2	1/3R1	1/3R2	$\bar{X}$	S	S/ n
	cm														
28 June	51.5	52.5	63.5	62.5	52.5	97.5	52.5	52.5	22.7	52.7	37.5	47.0	53.7	17.5	5.06
28 July	127.5	97.5	127.5	127.5	142.5	127.5	157.5	127.5	112.5	112.5	82.5	112.5	121.3	19.7	5.69
20 Aug.	157.5	157.5	142.5	127.5	142.5	142.5	157.5	142.5	127.5	142.5	112.5	112.5	138.8	15.8	4.57

	Woodworth														
	Plot														
	2				24				43						
Date	R1	R2	1/3R1	1/3R2	R1	R2	1/3R1	1/3R2	R1	R2	1/3R1	1/3R2	$\bar{X}$	S	S/ n
	cm														
28 June	37.5	49	35	52	52.5	37.5	52.5	48.5	52.7	62.5	51.0	52.0	48.6	8.0	2.31
28 July	112.5	142.5	127.5	112.5	127.5	112.5	142.5	97.5	112.5	112.5	97.5	112.5	117.5	14.8	4.28
20 Aug.	172.5	142.5	157.5	142.5	142.5	142.5	157.5	127.5	127.5	127.5	127.5	127.5	141.3	14.9	4.31

Table 8. Mean hydraulic potential[+] at the 130 cm depth as a function of date under five soybean cultivars.

	Mean hydraulic potential				
Cultivar	9 July	17 July	25 July	6 August	20 August
	-cm of H_2O				
Bonus	268 a[‡]	289 a	309 a	370 a	443 a
Calland	277 a	304 a	326 a	397 a	544 a
Clark 63	262 a	280 a	299 a	364 a	436 a
Williams	277 a	396 a	321 a	388 a	545 a
Woodworth	272 a	294 a	322 a	395 a	508 a
	Treatment significance level[§]				
	0.5969	0.6125	0.5654	0.3591	0.1452
	Block significance level[§]				
	0.0317	0.6125	0.1899	0.3310	0.4391

[+] Referenced to the soil surface, measured with tensiometers.

[‡] Treatment means within a column followed by the same letter are not different at the 0.05 level of significance according to Duncan's multiple range test.

[§] Treatment and block significance levels were determined using the SAS procedure ANOVA.

Table 9. Mean hydraulic potential[+] at the 150 cm depth as a function of date under five soybean cultivars.

Cultivar	Mean hydraulic potential				
	9 July	17 July	25 July	6 August	20 August
	-cm of H_2O				
Bonus	267 a[++]	287 a	306 a	350 a	413 ab
Calland	279 a	304 a	320 a	367 a	434 ab
Clark 63	262 a	276 a	295 a	348 a	391 b
Williams	277 a	301 a	321 a	369 a	437 a
Woodworth	273 a	294 a	313 a	390 a	431 ab
	Treatment significance level[§]				
	0.8727	0.4860	0.2107	0.4690	0.1649
	Block significance level[§]				
	0.1459	0.1075	0.0519	0.1827	0.2965

[+] Referenced to the soil surface, measured with tensiometers.

[++] Treatment means within a column followed by the same letter are not different at the 0.05 level of significance according to Duncan's multiple range test.

[§] Treatment and block significance levels were determined using the SAS procedure ANOVA.

Table 10. Hydraulic potential referenced to the soil surface measured with tensiometers placed at 130 cm and 150 cm depths in five soybean cultivars.

	Bonus					
	130 cm			150 cm		
	Plot			Plot		
	3	37	42	3	37	42
	-cm of H_2O			-cm of H_2O		
July 1	250.0	192.8	260.3	---	254.0	262.8
July 2	118.8	176.5	260.3	251.3	254.0	260.3
July 7	266.3	202.8	270.3	268.8	267.8	271.5
July 8	---	---	264.0	270.0	264.0	266.5
July 9	272.5	266.5	265.3	270.0	264.0	266.5
July 10	273.8	267.8	265.3	272.5	266.5	266.5
July 11	277.5	271.5	266.5	276.3	269.0	267.8
July 14	287.5	277.8	270.3	286.3	275.3	271.5
July 15	193.8	279.0	271.5	290.0	279.0	274.0
July 16	298.8	282.8	274.0	300.0	282.8	275.3
July 17	303.8	286.5	276.5	297.5	285.3	277.8
July 18	303.8	290.3	279.0	302.5	289.0	279.0
July 21	326.3	300.3	284.0	311.3	301.5	285.3
July 23	320.0	306.5	386.5	315.0	307.8	289.0
July 24	327.5	309.0	287.8	317.5	309.0	289.0
July 25	330.0	309.0	289.0	320.0	209.0	290.3
July 28	343.8	319.0	295.3	328.8	319.0	295.3
July 29	343.8	322.8	297.8	332.5	320.3	296.5
July 30	362.5	329.0	300.3	337.5	324.0	302.8
July 31	356.3	335.3	304.0	338.8	329.0	302.8
Aug. 1	377.5	334.0	306.5	343.8	331.5	306.5
Aug. 4	388.8	356.5	341.0	356.3	341.5	312.8
Aug. 6	401.3	385.3	324.0	371.3	354.0	324.0
Aug. 7	397.5	400.0	329.0	362.5	359.0	329.0
Aug. 8	413.8	405.3	335.3	382.5	365.3	334.0
Aug. 11	458.8	450.3	357.8	408.8	387.8	352.8
Aug. 12	473.8	477.8	366.5	420.0	296.5	360.3
Aug. 13	468.8	496.5	379.0	425.0	402.8	367.8
Aug. 15	455.0	449.0	374.0	420.0	391.5	366.5
Aug. 18	451.3	449.0	371.5	427.5	385.3	369.0
Aug. 19	470.0	459.0	372.8	433.8	399.0	370.3
Aug. 20	473.8	470.8	385.3	446.3	409.0	384.0
Aug. 22	492.5	484.0	395.3	455.0	417.8	382.8
Aug. 26	567.5	549.0	427.8	480.0	436.5	404.0
Aug. 27	570.0	535.3	411.5	482.5	430.3	402.8
Aug. 29	590.9	545.3	417.8	448.8	431.5	407.8
Sept 2	718.8	600.3	449.0	522.5	471.5	426.5
Sept 3	762.5	624.0	489.0	541.3	512.8	439.0
Sept 6	817.5	642.8	466.5	536.3	421.5	437.8
Sept 8	808.8	650.3	534.0	561.3	452.8	447.8
Sept 9	810.0	652.8	497.8	557.5	451.5	447.8
Sept 10	810.0	656.5	504.0	568.8	461.5	451.5
Sept 13	807.5	655.3	470.3	555.0	450.3	435.3

Table 10. (continued)

	Calland					
	130 cm			150 cm		
	Plot			Plot		
	19	23	44	19	23	44
	-cm of H_2O			-cm of H_2O		
July 1	---	---	255.3	289.0	264.0	249.0
July 2	---	---	267.8	295.3	265.3	246.5
July 7	---	---	292.8	306.5	279.0	254.0
July 8	289.0	---	262.8	287.8	276.5	266.5
July 9	291.5	276.5	264.0	290.3	276.5	269.0
July 10	289.0	280.3	256.3	286.5	277.8	269.0
July 11	291.5	271.5	270.3	291.5	279.0	272.8
July 14	312.8	289.0	277.8	311.5	285.3	281.5
July 15	316.5	282.8	284.0	312.8	286.5	284.0
July 16	319.0	294.0	289.0	314.0	289.0	286.5
July 17	324.0	296.5	291.5	330.3	291.5	289.0
July 18	327.8	300.3	294.0	320.3	294.0	292.8
July 21	340.3	314.0	302.8	331.5	304.0	301.5
July 23	349.0	301.5	315.3	336.5	306.5	307.8
July 24	351.5	306.5	316.5	340.3	307.8	309.0
July 25	352.8	306.5	317.8	340.3	307.8	310.3
July 28	366.5	320.3	325.3	351.5	315.3	319.0
July 29	357.3	326.5	327.8	356.5	317.8	321.5
July 30	385.3	330.3	331.5	355.3	325.3	324.0
July 31	390.3	331.5	339.0	364.0	325.3	327.8
Aug. 1	401.5	339.0	345.3	371.5	327.8	332.8
Aug. 4	421.5	344.0	362.8	384.0	336.5	342.8
Aug. 6	447.8	359.0	382.8	400.3	3478	352.8
Aug. 7	474.0	362.8	396.5	404.0	350.3	---
Aug. 8	485.3	366.5	411.5	410.3	357.8	359.0
Aug. 11	542.8	379.0	460.3	424.0	395.3	376.5
Aug. 12	571.5	390.3	485.3	429.0	414.0	384.0
Aug. 13	610.3	412.8	511.5	441.5	406.5	391.5
Aug. 15	586.5	401.5	499.0	429.0	380.3	396.5
Aug. 18	590.3	401.5	487.8	431.5	384.0	400.3
Aug. 19	586.5	415.3	501.5	440.3	392.8	411.5
Aug. 20	595.3	515.3	521.5	451.5	424.0	422.8
Aug. 22	611.5	422.5	542.8	411.8	401.5	417.8
Aug. 26	694.0	462.8	661.5	444.0	412.8	435.3
Aug. 27	682.8	441.5	669.0	446.5	399.0	429.0
Aug. 29	687.8	449.0	666.5	465.3	406.5	435.3
Sept 2	697.8	496.5	746.5	469.0	426.5	446.5
Sept 3	706.5	532.8	765.3	482.8	447.8	455.3
Sept 6	741.5	467.8	799.0	---	415.3	475.3
Sept 8	741.5	530.3	794.0	---	434.0	462.8
Sept 9	739.0	481.5	782.8	---	435.3	460.3
Sept 10	752.3	487.8	784.0	447.8	436.5	465.3
Sept 13	752.8	469.0	812.8	454.0	430.3	457.8

Table 10. (continued)

	Clark 63					
	130 cm			150 cm		
	Plot			Plot		
	17	22	38	17	22	38
	-cm of H_2O			-cm of H_2O		
July 1	270.0	---	---	272.5	273.0	---
July 2	270.0	---	---	268.8	274.3	195.3
July 7	282.5	---	---	285.0	281.8	319.0
July 8	241.3	278.0	277.8	237.5	278.0	279.0
July 9	225.0	280.5	280.3	223.8	280.3	381.5
July 10	225.0	280.5	280.3	233.8	280.5	281.5
July 11	225.0	284.3	282.8	223.8	283.0	285.3
July 14	227.5	290.5	290.3	225.0	289.3	291.5
July 15	236.2	296.8	292.8	235.0	291.8	279.0
July 16	233.8	301.8	296.5	230.0	294.3	297.8
July 17	231.3	306.8	300.3	228.8	299.3	300.3
July 18	230.0	311.8	305.3	227.5	304.3	305.3
July 21	243.8	329.3	320.3	240.0	304.3	314.0
July 23	252.5	311.8	325.3	248.8	308.0	322.8
July 24	251.3	308.0	329.0	247.5	305.5	324.0
July 25	258.8	310.5	327.8	253.8	305.5	325.3
July 28	267.5	330.5	339.0	262.5	320.5	335.3
July 29	271.3	335.5	342.8	263.8	324.3	339.0
July 30	277.5	343.0	350.3	268.8	329.3	347.8
July 31	286.3	348.0	357.8	272.5	333.0	346.5
Aug. 1	292.5	356.8	362.8	276.3	338.0	350.3
Aug. 4	306.3	371.8	379.0	282.5	349.3	367.8
Aug. 6	332.5	306.8	374.0	296.3	363.0	385.3
Aug. 7	338.8	474.0	425.3	279.5	369.3	382.8
Aug. 8	353.8	405.5	445.3	303.8	379.3	391.5
Aug. 11	405.0	421.8	514.0	323.8	408.0	391.5
Aug. 12	417.5	429.3	551.5	328.8	418.0	407.8
Aug. 13	412.5	444.3	589.0	315.0	415.5	409.0
Aug. 15	457.5	438.0	542.8	373.8	400.4	410.3
Aug. 18	437.5	425.5	531.5	360.0	401.8	399.0
Aug. 19	438.8	434.3	561.5	352.5	404.3	411.5
Aug. 20	438.8	434.5	435.0	352.5	409.3	411.5
Aug. 22	455.0	443.0	729.0	351.3	411.8	414.0
Aug. 26	635.0	480.5	---	377.5	419.3	432.8
Aug. 27	621.3	468.0	---	385.0	415.5	425.3
Aug. 29	640.0	476.8	752.8	418.8	419.3	426.5
Sept 2	772.5	503.0	---	507.5	441.8	455.3
Sept 3	805.0	524.3	---	576.3	471.8	474.0
Sept 6	838.8	483.0	---	475.0	421.8	---
Sept 8	831.3	536.8	---	488.8	433.0	---
Sept 9	833.8	521.8	---	480.0	435.5	---
Sept 10	831.8	535.5	---	292.5	436.5	454.0
Sept 13	835.0	---	---	460.0	443.0	450.3

Table 10. (continued)

	Williams					
	130 cm			150 cm		
	Plot			Plot		
	4	18	39	4	18	39
	-cm of H_2O			-cm of H_2O		
July 1	227.5	281.8	270.3	225.5	---	271.5
July 2	225.0	284.3	271.5	222.5	---	271.5
July 7	201.3	296.8	284.0	201.3	---	285.3
July 8	253.8	290.5	380.3	---	298.0	279.0
July 9	253.8	294.3	281.5	255.0	296.8	280.3
July 10	255.0	294.3	282.8	256.3	296.8	280.3
July 11	258.8	284.3	282.8	250.0	300.5	282.8
July 14	267.5	305.5	286.5	267.5	309.3	387.8
July 15	271.3	309.3	289.0	271.3	311.8	290.3
July 16	275.0	311.8	291.5	277.5	315.5	291.5
July 17	278.8	315.5	292.8	286.3	321.8	294.0
July 18	283.8	219.3	296.5	287.5	326.8	305.3
July 21	295.0	331.8	302.8	297.5	338.0	300.3
July 23	302.5	338.5	310.3	303.8	345.5	307.8
July 24	303.8	341.8	312.8	305.0	346.8	309.0
July 25	305.0	343.0	315.3	307.5	345.5	309.0
July 28	315.0	356.8	326.5	316.3	354.3	316.5
July 29	343.8	360.5	326.5	320.0	358.0	317.8
July 30	322.5	369.3	326.5	325.0	350.5	322.8
July 31	323.8	373.0	332.8	323.8	364.8	319.0
Aug. 1	331.3	301.8	335.3	330.0	373.0	321.5
Aug. 4	341.8	405.5	352.8	338.8	379.3	339.0
Aug. 6	356.3	434.3	374.0	350.0	393.0	365.3
Aug. 7	363.8	441.8	377.8	357.5	398.0	359.0
Aug. 8	373.8	468.0	386.5	366.3	404.3	361.5
Aug. 11	417.5	550.5	450.3	393.8	419.3	391.5
Aug. 12	436.3	596.8	471.5	402.5	421.8	399.0
Aug. 13	461.3	653.0	467.8	413.8	435.5	410.3
Aug. 15	446.3	613.0	434.0	373.8	426.8	406.5
Aug. 18	456.3	608.0	434.0	420.0	426.8	409.0
Aug. 19	465.0	640.5	446.5	430.0	439.3	415.3
Aug. 20	486.3	670.5	477.8	445.0	443.0	424.0
Aug. 22	522.5	696.8	521.5	458.8	449.3	431.5
Aug. 26	690.0	770.5	805.3	471.3	476.8	465.3
Aug. 27	695.0	776.8	787.8	471.3	456.8	469.0
Aug. 29	711.3	776.8	780.3	471.3	461.8	470.3
Sept 2	807.5	784.3	795.3	527.5	481.8	494.0
Sept 3	820.0	785.5	809.0	572.5	498.0	507.8
Sept 6	840.0	803.0	832.8	507.5	488.0	506.5
Sept 8	836.3	803.0	822.8	517.5	503.0	510.3
Sept 9	836.3	803.0	834.0	513.8	479.3	515.3
Sept 10	837.5	799.3	826.5	525.0	503.0	522.8
Sept 13	843.8	815.5	834.0	507.5	488.0	500.3

Table 10. (continued)

	Woodworth					
	130 cm			150 cm		
	Plot			Plot		
	2	24	43	2	24	43
	-cm of H_2O			-cm of H_2O		
July 1	250.0	249.0	---	243.8	3478	---
July 2	240.0	249.0	---	244.0	249.0	---
July 7	240.0	260.3	---	243.8	264.0	---
July 8	276.3	259.0	275.3	280.0	249.0	275.3
July 9	280.0	269.3	276.5	285.0	257.8	276.5
July 10	281.3	262.8	277.8	285.0	261.5	276.5
July 11	282.5	265.3	282.8	286.3	265.3	282.8
July 14	283.8	275.3	290.3	285.0	2728	289.0
July 15	292.5	279.0	292.8	293.8	277.8	290.3
July 16	295.0	281.5	302.8	296.3	381.5	300.3
July 17	298.8	281.5	301.5	298.8	284.0	297.8
July 18	302.5	290.3	304.0	301.3	287.8	300.3
July 21	317.5	301.5	317.8	311.3	294.0	312.8
July 23	323.8	307.8	325.3	315.0	305.3	321.5
July 24	326.3	309.0	327.8	305.0	307.8	322.8
July 25	326.3	311.5	327.8	307.5	307.8	324.0
July 28	337.5	319.0	342.8	323.8	314.0	336.5
July 29	342.5	325.3	347.8	325.0	316.5	340.3
July 30	348.8	327.8	355.3	335.0	324.0	351.5
July 31	351.3	331.5	360.3	332.5	321.5	349.0
Aug. 1	357.5	337.8	369.0	340.0	325.3	354.0
Aug. 4	356.3	352.8	396.5	357.5	335.3	365.3
Aug. 6	380.0	375.3	429.0	433.8	357.8	377.8
Aug. 7	382.5	386.5	441.5	425.0	347.8	381.5
Aug. 8	388.8	405.3	462.8	428.8	357.8	386.5
Aug. 11	428.8	485.3	509.0	429.0	385.3	395.3
Aug. 12	442.5	522.8	542.8	432.0	396.5	400.3
Aug. 13	446.3	555.3	590.3	431.0	409.0	412.3
Aug. 15	423.8	499.0	539.0	433.0	386.5	407.8
Aug. 18	429.0	485.3	574.0	440.0	385.3	407.8
Aug. 19	436.3	501.5	506.5	439.0	402.8	419.0
Aug. 20	467.5	536.5	520.0	448.0	411.5	436.5
Aug. 22	487.5	572.8	774.0	---	409.0	419.0
Aug. 26	481.3	727.8	815.3	---	411.5	435.3
Aug. 27	467.5	709.0	841.5	---	409.0	424.0
Aug. 29	463.8	704.0	834.0	---	415.3	427.8
Sept 2	536.3	777.8	834.0	---	441.5	436.5
Sept 3	526.3	792.8	---	---	477.8	456.5
Sept 6	452.5	827.8	---	---	430.3	456.5
Sept 8	476.3	814.0	---	---	440.3	456.5
Sept 9	461.3	810.3	---	---	435.3	437.8
Sept 10	477.5	800.3	---	---	441.5	440.3
Sept 13	451.3	781.5	---	---	486.5	439.0

Table 11. Mean total water in the 0-150 cm soil profile as a function of date under five soybean cultivars.

Cultivars	Mean total water									
	19 Jun	30 Jun	7 Jul	17 Jul	25 Jul	1 Aug	5 Aug	20 Aug	2 Sept	20 Sept
	cm of H_2O									
Bonus	48.7a[+]	47.5a	43.6a	35.6a	40.6a	33.5a	30.5a	32.1a	26.8a	30.3a
Calland	45.4a	44.4a	39.4ab	33.2a	35.6a	30.1a	28.7a	29.7a	24.7a	26.9a
Clark 63	44.8a	43.1a	38.9b	32.2b	37.9a	31.6a	28.2a	29.1a	25.1a	27.1a
Williams	47.0a	47.5a	44.9a	37.8a	40.4a	33.5a	30.5a	31.3a	26.1a	27.4a
Woodworth	45.6a	44.3a	44.3ab	33.9a	35.6a	30.8a	28.2a	29.2a	26.4a	28.1a
	Treatment significance level[‡]									
	0.4511	0.2882	0.1261	0.2249	0.1467	0.5471	0.7986	0.4244	0.7930	0.3712
	Block significance level[‡]									
	0.0609	0.0593	0.1070	0.6676	0.0300	0.1109	0.2074	0.1193	0.4396	0.1951

[+] Treatment means within a column followed by the same letter are not significantly different at the 0.05 significance level according to Duncan's multiple range test.

[‡] Treatment and block significance levels were determined using the SAS procedure ANOVA.

Table 12. Mean total water content for designated depth intervals in the 0-150 cm soil profile as a function of date under five soybean cultivars.

	Mean total water content								
	Soil depth								
	0-52 cm			52-97 cm			97-150 cm		
Cultivars	30 Jun	25 Jul	20 Aug	30 Jun	25 Jul	20 Aug	20 Jun	25 Jul	20 Aug
	cm of H_2O								
Bonus	17.2a[+]	18.0a	16.3a	12.4a	7.5a	4.7a	17.9a	15.1a	11.0a
Calland	16.8a	15.8a	15.3a	11.0a	5.7a	3.7a	16.6a	14.2a	10.2ab
Clark 63	16.4a	16.7a	15.2a	11.1a	7.7a	3.9a	15.6a	12.9a	9.5ab
Williams	18.3a	18.2a	16.6a	12.5a	8.3a	4.9a	16.9a	14.2a	9.8ab
Woodworth	17.8a	17.3a	16.9a	11.2a	6.2a	4.0a	15.2a	13.0a	8.4b
	Treatment significance level[‡]								
	0.4501	0.2009	0.5811	0.3053	0.3173	0.3536	0.2208	0.2483	0.1712
	Block significance level[‡]								
	0.8165	0.0891	0.5881	0.0643	0.4100	0.3726	0.0297	0.0226	0.1750

[+] Treatment means within a column followed by the same letter are not significantly different at the 0.05 level according to Duncan's multiple range test.

[‡] Treatment and block significance levels were determined using the SAS procedure ANOVA.

Table 13. Mean hydraulic gradients as a function of date under five soybean cultivars for summer, 1975.

Date	Bonus	Calland	Clark 63	Williams	Woodworth
			cm of H_2O/cm		
July 1	---	---	---	---	---
July 2	1.84	---	---	---	---
July 7	1.15	---	---	---	---
July 8	---	---	- .04	---	- .11
July 9	- .06	- .06	0.00	.04	- .04
July 10	- .02	- .02	0.00	.02	- .02
July 11	- .04	1.67	0.00	.29	- .06
July 14	- .04	- .02	- .04	.09	- .04
July 15	- .02	0.00	- .33	.06	- .04
July 16	.04	- .21	- .16	.10	- .02
July 17	.10	- .02	- .17	.25	- .02
July 18	.04	- .25	- .17	.33	- .12
July 21	- .21	- .34	- .59	.10	- .31
July 23	- .02	- .25	- .17	.11	.25
July 24	- .15	- .29	- .15	.04	- .46
July 25	- .15	- .31	- .21	- .02	.44
July 28	- .25	- .44	- .31	- .19	.42
July 29	- .25	- .56	- .38	- .58	- .56
July 30	- .46	- .71	- .42	- .83	.36
July 31	- .42	- .73	- .67	- .38	- .67
Aug. 1	- .60	- .90	- .79	- .40	.75
Aug. 4	- .81	-1.08	- .96	- .70	.79
Aug. 6	-1.02	-1.48	- .81	- .94	.25
Aug. 7	-1.28	-1.70	-3.14	-1.15	- .94
Aug. 8	-1.21	-2.27	-2.17	-1.60	-1.37
Aug. 11	-1.97	-3.71	-3.63	-3.56	-6.07
Aug. 12	-3.35	-3.67	-4.06	-4.69	-8.55
Aug. 13	-2.50	-4.92	-5.11	-5.38	-9.32
Aug. 15	-1.67	-4.69	-4.23	-4.77	-6.17
Aug. 18	-2.00	-4.40	-3.90	-4.04	-4.98
Aug. 19	-1.65	-4.31	-4.44	-4.46	-5.19
Aug. 20	-1.50	-4.35	-4.54	-4.75	-6.67
Aug. 21	-1.51	-4.73	-5.15	-5.38	-8.23
Aug. 22	-1.94	-5.76	-7.50	-6.69	-9.87
Aug. 26	-3.74	-8.77	---	-14.21	-12.57
Aug. 27	-3.35	-8.65	---	-14.38	-12.81
Aug. 29	-4.42	-8.27	-10.08	-14.42	-12.27
Sept 2	-5.79	-9.98	---	-14.73	-13.85
Sept 3	-6.37	-10.31	---	-13.92	-9.62
Sept 6	-8.85	---	---	-16.23	-9.84
Sept 8	-8.85	---	---	-15.52	-9.84
Sept 9	-8.40	---	---	-16.08	-9.96
Sept 10	-10.15	-11.25	---	-15.21	-9.90
Sept 13	-8.21	-11.54	---	-16.63	-7.68

Table 14. Soybean root density (mean combined counts of horizontal and vertical line transects) per depth increment in relation to date.

O-NI

Depth(cm)	June 15	June 19	June 22	June 29	July 1	July 6	July 8	July 13	July 15	July 21	July 28	Aug 28	Sept 15
							counts						
0-15	18.0	19.9	27.0	26.7	26.4	25.7	28.5	26.0	37.2	30.4	37.7	17.1	17.1
15-30	13.6	16.0	16.0	17.4	17.4	18.3	23.5	19.6	21.3	19.0	29.0	17.4	12.3
30-45	3.6	5.3	5.3	7.6	6.7	13.0	13.3	11.6	16.7	9.5	20.3	14.0	11.6
45-60	1.5	4.7	4.7	9.0	6.4	8.4	19.8	11.5	19.5	11.1	22.7	21.3	13.7
60-75		2.5	3.3	5.3	4.6	7.3	11.9	12.6	21.7	11.7	23.3	15.0	14.0
75-90		1.5	1.0	5.6	2.3	5.3	7.5	7.7	20.0	9.7	14.7	15.7	10.0
90-105				13.2	4.3	10.0	11.3	12.6	24.0	13.4	30.0	14.3	15.4
105-120				1.7	1.5	2.0	6.5	11.7	19.2	12.3	22.7	19.3	14.7
120-135				1.0			1.0	5.0	11.5	7.0	13.4	22.6	13.7
135-150										4.3	7.0	12.7	15.6
150-165										.7	3.7	12.0	14.6
Total	36.7	50.2	57.3	85.1	69.6	90.0	123.3	118.3	191.1	129.1	224.5	181.4	152.7

O-I

Depth(cm)	June 15	June 19	June 22	June 29	July 1	July 6	July 8	July 13	July 15	July 21	July 28	Aug 28	Sept 15
							counts						
0-15	16.3	17.9	28.0	32.0	36.7	34.2	35.6	27.6	39.2	39.6	44.1	20.7	18.0
15-30	17.9	16.6	16.4	17.0	17.2	23.0	24.3	23.3	30.5	29.1	30.3	18.9	17.0
30-45	9.3	8.3	7.0	9.7	9.0	12.9	13.6	10.7	11.9	11.7	13.9	4.6	16.7
45-60	1.0	3.5	4.6	4.4	5.7	19.4	11.0	12.5	13.8	9.0	17.0	12.7	16.0
60-75		1.0	1.7	4.0	5.3	9.0	8.9	15.6	24.8	10.1	20.4	21.8	16.3
75-90				2.3	4.3	7.7	11.7	9.0	21.7	13.0	28.3	18.4	16.0
90-105				1.7	4.3	7.1	6.4	10.9	20.1	19.0	24.9	19.0	25.0
105-120					.3	3.4	5.3	10.3	11.0	12.6	18.7	19.3	15.0
120-135							1.7	4.3		4.6	19.0	15.3	10.7
135-150										1.6	9.6	16.0	10.7
150-165											2.0	10.0	10.7
Total	44.5	47.3	57.7	71.3	82.8	116.7	118.5	124.2	173.0	150.3	228.2	176.7	172.1

Table 14. (continued)

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Depth(cm)	June 15	June 19	June 22	June 29	July 1	July 6	July 8	July 13	July 15	July 21	July 28	Aug 28	Sept 15
	counts												
0-15	13.0	19.3	26.0	35.4	34.1	31.7	34.6	33.7	39.2	33.3	43.0	22.8	15.9
15-30	14.0	18.3	24.0	27.7	30.2	29.4	23.2	34.3	30.8	34.7	23.9	20.6	21.7
30-45	4.2	4.9	8.0	10.8	10.7	15.3	15.2	16.7	12.5	14.9	16.7	11.6	7.3
45-60	2.2	5.7	6.7	7.0	7.3	12.4	8.5	18.3	14.2	15.3	15.6	18.9	14.0
60-75	1.0	1.7	3.0	5.3	7.3	11.0	11.6	21.4	25.5	21.3	28.0	21.0	22.0
75-90			1.0	3.3	2.3	11.6	9.0	21.6	19.3	21.3	25.0	28.7	24.2
90-105				3.0	2.0	8.0	2.3	19.1	17.1	22.0	13.3	34.8	19.8
105-120						1.0	3.3	13.8	20.0	14.4	20.0	21.3	25.9
120-135							3.3	2.7	9.0	11.6	11.1	13.7	16.6
135-150										1.0	9.3	15.6	10.7
150-165											2.3	14.6	9.7
Total	34.4	49.9	68.7	82.5	93.9	120.4	111.0	181.6	187.6	189.5	208.2	223.7	186.7

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Depth(cm)	June 15	June 19	June 22	June 29	July 1	July 6	July 8	July 13	July 15	July 21	July 28	Aug 28	Sept 15
	counts												
0-15	16.2	24.0	28.2	33.6	37.6	29.3	34.8	36.3	39.3	42.3	43.7	21.6	25.0
15-30	9.0	18.2	18.2	23.5	26.0	24.7	28.6	37.9	34.4	35.6	31.7	21.4	20.7
30-45	3.7	7.0	8.4	8.3	9.3	13.3	11.4	21.7	16.6	18.0	19.7	12.7	14.0
45-60	.7	1.0	4.6	8.7	8.0	12.6	9.6	23.0	15.9	17.4	21.0	17.7	30.9
60-75		1.0	2.0	3.3	4.6	6.0	8.3	14.7	13.5	16.0	26.6	29.1	39.0
75-90			1.0	4.0	4.3	6.6	8.3	20.5	23.3	22.7	31.0	27.7	31.1
90-105				5.2	8.5	12.0	17.0	20.7	31.1	38.2	39.2	33.1	31.4
105-120				.7	.7	2.3	6.5	10.0	18.7	34.4	35.0	37.3	32.4
120-135								.3	1.4	7.0	16.7	25.4	23.7
135-150									.3	1.3	7.8	30.0	18.0
150-165										1.3	5.7	26.4	14.7
Total	29.6	51.2	62.4	87.3	99.0	106.8	124.5	185.1	194.8	234.2	277.9	282.4	280.9

Table 14. (continued)

112-NI

Depth(cm)	June 15	June 19	June 22	June 29	July 1	July 6	July 8	July 13	July 15	July 21	July 28	Aug 28	Sept 15
	counts												
0-15	17.1	18.0	22.0	32.4	35.0	40.5	39.3	40.1	50.0	43.3	34.4	25.7	19.6
15-30	8.4	13.7	17.1	21.0	23.3	23.4	23.9	35.9	38.1	34.3	25.9	25.1	26.3
30-45	4.0	5.9	10.0	9.3	13.0	14.7	16.2	18.3	25.4	19.6	24.0	17.6	17.3
45-60	1.5	3.0	2.3	9.0	8.4	10.3	10.8	16.2	15.0	13.7	20.3	21.4	17.1
60-75	.3	2.7	1.7	4.4	3.3	10.3	10.6	21.1	17.6	24.7	32.0	27.4	28.0
75-90		1.0	1.0	1.7	1.3	5.7	8.3	18.6	19.6	19.0	34.7	30.0	38.0
90-105		.3	.3	1.5	1.8	7.0	2.3	18.6	22.3	20.0	34.3	30.4	39.3
105-120				1.5	3.7	5.3	4.8	23.0	18.2	14.4	26.0	22.7	29.4
120-135				1.0	1.7	3.3	4.0	17.1	11.3	8.6	14.7	16.1	24.7
135-150						.3	1.7	10.8	9.2	6.0	19.3	11.3	24.3
150-165									4.6	4.3	11.0	7.0	24.0
Total	31.3	44.6	54.4	81.8	90.2	120.8	121.9	219.7	231.3	207.9	276.6	234.7	288.3

112-I

Depth (cm)	June 15	June 19	June 22	June 29	July 1	July 6	July 8	July 13	July 15	July 21	July 28	Aug 28	Sept 15
	counts												
0-15	13.4	22.4	27.6	37.7	35.5	45.1	48.0	56.3	53.0	38.4	45.6	37.7	25.3
15-30	9.8	13.3	17.9	26.7	13.4	27.7	27.0	22.0	37.0	27.7	31.3	20.3	16.7
30-45	8.5	5.3	5.3	9.6	6.0	13.4	14.3	14.2	19.0	11.7	22.6	11.7	11.7
45-60	1.8	2.4	2.7	5.0	4.6	10.3	18.1	12.9	16.0	10.7	25.4	14.4	14.3
60-75	.3	2.7	2.7	4.7	5.6	15.3	17.7	17.8	20.8	19.8	35.0	25.3	22.7
75-90			3.7	5.4	6.3	14.0	20.0	10.2	21.5	23.3	36.8	27.7	23.9
90-105			.6	4.4	4.7	13.0	18.3	10.0	29.3	21.4	41.6	28.3	30.0
105-120			.3		.3	9.5	11.3	9.7	23.3	23.0	39.7	19.6	23.3
120-135						.3	5.6	12.0	11.5	12.6	24.7	17.7	19.0
135-150								3.7	1.7	5.9	12.0	21.4	16.7
150-165										1.0	4.3	17.3	16.7
Total	33.8	46.1	60.8	93.5	76.5	148.6	180.3	168.8	233.1	195.5	309.0	241.4	220.3

Table 15. Mean root depth of soybeans in relation to date, nitrogen fertilization, and water treatment.

	Root depth									
	Jun			Jul						
Treatment	15	19	22	29	1	6	8	13	15	21
	cm									
0-NI	55a +	65a	85b	120a	120a	125a	123a	130a	130a	145ab
0-I	55a	65a	80b	95ab	100a	100a	115a	125a	125a	135ab
56-NI	55a	75a	75b	75b	95a	100a	110a	120a	125a	130b
56-I	50a	75a	80b	105a	105a	110a	115a	120a	135a	145ab
112-NI	60a	80a	90ab	115a	115a	120a	125a	135a	150a	155ab
112-I	55a	75a	105a	110a	120a	125a	130a	140a	145a	165a
	Treatment significance level ‡									
	0.9853	0.6864	0.0529	0.0333	0.3252	0.3415	0.4848	0.6560	0.2210	0.2399

+ Treatment means within a column followed by the same letter are not significantly different at the 0.05 significance level according to Duncan's multiple range test.

‡ Treatment significance level was determined using the SAS procedure ANOVA.

Table 16. Root depth of soybeans in relation to date, water treatment, and nitrogen fertilization.

	O-NI			O-I		
	BOX			BOX		
Date	5	13	17	2	9	18
	cm					
June						
15	60	45	60	45	60	60
19	75	45	74	45	75	75
22	90	75	90	90	75	75
29	135	120	105	105	105	75
July						
1	135	120	105	120	105	75
6	135	120	120	120	105	75
8	130	120	120	135	105	105
13	135	135	120	135	135	105
15	135	135	120	135	135	105
21	165	150	120	150	150	105
28	165	165	165	165	165	165
Aug						
28	165	165	165	165	165	165
Sept						
15	165	165	165	165	165	165

	56-NI			56-I		
	BOX			BOX		
Date	4	8	12	3	6	10
	cm					
June						
15	30	75	60	60	45	45
19	75	75	75	75	75	75
22	75	75	75	75	75	90
29	75	75	75	105	120	90
July						
1	90	90	105	105	120	90
6	105	90	105	120	120	90
8	105	105	120	120	20	105
13	120	105	135	120	135	105
15	120	120	135	135	150	120
21	135	120	135	135	165	135
28	135	120	150	165	165	165
Aug						
28	165	165	165	165	165	165
Sept						
28	165	165	165	165	165	165

Table 16. (continued)

	112-NI			112-I		
		BOX			BOX	
Date	1	7	15	11	14	16
	------------	------------	------------	cm ------------	------------	------------
June						
15	75	45	60	60	30	75
19	105	60	75	75	75	75
22	105	90	75	105	120	90
29	135	90	120	105	120	105
July						
1	135	90	120	120	120	120
6	150	90	120	120	120	135
8	150	105	120	135	120	135
13	165	105	135	135	120	135
15	165	135	150	150	135	135
21	165	135	165	165	135	135
28	165	165	165	165	165	165
Aug						
28	165	165	165	165	165	165
Sept						
28	165	165	165	165	165	165

SOYBEAN ROOT SYSTEMS AS INFLUENCED BY CULTIVAR, NITROGEN FERTILITY, AND WATER LEVEL

by

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B. S., Kansas State University, 1975

AN ABSTRACT OF A MASTER's THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas
1981

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INFLUENCED BY CULTIVAR, NITROGEN

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ABSTRACT

Knowledge of the relation between root development and soil water extraction is necessary to evaluate genetic potential of parent soybean lives for water-use efficiency and conservation of irrigation water. This study was conducted to examine root development and to measure the corresponding water depletion patterns of five soybean [Glycine max (L.) Merr.] cultivars: 'Bonus', 'Calland', 'Clark 63', 'Williams', and 'Woodworth'. Soil cores were collected for root determination with a tractor mounted coring machine on three dates during the growing season. Roots were washed free of soil using a 35 mesh screen. Soil water was determined in the 15 cm to 150 cm soil profile at 15cm intervals using neutron moderation, and in the 0 cm to 15 cm depth by gravimetric sampling. Two mercury manometer tensiometers were installed in the crop row in each plot for determination of hydraulic potential, one at 130 cm depth and one at the 150 cm depth.

Results showed the five soybean cultivars did not vary significantly in either root dry matter or root depth, or in soil water use. Additionally, soybean yields of the five cultivars were not significantly different.

Because of the suggested need of soybeans for nitrogen, a study was conducted to measure the influence of preplant applied nitrogen on soybean [Glycine max (L.) Merrill cv. 'Williams'] root growth under

watered and unwatered field conditions. A rhizotron was used for obtaining the root depth and density measurements, which were taken twice a week from 15 June to 1 July once a week until 28 August, and the final measurement taken on 15 September.

Statistical analysis of the root counts (root density) showed significant nitrogen and irrigation interaction effects. The influence of irrigation on total root density at the 0 kg N and 112 kg N per hectare treatments was variable and no consistent trends over the sampling period were established. However, the 56 kg of N per hectare treatment showed a significantly higher total root density as a response to irrigation. Root depth, physiological stage development and soybean dry matter yields showed no significant differences between each N-treatment and accompanying water level.

Additional index words: Soil water depletion, nuetron moderation, hydraulic potential, tensiometer, nitrogen, root growth, rhizotron.