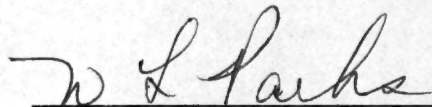


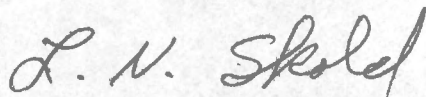
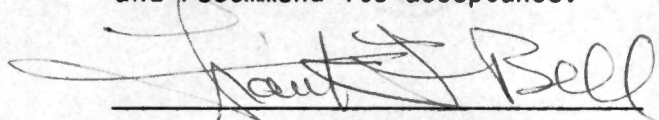
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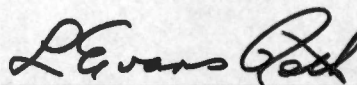


W. L. Parks, Major Professor

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EFFECT OF SOYBEAN PLANTING PATTERNS
ON SOME PLANT ENVIRONMENTAL
MEASUREMENTS AND YIELD



A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Hamid Shahandeh

March 1981

3049679

ACKNOWLEDGMENTS

I wish to express my sincere gratitude and appreciation to those whom I owe so much during the course of this study.

Special thanks go to:

Dr. W. L. Parks, my major professor, for his great help in planning and directing this research, understanding, guidance and friendship throughout this study.

Professor L. N. Skold and Dr. F. F. Bell, committee members, for their constructive criticisms, suggestions in writing this thesis, and for serving as members of the author's graduate committee.

Mrs. Maude Hicks for her great assistance drawing figures.

John Davis and Tim Bateman for their friendship and cooperation and intelligent understanding of my situation.

My family for their encouragement, support, and enthusiasm during the course of this study.

ABSTRACT

'Essex' soybeans (Glycine max (L.) Merr.) were used to investigate how the relationship between plant density and distribution and environmental weather factors such as radiation, temperature and soil moisture influences soybean yield. Field studies were conducted during the 1980 growing season on a Sequatchie loam soil at the Plant and Soil Science Field Laboratory near Knoxville, Tennessee.

Soybean yields were measured at plant populations of 2, 4, 6, 8, 10, and 12 plants per 30 cm of row in 25 cm, 51 cm, 76 cm, and 102-cm rows.

Soil moisture depletion was measured by neutron meter in the middle of the row and adjacent to the row to determine the pattern of soil moisture as affected by different plant populations and row spacings.

Incoming radiation was measured at the top of the plant canopy and down vertically in the middle of the row and over the main axis of the plant. Vinyl tipped waterproof probes were used for soil temperature measurements at 8 plants per 30 cm of the row for 25, 51, and 76-cm row spacings.

As an average of all plant populations the highest yields were obtained from the 25-cm row spacing. Among plant populations, the yield for 2 plants per 30 cm of row was the lowest regardless of the row spacing. Interactions of the number of plants and row spacings showed that the 25-cm row spacing with 8 or 10 plants per 30 cm of row generally outyielded all other planting patterns.

Percent surface soil moisture early in the season was very similar for all planting patterns. Later in the season the pattern of soil moisture was indicated that regardless of row spacing, moisture use in the row was higher than in the middle of the row. Moisture content in wider rows (76, 102 cm) was higher than in narrower rows probably because of less competition among plants to exploit surface moisture and larger area between rows. Yields were reduced in relation to the reduction in surface soil moisture.

Soybeans which were grown in narrow rows had a significant effect on solar interception. Number of plants per 30 cm of the row was not as influential on light interception as row spacings. The percent of radiation reaching the soil surface in the middle of the row increased with row width.

During the day early in the season at full canopy closure there was no significant difference between middle-of-the-row and in-the-row soil temperatures at 25-cm row spacing. The soil temperature reached its maximum value about 2 hours after the maximum air temperature. Soil temperature difference at time of canopy closure was not significant between the 25-cm and 76-cm row spacings.

TABLE OF CONTENTS

CHAPTER	PAGE
I. INTRODUCTION	1
II. LITERATURE REVIEW	2
Effect of Water Stress	3
Effect of Temperature	9
Effect of Light	12
III. MATERIALS AND METHODS	16
Experiment I	16
Experiments II, III, IV	18
IV. RESULTS AND DISCUSSION	22
Effect of Planting Pattern on Yield	22
Effect on Surface Soil Moisture	26
Effect of Light Intensity	37
Effect of Temperature	40
V. SUMMARY AND CONCLUSION	46
LITERATURE CITED	48
APPENDICES	53
Appendix A	54
Appendix B	67
Appendix C	74
VITA	81

LIST OF TABLES

TABLE	PAGE
1. Soybean Plant Population for the 24 Treatments	17
2. Soybean Yield for Different Treatments in 1980	23
3. Analysis of Variance of the Soybean Yields	24
4. Yield in Kg/Ha of Essex Soybean in 1980 as Influenced by the Same Row Spacing at Different Number of Plants	25
5. Yield in Kg/Ha of Essex Soybean in 1980 as Influenced by the Same Number of Plants at Different Row Spacings	27
6. Surface Soil Moisture as Influenced by Different Planting Patterns on June 23 and 27	55
7. Surface Soil Moisture as Influenced by Different Planting Patterns on July 1 and 8	56
8. Surface Soil Moisture as Influenced by Different Planting Patterns on August 4 and 8	57
9. Surface Soil Moisture as Influenced by Different Planting Patterns on July 18 and 21	58
10. Surface Soil Moisture as Influenced by Different Planting Patterns on July 25 and 30	59
11. Surface Soil Moisture as Influenced by Different Planting Patterns on July 11 and 14	60
12. Surface Soil Moisture as Influenced by Different Planting Patterns on August 11 and 15	61
13. Surface Soil Moisture as Influenced by Different Planting Patterns on August 25 and 29	62
14. Surface Soil Moisture as Influenced by Different Planting Patterns on August 22 and 20	63
15. Surface Soil Moisture as Influenced by Different Planting Patterns on September 3 and 5	64
16. Surface Soil Moisture as Influenced by Different Planting Patterns on September 9 and 12	65
17. Surface Soil Moisture as Influenced by Different Planting Patterns on September 15 and 19	66

TABLE

PAGE

18.	Percent of Radiation Reaching to Soil Surface During July 14 and 16 at Different Planting Pattern	68
19.	Percent of Radiation Reaching to Soil Surface During July 25 and 30 at Different Planting Pattern	69
20.	Percent of Radiation Reaching to Soil Surface During August 4 and 6 at Different Planting Pattern	70
21.	Percent of Radiation Reaching to Soil Surface During August 8 and 11 at Different Planting Pattern	71
22.	Percent of Radiation Reaching to Soil Surface During September 3 and 6 at Different Planting Pattern	72
23.	Percent of Radiation Reaching to Soil Surface During September 8 and 19 at Different Planting Pattern	73
24.	Soil Temperature (c) at 2.5-cm as Influenced by 8 Plants Per 30-cm of the Row for 25 and 76 cm Row Spacing During July 14, 16, and 30	75
25.	Soil Temperature (c) at 2.5-cm as Influenced by 8 Plants Per 30-cm of the Row for 25 and 76 cm Row Spacing During August 4, 6, and 8	76
26.	Soil Temperature (c) at 2.5-cm as Influenced by 8 Plants Per 30-cm of the Row for 25 and 76 cm Row Spacing During August 11, 13, and 15	77
27.	Soil Temperature (c) at 2.5-cm as Influenced by 8 Plants Per 30-cm of the Row for 25 and 76 cm Row Spacing During August 20, 25, and September 3	78
28.	Soil Temperature (c) at 2.5-cm as Influenced by 8 Plants Per 30-cm of the Row for 25 and 76 cm Row Spacing During September 6, 8, and 15	79
29.	Soil Temperature (c) at 2.5-cm as Influenced by 8 Plants Per 30-cm of the Row for 25 and 76 cm Row Spacing During September 19	80

LIST OF FIGURES

FIGURE	PAGE
1. Yield of Essex Soybeans at Different Plant Populations and Row Spacings	28
2. Effect of Plant Population on Yield on Each Row Spacing	29
3. Effect of Row Spacing on Yield at Each Plant Row Density (pp. 30 cm row)	30
4. Surface Soil Moisture for Different Planting Patterns in Middle of the Row on June 25	31
5. Surface Soil Moisture at Different Growth Stages for 25-cm Row Spacing	32
6. Surface Soil Moisture at Different Growth Stages for 51-cm Row Spacing	33
7. Surface Soil Moisture at Different Growth Stages for 76-cm Row Spacing	34
8. Surface Soil Moisture at Different Growth Stages for 102-cm Row Spacing	35
9. Effect of Different Planting Patterns on Amount of Radiation Intensity Reaching the Soil on July 14	36
10. Effect of Different Planting Patterns on Amount of Radiation Intensity Reaching the Soil on July 30	39
11. Soil Temperature Changes at 2.5 cm Depth During the Day of July 14	41
12. Diurnal Surface Soil Temperature Measurement for August 11	42
13. Relation Between Average Daily Air Temperature and Average Daily Soil Temperature at 2.5 cm in Middle and in the 25-cm Row Spacing During Growing Season	44
14. Relation Between Average Daily Air Temperature and Average Daily Soil Temperature at 2.5 cm in Middle and in the 76-cm Row Spacing During Growing Season	45

CHAPTER I

INTRODUCTION

Determining the optimum stand of soybean (Glycine max (L.) Merr.) plants per unit area (density) has been the subject of many studies. From the theoretical standpoint, the square pattern should be ideal, because this arrangement would offer all plants an equal opportunity to reach their maximum potential. However, in actual practice, this plant spacing is not easy to attain.

Plant population is determined by two factors--distance between rows and spacing within the row. In this study the growth and yield of soybeans in relation to these factors have been analyzed.

The approach attempts to show the importance of the size and activity of leaf surface as two components governing crop growth rate, in combination with factors such as light interception, soil water regime, row width, and plant population for obtaining maximum soybean yield.

Temperature and water stress were the main environmental factors affecting leaf extension rate. Since soybean leaves are the principal light intercepting and photosynthesizing organs, anything that could increase sunlight interception should increase yield. Therefore, modifying the energy balance of the plant canopy by changing planting patterns was the principal objective of this study.

CHAPTER II

LITERATURE REVIEW

During the past 30 years significant increases in the yield of soybeans have resulted from improved cultural practice and new varieties. Now, possibilities for further improvement in cultural practice are diminishing rapidly. Improvement in yield will probably depend to an increasing extent on a more thorough understanding of the effect of the environment surrounding the soybean plant (22).

Most soybeans are under wide row (75 or 100 cm) culture, yet many tests clearly demonstrate that narrow spacings (25 or 50 cm) give substantially greater yields. Whether the yielding superiority of narrow rows is primarily because of greater light interception during flowering and seed set or the most efficient exploitation of moisture has not been fully explained (36).

Narrow rows contribute to efficient water use when water is readily available to the plant at the soil surface. Under these conditions neither space between rows nor plant population has much effect on water loss. Closely spaced rows intercept more solar energy. Consequently, transpiration is high relative to evaporation. In widely spaced rows, more solar energy reaches the ground and causes more evaporation. As a result, the total water loss is approximately equal in widely and closely spaced rows. But when the soil surface dries, evaporation is limited by the moisture supply in the upper 10 to 15 cm of soil (3).

Narrow rows and more evenly distributed plants in the row give cooler soil temperatures. This effect is a result of earlier uniform shading of soil with up to 95% of the incoming radiation intercepted by the soybeans. The uniform shading results in a cooler soil temperature and reduces the rate of evaporation, and the soil water is

conserved for transpiration while the total quantity of water lost in evapo-transpiration from a unit area of ground changes little (10-15%) under a standard supply of radiation. The common observation is made that when more of the water is used for transpiration, the better the yield (8).

Thus it seems that an important research area on soybean yield is the determination of the environmental factors that are most limiting for soybeans under different plant densities. Measurements of micro climate are important for understanding of the plant environment.

There are many weather variables which affect crop growth and development in different ways and at different times during the growth cycle. Weather and growth are closely coupled. The environment controls photosynthesis and the rate of growth and development. At any point in time the actual size of the plant and its capacity to exploit the environment, depends on the extent of its photosynthetic capability.

Measurements of photosynthesis are normally expressed as net photosynthesis (P_n), that is total photosynthesis minus respiration. There are three main weather factors which influence net photosynthesis of a crop. Two of these are radiation and temperature which influence P_n directly: the third is the complex of weather factors which causes plant water stress (3).

Effect of Water Stress

Water is often the primary limiting factor in soybean production and is therefore an important management concern. Growth of the soybean from germination to maturity is, in general, proportional to available moisture supply.

The long flowering period and extensive root system of the

soybean enables the plant to escape or survive short periods of drought stress. Failure, due to water stress, of early flowers to set pods may be compensated for by excellent pod set of late flowers if moisture becomes available. A shortage of moisture during the pod-filling stage reduces yields more than stress during earlier stages, including the flowering stage. A moisture deficit for two to four weeks immediately after flower-bud differentiation reduces growth and causes heavy flower and pod shedding (8, 23).

Plant population has an effect on ET similar to that of plant cover. Black (4) offers the following theory as a means to account for the trend of evapo-transpiration with density of vegetative canopy where the availability of soil water for evaporation and evapo-transpiration is limited. Where there is a deficiency of water for evaporation from bare soil containing available water at some depth below the surface, the high conductivity of plants for water replaces in part the loss of water conductivity that has occurred in the surface portion of the soil. An increase in density of vegetative canopy from zero up to the maximum the soil will support then causes an increase in evapo-transpiration. Concurrently with the increased use of water, however, the availability of soil water to plants decreases. In consequence, the plants lose water less rapidly than they would if the drying effect had not occurred. Because a given decrease in water content of soil has an increasingly pronounced effect on availability of water to plants as soil dries, the decrease in availability counterbalances more effectively the greater potential loss due to extra plant surface as the supply of available water approaches exhaustion.

According to the preceding theory, the independence of

evapo-transpiration and density of vegetative canopy exists for a different reason where soil is dry or moist. Under moist conditions, the control is in the soil. Under intermediate conditions, the control may be partly in the atmosphere, partly in the soil, and partly in the plants (4).

Plant roots absorb soil water in response to a water potential gradient. Assuming soil water evaporation is small and a well-developed canopy exists, transpiration begins soon after sunrise and generally follows the trend of the solar radiation flux throughout the day. Leaf water potential declines rapidly as transpiration increases and the resulting difference in potential between the leaf and the soil is proportioned to the transpiration rate. The larger potential difference between the leaves and the roots than between the soil and the roots indicates that resistance is greater to water flow through the plant organs than through the soil to the root surface (31).

Roots of actively growing annual crops generally grow the same extent in proportion to the top growth. Roots of young plants absorb water primarily from the upper part of soil profile where the root concentration is greatest. Water then is absorbed from deeper depths as the plant grows. Even when plant roots reach the lower part of the soil profile, more water is extracted from the upper parts of a profile with low water potentials throughout the root system because root density is usually greater near the soil surface and the specific free energy of water near the surface makes it more accessible than water deep in the profile where root density is lower (31).

The root system of soybean consists, principally, of branched, lateral, and secondary roots. These develop in four longitudinal rows

off the enlarged upper 10 to 15 cm of the primary root. In row plantings, the laterals extent 34 to 45 cm between rows before turning sharply downward. Most root dry weight (80 to 90%) occurs in the top 15 cm of the soil, largely because of enlargement of the primary root and the concentration of nodule tissue there. Lateral roots first appear three to seven days after germination and by one month, the primary root has extended downward 45-60 cm and major laterals have extended horizontally 20-25 cm. About 60 days after planting, perhaps earlier under dry conditions, horizontal extension terminates and five to six of the major laterals turn sharply downward near mid-row, perhaps because of antagonism between roots of adjacent rows (36).

Peters and Johnson (29) found in water use, depth of rooting seemed to be of more significance than lateral development. Considerable subsoil moisture was used, but inter-row water extraction was only about one-half as efficient as below the rows. Using plastic-covered irrigated field plots, they also assessed soybean transpiration potential to be about 129 mm from beginning blooms until maturity. With frequent rainfall and abundant water availability they found total water use was 392 mm (95% of open-pan evaporation) over the same period.

Growth of roots as well as the rest of the plant is affected by soil moisture conditions. Soybeans use water from progressively greater depth throughout the season. Swan (18) found water use directly in the row to be double that at points one-quarter and one-half the distance between rows. However, when moisture supply was increased by irrigation, the water use from the between-row locations increased to about two-thirds that in the row (18).

Peters and Johnson (29) reduced row spacing from 100 cm to 50 cm

and doubled population density. They increased transpiration from 129 mm to 226 mm. It is likely that this response was mainly a consequence of increasing the amount of exposed leaf surface in the earlier part of the season; but, remembering that they also found roots to be not as efficient in extracting water from the inter-row space as directly below the row, some of the increased transpiration was probably related to root distribution also.

Evapo-transpiration is a function of soil, plant and meteorological factors. Gates and Hanks (16) listed plant species, plant population, plant height, light reflection by plants, row spacing and orientation, rooting depth and extent, and stage of growth as specific factors that influence evaporation from plant communities.

Lemon et al. (19) found evapo-transpiration to be controlled by soil moisture tension, physiological factors, the relation of soil moisture of an irrigated area to that of its surroundings, as well as by purely meteorological factors of radiation, wind, air, temperature, and humidity.

Penman et al. (28) reported that for annual crops, plant evaporation was proportional to leaf area (i.e., to plant population per unit area) before plant leaves begin to shade each other, but the area of ground shaded becomes dominant after plants begin to overlap.

There is little information on the combination of all these factors, but from existing studies on plant population, row width, and soil water regime, water stress at the critical stage of growth seems to be the most limiting factor.

Timmon et al. (45) reported that neither row spacing nor plant population significantly affected evapo-transpiration. Highest water

use efficiency was obtained for the lower plant population in 20 cm rows.

Doss and Thurlow (13) studied soybeans planted in 60 and 90 cm rows and found that water use rates were influenced more by soil water regime than by row width. They found one exception early in the season when the plants were 25 to 60 cm high that more water was used by the 90 cm rows than on the 60.

Taylor (44) conducted an experiment to test the hypothesis that wide-row soybeans will yield as much, or more than narrow-row soybeans during years of low seasonal water supply. Soybeans were grown in 25, 50, 75, and 100-cm row widths with a density of 16 plants/m². During a year when water supply was high, narrow-row soybean (25 cm) yielded 17% more than 100-cm row. During years with lower seasonal water supplies, there were no significant differences in yield among the 25, 50, 75, and 100-cm rows.

Runge and Odell (32) found that above-normal precipitation during July (period of major vegetative growth) and from mid-August to mid-September (pod-filling period) increased soybean yield, but abundant rainfall during the periods decreased yields. In the first half of August, soybeans were in the early pod stage. Two cm of rain above the average during the last week in August or the first week in September increased yield by 120 kg/ha.

Doss et al. (12) reported similar results in that they found that the pod filling stage was the most critical stage to withhold water.

Yazdi-Samadi and Saadati (51) have reported that in field-grown soybeans an increased amount of water resulted in increased nodulation, height, number of seeds per pod, yield, oil percentage, and root lengths; however, it reduced the seed protein percentage.

Studies in Tennessee have shown that supplemental irrigation for soybean varieties has increased the yield in 6 of 10 years. Yield increases of 9.3 bu/acre/year were obtained from the application of 6.4 inches of water per year (26).

Planting date and the availability of soil moisture appear to be other environmental factors affecting soybean yield responses to variable row spacings. Studies reported an advantage for early maturing varieties at the wider row spacing when planted late. These results are most prevalent in soils that have dry hardpans or low water holding capacity. In these conditions, some soil water was available between the rows when the plants were in the pod stage (39).

While there may be some question about applicability of data from corn, sorghum, and peanuts to soybeans, there may be some similar effects. At any rate, the literature does seem to indicate that for many crops in rows narrow enough for complete shading of the ground and thus reducing the radiation reaching the soil surface, ET can be less than for the same crop in wide rows (6, 7, 31, 50).

Effect of Temperature

The shortwave solar radiation received by the crop surface is composed of direct radiation from the sun, diffuse radiation from the sky, and reflected radiation from soil surface.

A portion of each of the short wave radiation fluxes exchanged to a crop is converted to other forms of energy. The amount of radiant energy which is converted is net radiation (R_N) and may be written as: $R_N = E + Q + S$. Where (E) is energy used in evaporation of water and changes in sensible heat of the air (Q) and soil (S). Early in the

growth of plants, cover is low and much of incoming radiation reaches the soil surface. The water of this surface which is free to evaporate is quickly lost as E, S and Q become large, that is soil and air temperature rise. Cooling of the soil surface then occurs through transfer of heat to air and through outgoing thermal radiation. With greater cover, a greater proportion of water in radiation is dissipated through transpiration of water from the leaves. As long as water supply is adequate, E will be the largest term (50-75% of the heat loss) and evaporative cooling will have a stronger influence on temperature.

Early and Cartter (14) found that, under greenhouse gravel-culture conditions, temperature variations between 12 and 37 C had only a slight affect on root growth (dry weight). But, although they barely reached the 5% level of significance, root temperatures from about 22 to 27 C appear to have been most favorable for maximum dry weight production of top and roots.

Both the total and distribution of cation uptake varies with temperature. Potassium uptake by soybean roots increased over the temperature range from 12 to 32 C, whereas calcium and magnesium uptake decreased by an equivalent amount (18).

Although growth of soybeans is influenced by temperature, efforts to develop a "degree-day" function for growth have not been successful. However, Soybean Development Unit (S.D.U.) has been developed by the following equation:

$$\text{S.D.U.} = 4.95 \times -0.0829 x^2 - 40.91$$

where x is temperature in centigrade. Growth prior to maximum podding was closely related to degree-days, but from podding to maturity, growth was more closely related to number of days than to degree-days. This

agrees with conclusion reached by Runge and Odell (32) concerning the effect of temperature variations during seed development (8).

It appears that temperature variations affect the seed composition and the yield. Runge and Odell (32) found that yields were slightly depressed by any period of temperature above the average during July and August. In June and September above-normal temperatures resulted in small increases in yield.

High temperatures (over 38 C) early in the season may have adverse effects, for example they greatly reduce the rate of node formation and the rate of growth of internodes. Increased pod and flower shedding occurs at high temperatures (18).

Stutte et al. (41) found that additions of supplemental water can increase soybeans yields in Arkansas. Yet the air temperature during the initial flowering stage can also influence potential yields. Correlation of seed yields from irrigated soybeans with the number of days exhibiting daily maximum temperature of 33.5 to 35.0 showed an inverse correlation from July 30 to August 19. Therefore, when water was removed as the limiting factor, high temperature was found to contribute to lower yields.

Results obtained by Biscoe et al. (3) showed during the early part of the growing season, in the absence of water stress, leaf extension rate was a linear function of temperature. From limited soil temperature measurements for West Tennessee, a correlation has been established that the soil temperature at a two-inch depth closely resembles the average air temperature.

In C_3 plants, because photochemical processes are not strongly temperature dependent, leaf photosynthesis is relatively insensitive to

temperature. Measurements of net photosynthesis on young crop canopies do not show a marked response to temperature, but later in the growing season high temperatures cause a sharp decrease in net photosynthesis (3).

Effect of Light

The interception of light and its distribution as a source of energy for photosynthesis is an important factor in crop productivity. The light saturation at 300 ppm CO₂ for plants in a greenhouse, plants in a growth chamber, and for top leaves in a canopy has been reported as 20 Klx, 40 Klx and 100 Klx, respectively. In field-grown soybeans, the higher the position of the leaves, the higher the rate of photosynthesis and the higher the light saturation intensity. Light saturation of soybean canopies was reported for 59 Klx to 70 Klx by Sakamoto and Shaw (8).

Shible and Weber (37) reported that dry matter production increased as leaf area increased, up to the critical leaf area index, and was directly related to the amount of light absorbed. However, they found that seed yield did not correlate with dry-matter production.

Shading of soybeans during the blooming period contributed to a higher proportion of aborted pods, possibly because of the lowering of the sugar level in the leaves or some other imbalance in the plant system (8). Reduction of sunlight to 50% of normal resulted in fewer branches, nodes and pods, and only 40% of the normal yield (8).

Beuerlein et al. (2) studied the effect of branch removal and spacing treatment on yield and light penetration within soybean canopies. A population (155,000 plants/ha) of plants without branches produced

the greatest yield. The yield increase was due to a large increase in the number of pods set per node on the debranched plants. Light intensity in the top one-fourth of the canopies was twice as great during the blooming stage as during the pod-filling stage. Branch removal had no effect on light penetration during the pod-filling stage but allowed 75% greater penetration through the top one-fourth of canopies during the blooming stage.

Leaf area production, after an initial lag, increases rapidly and linearly up to 5-8 (LAI) values at the end of blooming stage. Thereafter, LAI declines continually to values of 4-6 near physiological maturity, because of abscission of lower leaves. At similar planting densities, narrow rows reach greater LAI values than wide rows and have more leaves abscising during seed filling (36).

Under different cultural practices of narrow rows (25-50 cm) and high populations versus wide rows (75-100 cm) and low population, the former leaf average age is younger, because earlier closing of the canopy results in greater abscission of lower leaves (36).

The principal factors influencing canopy net photosynthesis are genotype, light, and LAI. A high proportion of light is intercepted in the periphery of canopy (25, 34, 37), which accounts for finding that carbon dioxide assimilation increased by up to 30% as the proportion of diffused light increased from less than 25% to more than 75% at 90 Klx. This result suggests that a less dense, more erect canopy could be beneficial to photosynthetic productivity. This suggestion has been supported by the fact that lower canopy leaves will exhibit increased photosynthesis under supplemental light (36). Enyi (15) found that for a soybean variety grown in Tanzania light was a major factor controlling

yield. High light intensity under the widely spaced plants tended to encourage the production of side branches, while low intensity under the closely spaced plants at the high population led to a reduction in the number of branches. He also found that with an increase in the amount of light intercepted, the number of nodes without pods increased, because at high populations either fewer nodes produced flowers, or more of the pods or flowers were aborted before maturity.

With soybeans of determinate growth habit, leaflet size and petiole length are not smaller at the top of the plant. Because upper leaves of determinate types are large, their canopies possess poorer light distribution characteristics than do indeterminate types. The lower leaves, although not parasitic, contribute little photosynthate. Narrow leaf types have been proposed for deeper light penetration (8). Shaw and Weber (35) found that maximum light penetration occurred when a small definitive amount of lodging was simulated.

It is difficult and expensive to reflect and supplement light. But some investigators used reflectant materials on soybean foliage to dissipate some of the excess solar radiation which is consumed in evapotranspiration, thus reducing water consumption.

Determination of an adequate plant density for maximum production is another objective of this study. In the literature different views are expressed as the optimum plant density requirements.

Weber et al. (46) reported that regardless of row spacing, maximum yields were obtained at approximately 129,000 plants/ha.

Luenchen (20) indicated that soybeans have the capacity to compensate for a wide range in plant densities without affecting yield. Thus yield variations were non-significant over a wide range of populations.

Contrary to many studies, Basnet et al. (1) reported where irrigation was involved, highest yields resulted at the lower plant density in wider rows (92 cm).

Wilcox (48) evaluated three soybean strains in approximately equidistant spacings at 14 plant densities ranging from 25,000 to 582,000 plants per hectare in India. He found that plant height, height of lowest pod and lodging increased with increasing plant density. Three strains differed in their response to population density in terms of seed yield/ha.

Donavan et al. (11) studied the effect of 15 planting patterns resulting from five row spacings and three intra-row spacings on soybean. The combination of the narrowest row spacing and widest intra-row spacing (17.5 x 7.5 cm) gave the highest yield.

Whiteley et al. (47) found that soybeans planted in 25-cm rows yielded as much as those planted in 102-cm row spacings. This result is in agreement with studies by Spidle et al. (39) conducted in North Dakota. When yields were averaged over seasons and varieties, the early planted 30-cm rows exceeded 90-cm rows by 41%.

The results of an experiment by Safo-Kantanko and Lawson (33) demonstrated that changes in inter-row widths were more critical to soybean yield than changes in plant arrangement. They concluded also that where suitable herbicides and equipment are available, short-season soybean growers will find it advantageous to adopt rows narrower than 30 cm.

Yield components of soybeans are changed as plant population is increased. Numbers of branches, pods, and seed per plant decreased as population increased (10, 20, 30, 46).

CHAPTER III

MATERIALS AND METHODS

The field experiments were conducted during the 1980 growing season on Sequatchie loam (fine loamy, siliceous, thermic, Humic Hapludult) at the Plant and Soil Science Field Laboratory near Knoxville, Tennessee.

Experiment I

Yield studies were conducted using 'Essex' soybeans. It was evaluated at six plant population in rows 25, 51, 76, and 102 cm apart. Plant population were 2, 4, 6, 8, 10, and 12 plants/30 cm of the row at approximately the number of plants per hectare shown in Table 1.

The experimental design was a split-plot with four replications having row width as the main plots and plants/30 cm of the row as sub-plots. Each plot consisted of seven 25-cm rows, six 51-cm rows, five 76-cm rows, and four 102-cm rows 750 cm long and with different numbers of plants per 30-cm of the row. Plots were planted using field planters in four randomized blocks. The rows were aligned north and south. An outer perimeter of border rows was planted to maintain uniformity within the plots and 120 cm alleys were maintained on row ends of the plots.

The initial planting was supplemented by using a jabber planter because of poor germination caused by inadequate moisture supply. The seeding rate was about the same for all plots but for the desired population levels, plants were thinned by hand when they were 12-15 cm high. Soybeans were fertilized with 227 kg/ha of 0-20-20 before planting.

TABLE 1
SOYBEAN PLANT POPULATION FOR THE 24 TREATMENTS

Row Width (cm)	Plant Population Plant/30-cm of the Row					
	2	4	6	8	10	12
	Plants per hectare					
25	258,233	516,467	774,703	1,291,170	1,420,300	1,544,403
51	129,109	258,218	387,328	516,437	645,497	744,656
76	86,074	172,149	258,223	344,298	430,372	516,446
102	64,556	129,114	193,670	258,226	322,782	387,340

Soil test results showed P and K at 24 and 140 kg/ha respectively, with soil pH around 6.7. Trifluralin (Treflan) herbicide was applied pre-plant, at rate of 0.75 kg/ha, and immediately soil incorporated. Weeds that were not controlled by Treflan were removed by hand.

All rows except the two outside ones of each plot were harvested and yields calculated from these weights.

Experiments II, III, IV

In these experiments, environmental effects were evaluated by means of measuring:

- II. Surface soil moisture
- III. Incoming radiation
- IV. Air and soil temperature.

To determine the relation between soybean yields and environmental factors such as radiation, temperature and soil moisture, surface soil moisture was measured twice a week. In each subplot measurements were taken in the middle of the row and adjacent to the row to determine the pattern of soil moisture use as affected by different planting arrangements.

In the 25-cm row only one measurement was taken because neutron meter covered the entire area between rows. Sampling sites were weed free and flat. All measurements were taken in the morning. Before any readings, the instrument was standardized.

Soil surface moisture was measured by use of a neutron moisture meter. The neutron meter has several advantages; first, moisture volume fractions are determined directly; second, a large volume of

soil is usually sampled; and third, the same sampling spot is used in successive measurements.

The instrument used for measurements in this experiment was a model 3411-B surface moisture-density gauge from Troxler Laboratories that provides direct reading in both SI and U. S. units for wet density, dry density, oven dry and volume percent moisture.

Radiological specifications for this instrument for gamma source is 8 ± 1 mci Cesium -137, and neutron source is $40 \pm 10\%$ mci Americium-241, Beryllium with 70,000 N/Sec.

The calibration of this instrument was made in terms of a ratio to a count made on the reference standard which was supplied with the instrument.

The 3411-B contains a μ P (microprocessor) which controls the majority of the instrument's function. The μ P, in conjunction with its crystal oscillator, provides the time standard for accumulation cycle. The μ P also updates the display, accumulates the moisture and density data counts, responds to the keyboard and rotary switches, and generates error codes if improper operation is detected. If the display indicates four zeros when the instrument is turned on, the microprocessor is probably working normally.

Americium-241 is used as a source of alpha particles and Beryllium as the target material. Neutrons produced by this reaction have average energy of 4.5 mev.

A Weston model 756 sunlight illumination meter was used to measure visible light intensity at the top of the canopy and down,

vertically in the middle of the row and over the main axis of the plant.

The light meter was sensitive to radiation within the range of 270 to 750 m μ . The meter had three sensitivity ranges which allowed measurement of light intensities from zero to 12,000 ft-c. At solar noon on a bright sunny day the meter measured direct sunlight to have an intensity of 11,000 ft-c.

During the months of July and August, and to mid-September, periodic measurements were made three days a week. Readings were taken at 9:00 and 12:00 a.m. and at 3:00 p.m. each day. Measurements were made in 25, 51, 76, and 120-cm row spacings with 2, 4, and 6; 4, 6, and 8; 6 and 12; and 8 and 12 plants per 30 cm of the row respectively.

Percent of light intercepted at different planting patterns is summarized in Appendix B.

An instrument shelter was located at the center of the block and soil and air temperatures were measured in plots near the shelter. The two closest and properly placed soybean plots around the shelter were the 25-cm row and 76-cm row with 8 plants per 30 cm of the row. A vinyl tipped, waterproof, soil probe with time constant of 7 seconds was placed in the soil at a 2.5 cm depth, one in the row and one in the middle of the row for each row spacing. Two stainless steel air temperature probes with time constant of 0.3 seconds were located outside the shelter to measure air temperature. Measurements were started before canopy closure in July and continued to mid-September. Readings were recorded at 2-hour intervals from 8:00 a.m. to 4:00 p.m. 3 days each week. During the period of measurement there were times in which readings were not made because of rainfall or irrigation.

The instrument used for this experiment was the Yellow Spring model 47 telethermometer. The instrument is calibrated both in Celsius and Fahrenheit. The Celsius scale was used in recording temperature measurements. Telethermometers are automatic and line voltage and frequency is 110 volts and 60 cycles.

CHAPTER III

RESULTS AND DISCUSSION

Effect of Planting Pattern on Yield

The yield per hectare for all treatments is summarized in Table 2. Analysis of variance of the yields (Table 3) shows that row spacings and populations were significant at the .01 and .05 levels of probability respectively. The 25-cm row spacing yielded significantly more than all other row spacings. Yields for 51-cm rows was significantly better than yield for 76 and 102-cm row spacings but there was no significant difference between yields for the 76 and 102-cm row spacings (Table 2).

The results obtained from Duncan's multiple range test on yield of plants per 30 cm of the row (Table 2) show no significant difference in yield for 6, 8, 10, and 12 plants, or between 6, 12 and 4 plants per 30 cm of row. Yield for 2 plants per 30 cm of the row was significantly lower than all others.

The lack of more significant yield difference among various plant population was probably because of a significant interaction between number of plants per 30 cm of row and row spacings.

The differences in yield among plant populations for 25-cm rows show (Table 4) that 12 plants yielded less than all others. This result was probably because of severe lodging due to the very high plant population. There was no significant difference among yields for 4, 6, 8, and 10 plants per 30 cm of the row. For 51-cm row spacings, the lowest bean yield was at 4 plants with no significant differences among yields

TABLE 2
SOYBEAN YIELD FOR DIFFERENT TREATMENTS IN 1980

Number of Plants per 30-cm	Row Spacing				mean
	25-cm	51-cm	76-cm	102-cm	
	kg/ha				
2	3992	3602	2581	2124	3074 c
4	4973	3165	2997	2749	3472 b
6	4348	3501	3575	3434	3709 ab
8	4677	4066	3757	3488	3996 a
10	4751	4408	3340	3320	3954 a
12	3683	3669	3662	3373	3596 ab
mean	4404 a	3735 b	3318 cd	3081 d	

* Means followed by the same letter(s) are not significantly different at the 0.05 level according to Duncan's multiple range test.

TABLE 3
ANALYSIS OF VARIANCE OF THE SOYBEAN YIELDS

Source of Variation	D. F.	Sum of Squares	Mean Square	F Value
Row spacings	3	24,302,244	8,100,748	21.60**
Replications	3	4,559,060	1,519,686	
Error (a)	9	3,374,260	374,917	
Plants/30 cm of row	5	9,235,129	1,847,025	2.98*
R.S. x pp 30 cm of row	15	9,305,614	620,374	1.98*
Error (b)	<u>60</u>	<u>18,112,447</u>	311,874	
Total	95	69,488,756		

* Significant at the 5% level of probability.

** Significant at the 1% level of probability.

TABLE 4
YIELD IN KG/HA OF ESSEX SOYBEAN IN 1980 AS INFLUENCED BY THE
SAME ROW SPACING AT DIFFERENT NUMBER OF PLANTS

		Number of Plant/30-cm of Row					
25-cm Row Spacing		<u>4</u>	<u>10</u>	<u>8</u>	<u>6</u>	<u>2</u>	<u>12</u>
	Yield (kg/ha)	4973 a	4751 ab	4677 ab	4348 abc	3992 bc	3682 c
51-cm Row Spacing		<u>10</u>	<u>8</u>	<u>12</u>	<u>2</u>	<u>6</u>	<u>4</u>
	Yield (kg/ha)	4408 a	4065 ab	3669 abc	3602 abc	3501 bc	3165 c
76-cm Row Spacing		<u>8</u>	<u>12</u>	<u>6</u>	<u>10</u>	<u>4</u>	<u>2</u>
	Yield (kg/ha)	3756 a	3662 a	3575 a	3340 ab	2997 ab	2580 b
102-cm Row Spacing		<u>8</u>	<u>6</u>	<u>12</u>	<u>10</u>	<u>4</u>	<u>2</u>
	Yield (kg/ha)	3488 a	3433 a	3373 a	3320 a	2748 ab	2123 b

* Means followed by the same letter(s) are not significantly different at the 0.05 level according to Duncan's multiple range test.

for 12, 10, 8 and 2 plants per 30 cm of row. Yields at 76 and 102-cm row spacings were greater at 8 plants per 30 cm of the row, although there was no significant difference among yields for 4, 6, 8, 10, and 12 plants. In contrast 3 plants per 30 cm of the row in both row spacings, yields were significantly lower (Table 4).

The performance of various soybean plants per 30 cm of row under a specific row spacing (Table 5) suggests that the 25-cm row spacing with 8 or 10 plants generally outyielded all other planting patterns. These results also suggest that plant population may be reduced to 6 or in some instances to 4, resulting in saving seeds without a significant reduction in yield.

The higher yields in the 25-cm row spacing were probably the result of a more even distribution of leaves which resulted in more interception of radiant energy (50).

Soybeans in 25-cm rows aided in more effective weed control by the preplant herbicide Treflan than other row spacings. They formed a complete canopy earlier and reduced this problem.

Yield of 51-cm row spacings was very close to that for 25-cm row spacing, being statistically different in only one of six plant spacings in the row. The lowest yield was at 2 plants per 30-cm of the row with 102-cm rows which was also the lowest plant density (Figure 1).

In general, yield variations were nonsignificant over a wide range of plant populations. Figures 2 and 3 show these variations due to different planting patterns.

Effect on Surface Soil Moisture

Percent surface soil moisture early in the season (Figure 4)

TABLE 5

YIELD IN KG/HA OF ESSEX SOYBEAN IN 1980 AS INFLUENCED BY THE
SAME NUMBER OF PLANTS AT DIFFERENT ROW SPACINGS

	Row Spacing 25-cm	51-cm	76-cm	102-cm
2 plants/30-cm of row				
Yield (kg/ha)	3992 a	3602 a	2580 bc	2123 c
4 plants/30-cm of row				
Yield (kg/ha)	4973 a	3165 bcd	2997 cd	2748 d
6 plants/30-cm of row				
Yield (kg/ha)	4348 a	3501 ac	3575 ac	3434 c
8 plants/30-cm of row				
Yield (kg/ha)	4677 a	4066 abc	3756 bc	3488 c
10 plants/30-cm of row				
Yield (kg/ha)	4751 a	4408 a	3340 bc	3320 c
12 plants/30-cm of row				
Yield (kg/ha)	3682 a	3669 a	3662 a	3373 a

* Means followed by the same letter (s) are not significantly different at the 0.05 level according to Duncan's multiple range test.

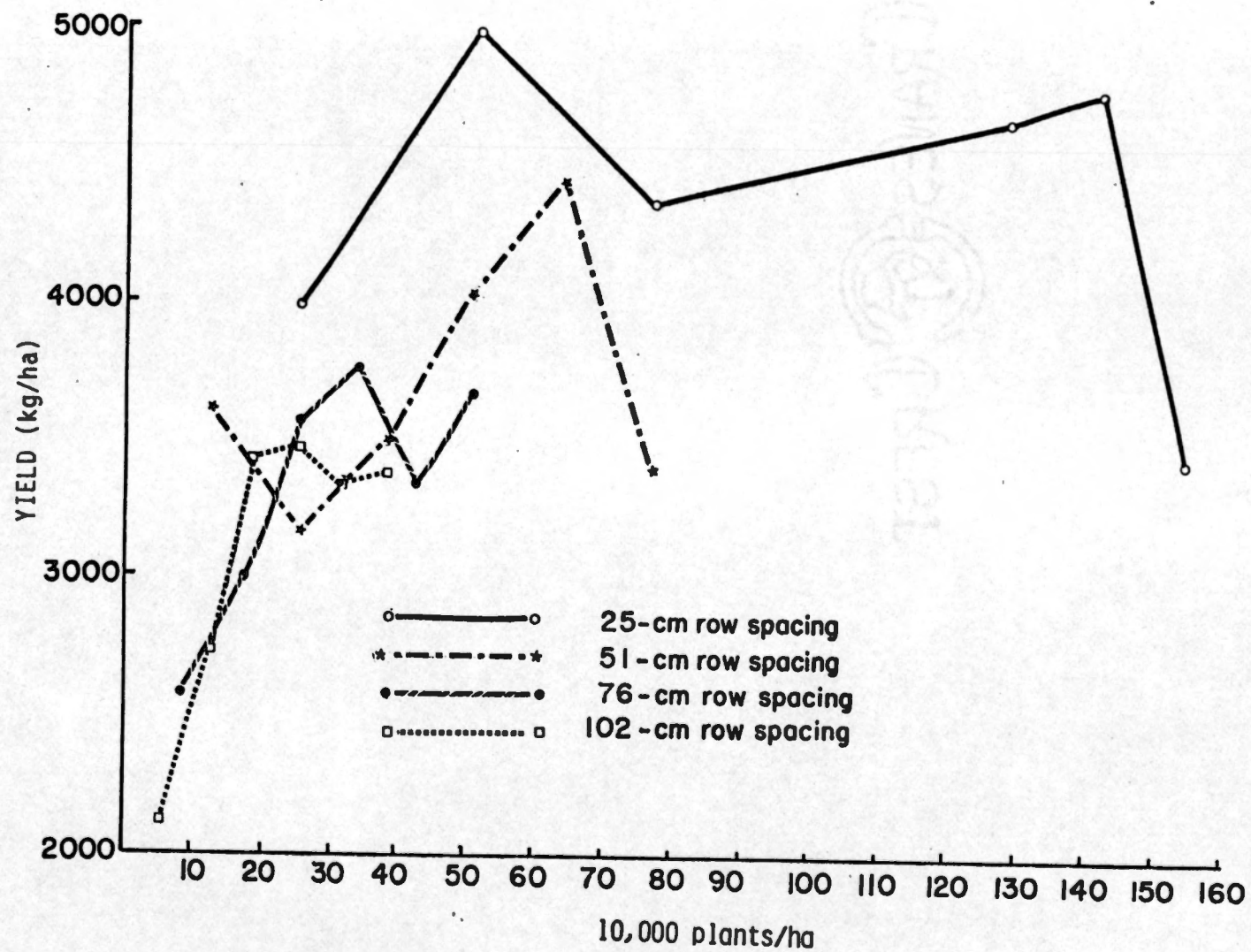


Figure 1. Yield of Essex Soybeans at Different Plant Populations and Row Spacings.

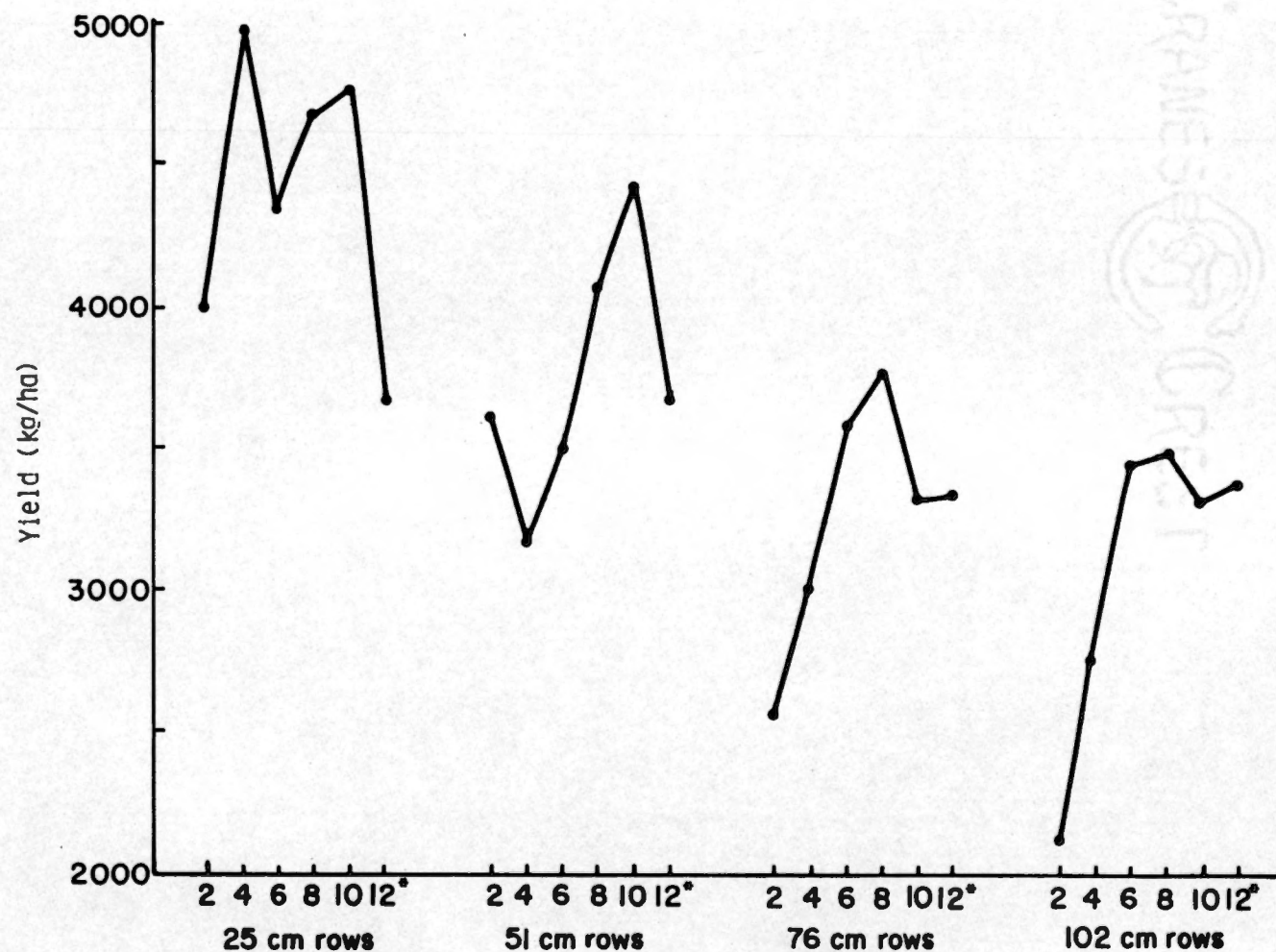


Figure 2. Effect of Plant Population on Yield at Each Row Spacing.

*Plants per 30 cm of row.

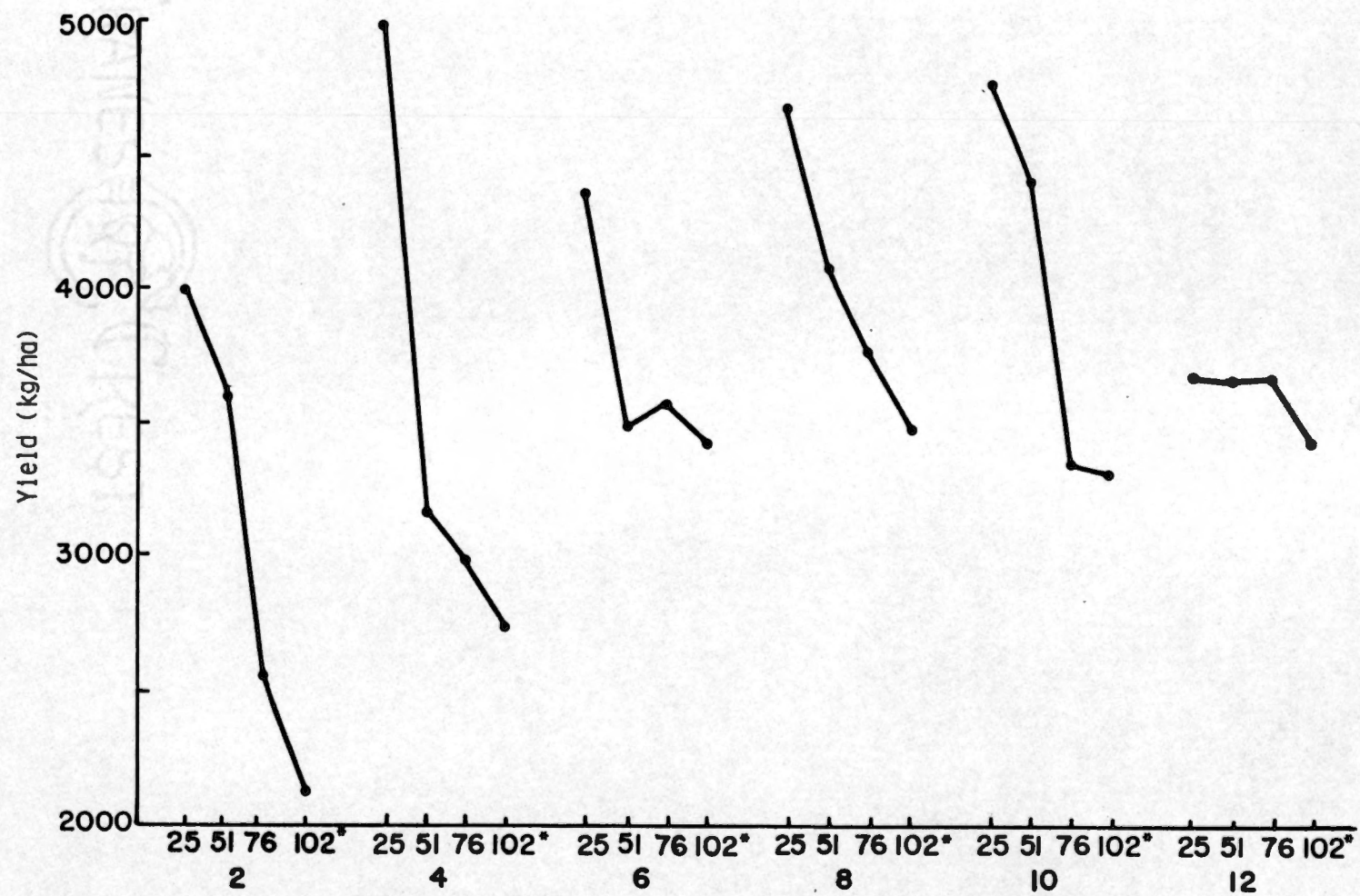


Figure 3. Effect of Row Spacing on Yield at Each Plant Row Density (pp 30 cm row)

* Row width in cm.

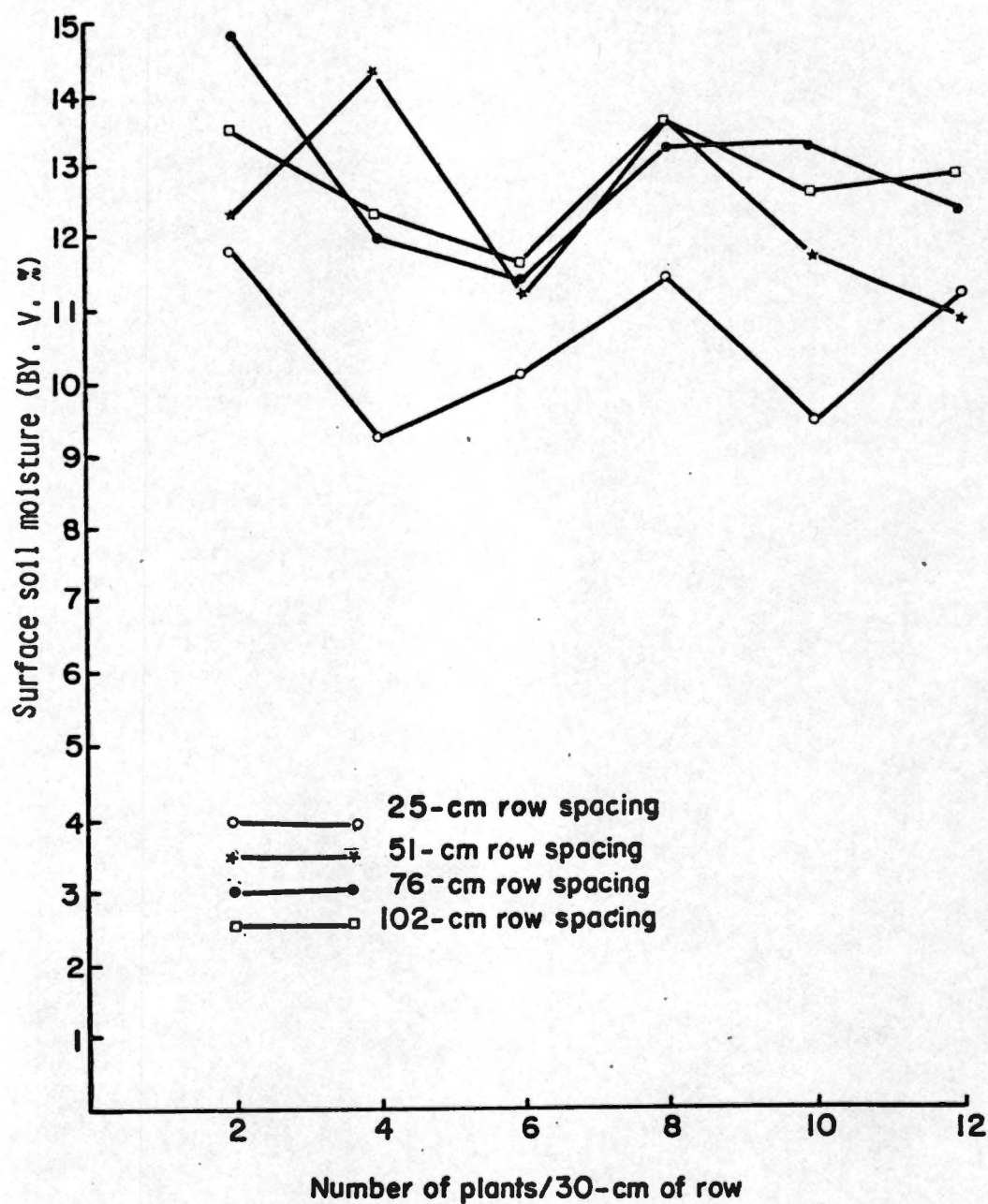


Figure 4. Surface Soil Moisture for Different Planting Patterns in Middle of the Row on June 25.

appears to be very similar for different planting patterns. At this stage of growth which is prior to canopy closure, leaf area was the most influential factor. Wider rows (76 and 102 cm) did differ from narrow rows (25 and 51 cm), but not significantly. The reason is because transpiration from narrow row was compensated for by evaporation from wide rows.

The pattern of moisture use by soybeans as related to distance from the row is also shown in Figures 4 through 8. These results indicate that regardless of row spacing moisture use in the row was higher than in the middle of the row.

As the season progressed, the difference on moisture use became more obvious (Figures 5-8). Water consumption after canopy closure is largely determined by atmospheric evaporation demand and water supply. In the 25-cm row spacing (Figure 5) full canopy closure was never attained by 2 or 4 plant per 30 cm of the row. In 51, 76, and 102-cm row spacing, moisture in middle of the row was higher than in the row. With enough moisture during critical growth stages, water use may be expected to be higher near the plant than at some distance from the plant because of the greater root concentration and a shorter distance for the water to be moved. At least 40% of root surface occurs in the top 15 cm (36). In this experiment where soil moisture was maintained at a high level throughout the critical growth stages either by irrigation or natural rainfall, results were inconsistent with the preceding discussion. Higher moisture content of wide rows (76 and 102 cm) is probably because of less exhaustion of surface moisture in the wider space between rows. Similar results were found by Peters and Johnson (29).

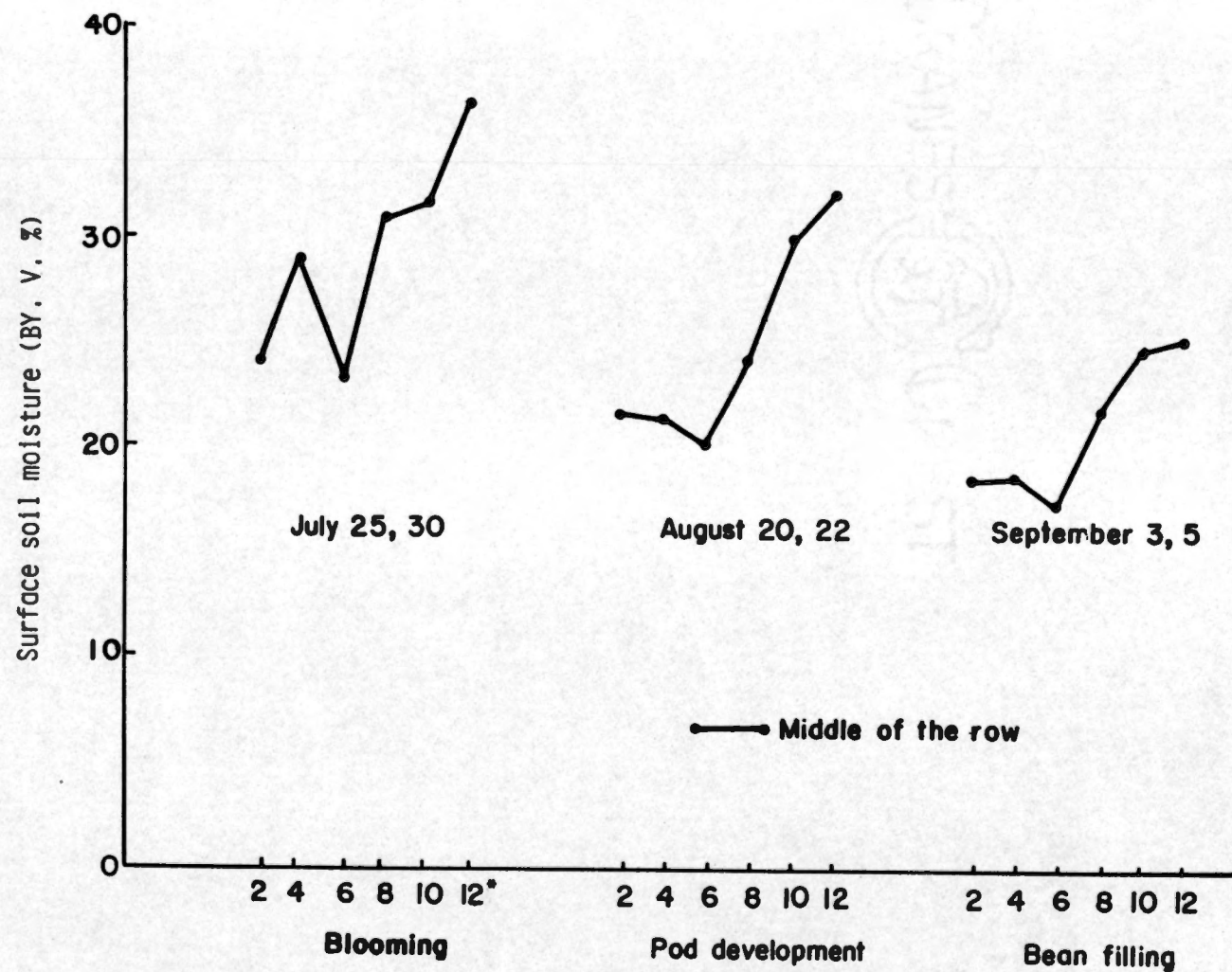


Figure 5. Surface Soil Moisture at Different Growth Stages for 25-cm Row Spacing.

* Number of plants/30 cm row

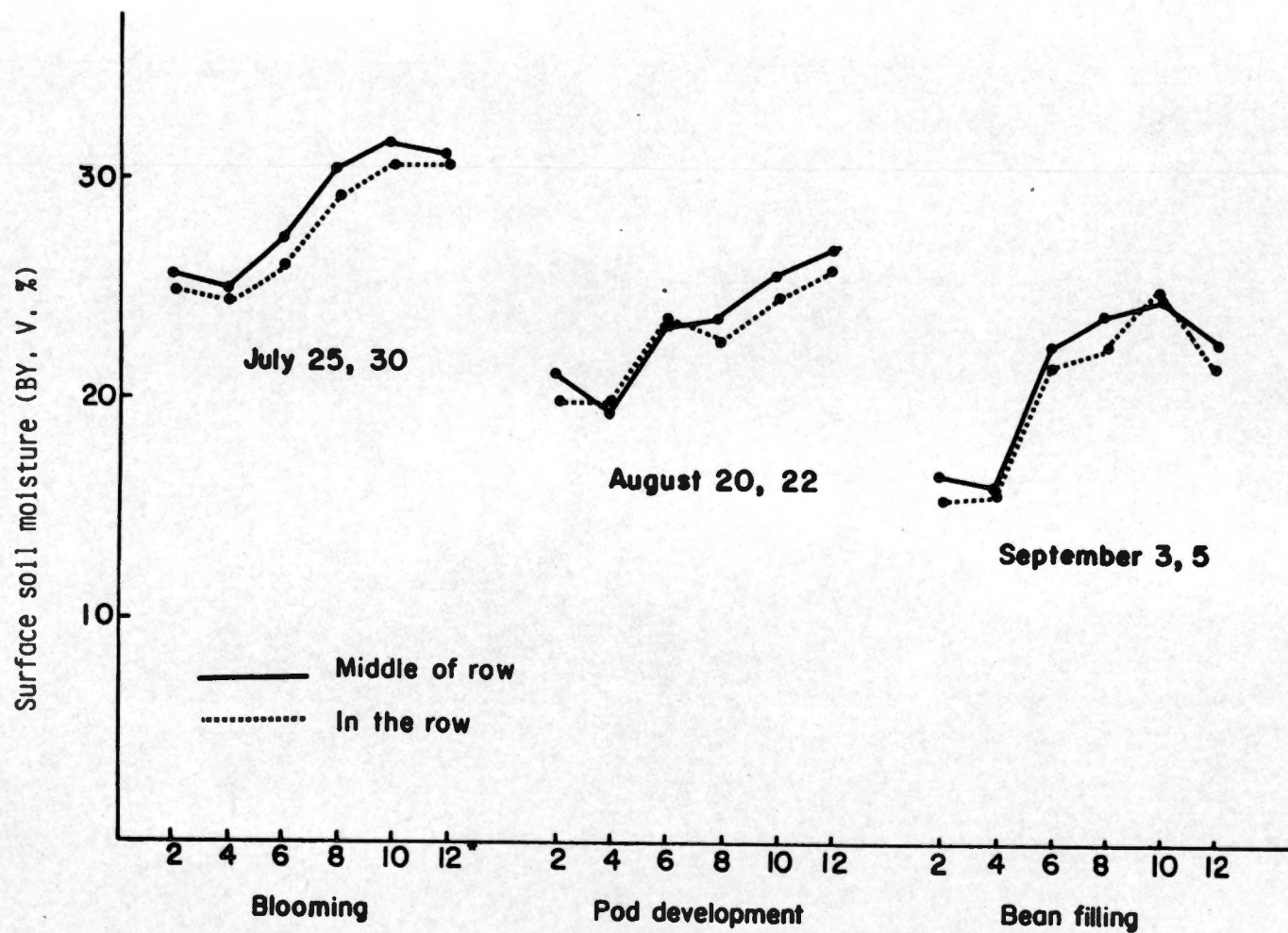


Figure 6. Surface Soil Moisture at Different Growth Stages for 51-cm row spacing.

* Number of plants/30-cm row

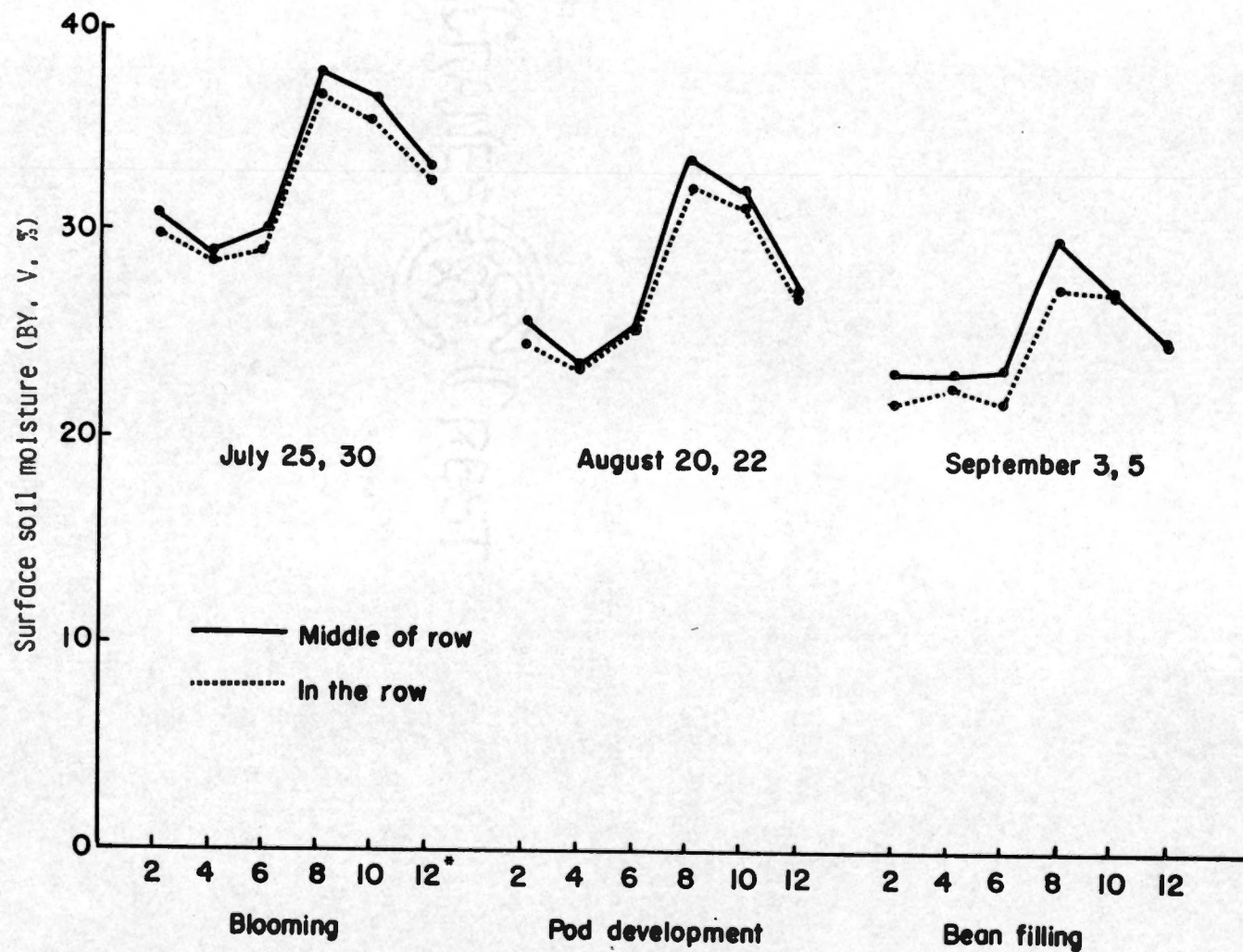


Figure 7. Surface Soil Moisture at Different Growth Stages for 76-cm Row Spacing.

* Number of plants/30-cm row

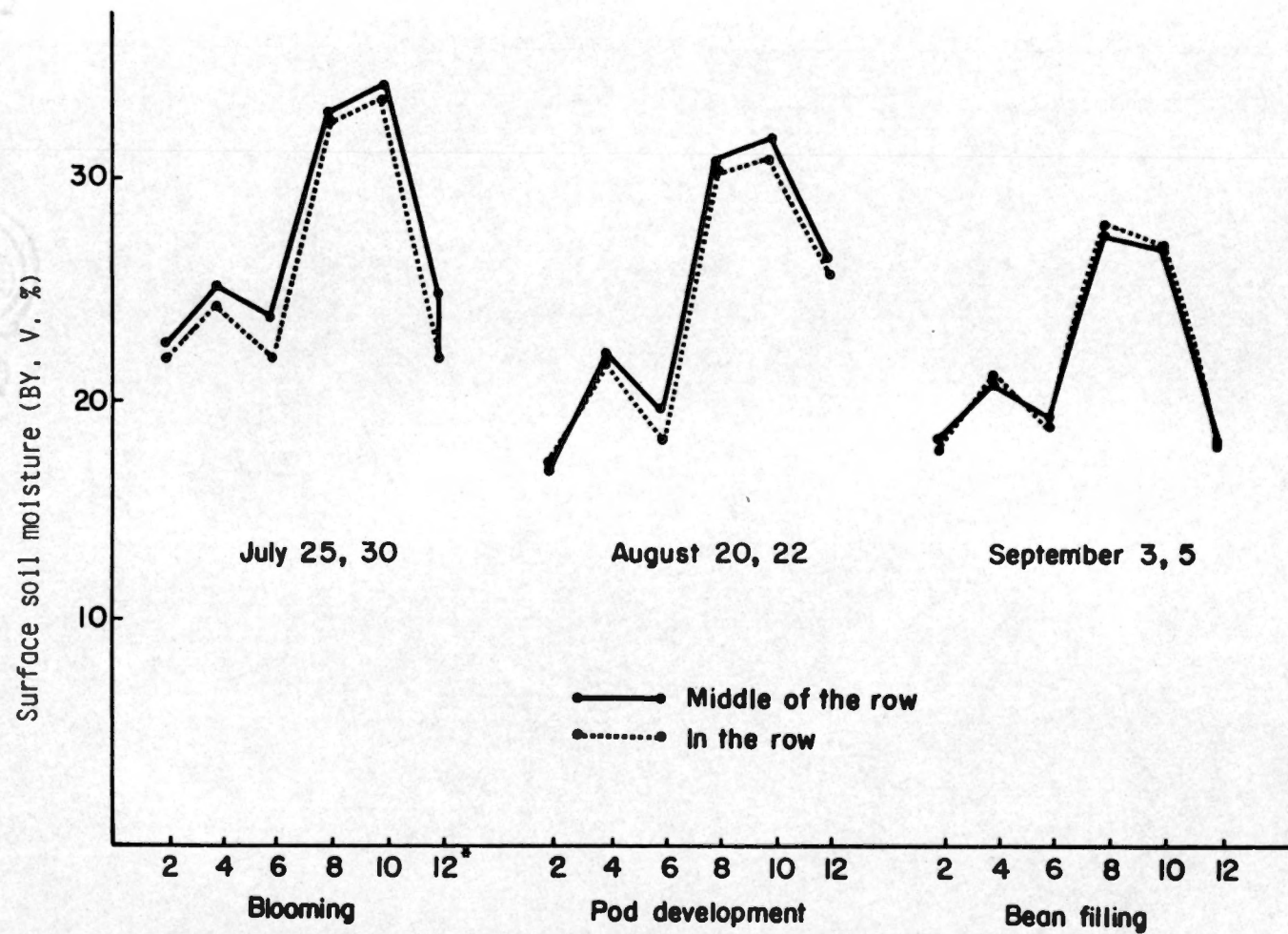


Figure 8. Surface Soil Moisture at Different Growth Stages for 102-cm Row Spacing.

* Number of plants per 30-cm row

The effect of planting pattern on surface soil moisture and soybean yield can be illustrated by comparing Figures 2 and 3 with 5 to 8. Highest yields were obtained from highest surface soil moisture at 8 or 10 plants per 30 cm of the row. Yields were reduced with reduction in surface soil moisture. Lowest yields were obtained in 2 plants per 30 cm of the row where soil surface moisture was lowest at flowering, at pod development (2 weeks later), and at the bean filling stage.

A gradual increase in density of plants increased evapotranspiration, while a decrease in density increased evaporation. Generally with increased use of water, the availability of soil water to plants decreases. In consequence, 6 and 8 plants per 30 cm of row which are in the middle of the plant population range lose water less rapidly (Figures 5-8).

Surface soil moisture measurements for different planting patterns are summarized in Appendix A.

Effect of Light Intensity

Canopy observation throughout the experiment showed no complete closing of space between the rows in 102 cm row spacing. Light intensity measurement suggests that plant population would influence leaf area production and consequently light interception.

Figures 9 and 10 show that when soybeans are grown in narrow rows, they have a significant effect on solar radiation interception. Wider spacings result in less interception at any stage of growth.

Number of plants per unit area (density) is not the determining factor for light interception, but planting pattern is the controlling factor (Figure 9). It is interesting to note that number of plants

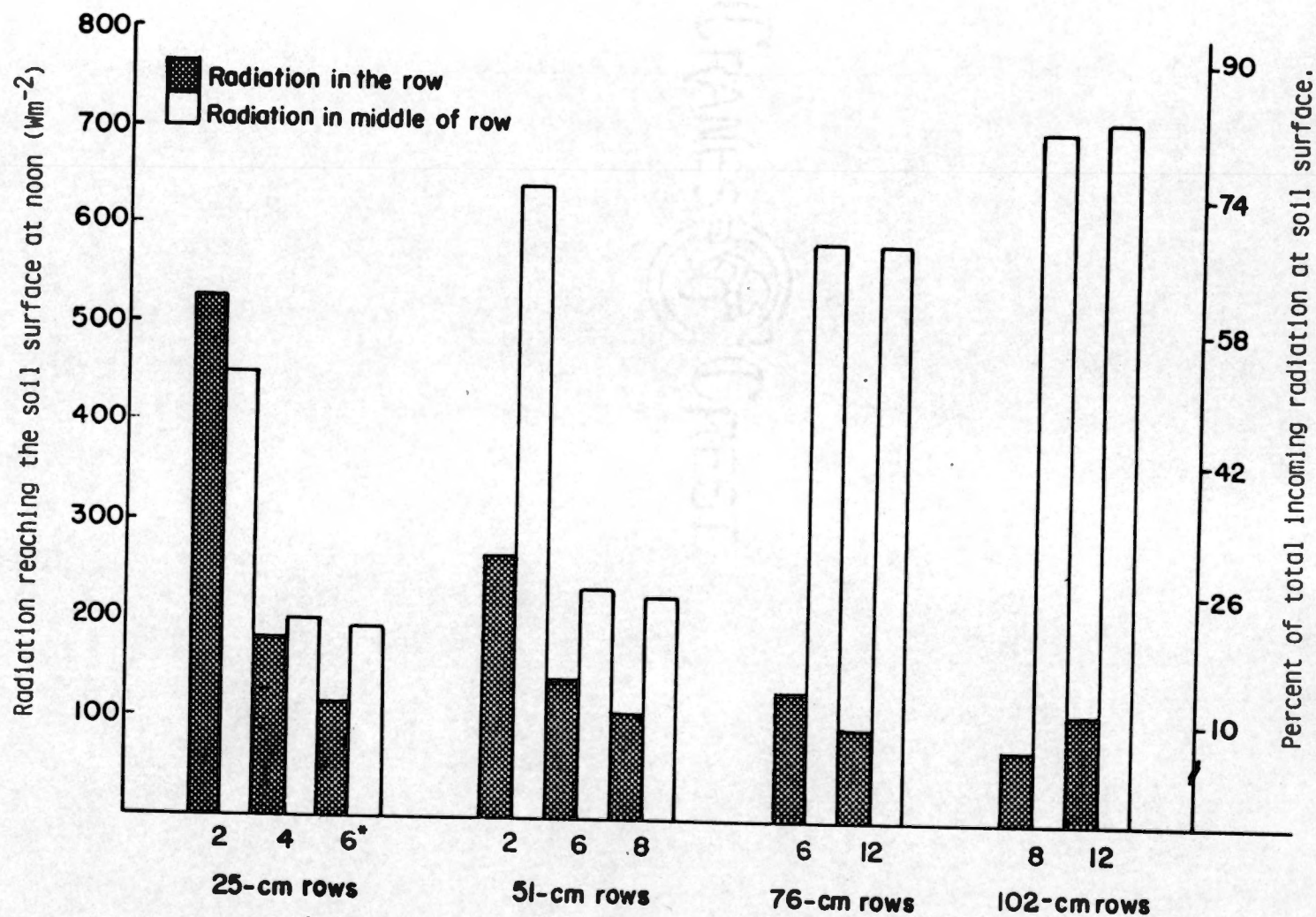


Figure 9. Effect of Different Planting Patterns on Amount of Radiation Intensity Reaching the Soil on July 14.

* Number of plants per 30-cm row

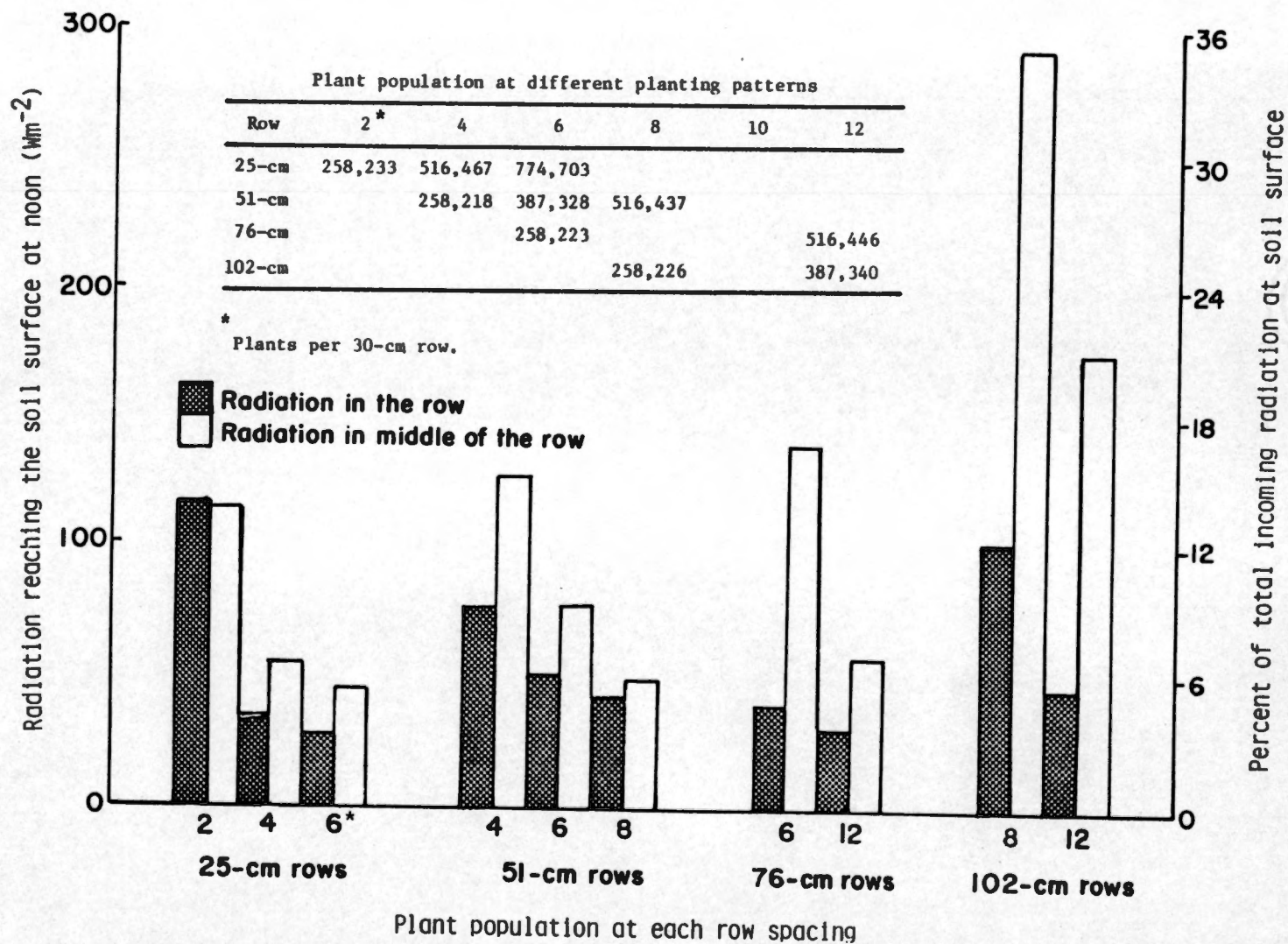


Figure 10. Effect of Different Planting Patterns on Amount of Radiation Intensity Reaching the Soil on July 30.

* Plants per 30-cm row

per 30 cm of the row is not as influential in light interception as row spacings. Four and 6 plants per 30 cm of the row at 25-cm row spacing received more uniform radiation in the row and middle of the row as the season progressed.

Radiation interception was higher in 25-cm row spacing than in other row spacings. During early season (Figure 9) radiation reaching ground in the row was about the same for different treatments. Percent radiation reaching the soil surface in the middle of the row increased with row width. Radiation reaching the soil surface between the rows was high early in the season for 25 and 51-cm rows, then decreased rapidly with time and remained relatively constant throughout the rest of the season.

These results are consistent with the Shibles and Weber (37) hypothesis that canopy closure by the time pod-fill starts allows more interception to occur during pod-fill and yields are greater in narrow rows when seasonal water supply is high. The highest yields achievement for this experiment were for 4 and 6 plants at 25-cm row spacing where the lowest light interception on the ground occurred.

Radiation measurements are summarized in Appendix B.

Effect of Temperature

From five daily observations it was possible to obtain an idea of the diurnal soil temperature variations. Figures 11 and 12 are curves of the diurnal variation of temperature before closure of the canopy and at full closure. These figures show that at 8 a.m. recorded temperatures in the row and middle of the row were very similar for both row spacings. As the day progressed the differences became obvious, but

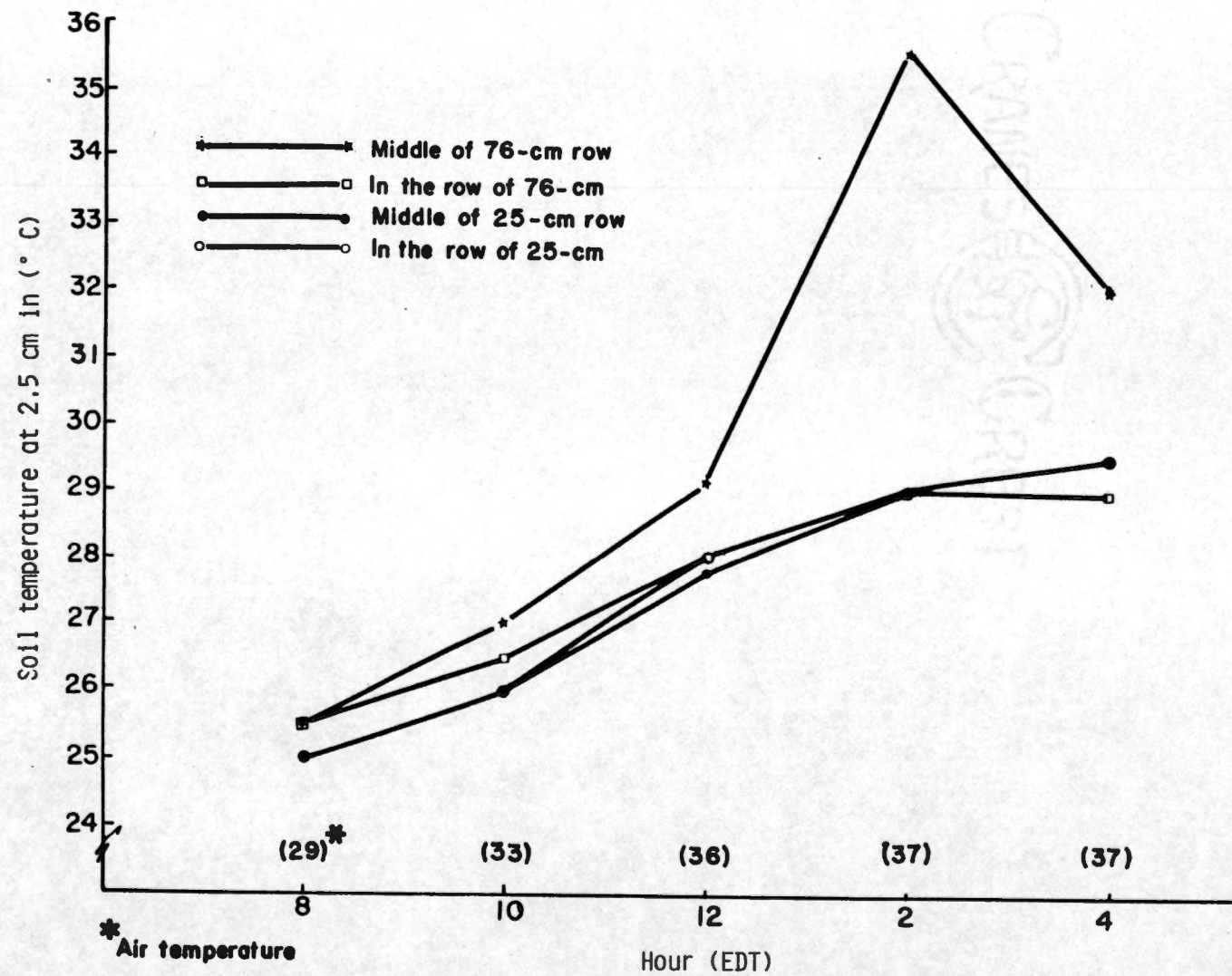


Figure 11. Soil Temperature Changes at 2.5 cm Depth During the Day of July 14.

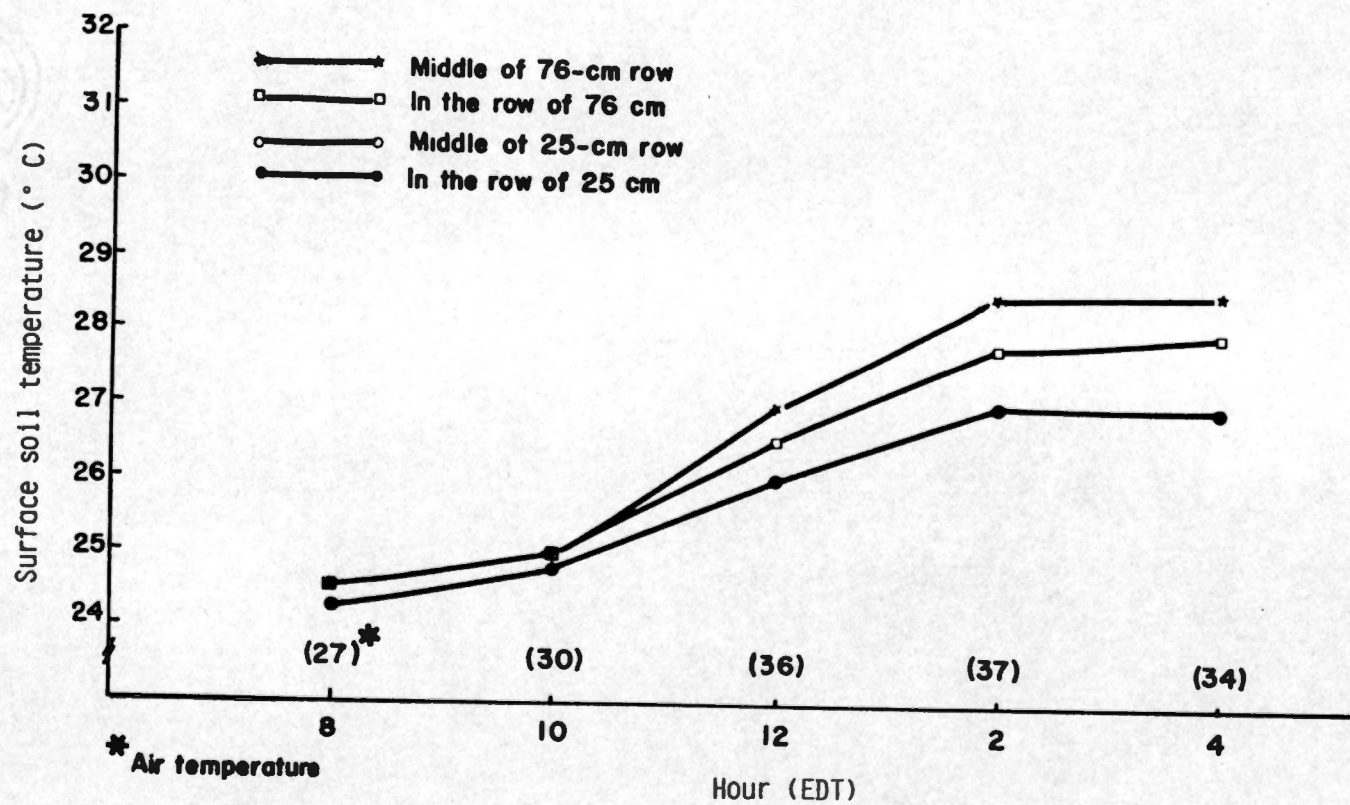


Figure 12. Diurnal Surface Soil Temperature Measurement for August 11.

for 25-cm row spacing, the difference in temperature throughout the day was very little. The 25-cm row spacing never exceeded 30C but temperature probe positioned in the middle of 76-cm row spacing exceeded 36C. This demonstrates the importance of plant cover since temperature between 22-27C at time of flowering has been stated to be the best possible range (36).

Plant canopy surface temperature is a function of energy balance, which is dominated by the availability of water to the surface. Early in the season when plant cover was not complete, the surface was usually actively evaporating and soil surface temperature was close to air temperature (Figure 13 and 14).

Another conclusion that may be drawn from Figures 11-14 is the lag time. The soil is heated at the surface by the sun. The maximum solar radiation arrives at 12:00 noon, but the maximum temperature at soil surface occurs at 2:00 p.m. because a temperature gradient must develop before heat begins to flow to lower depths.

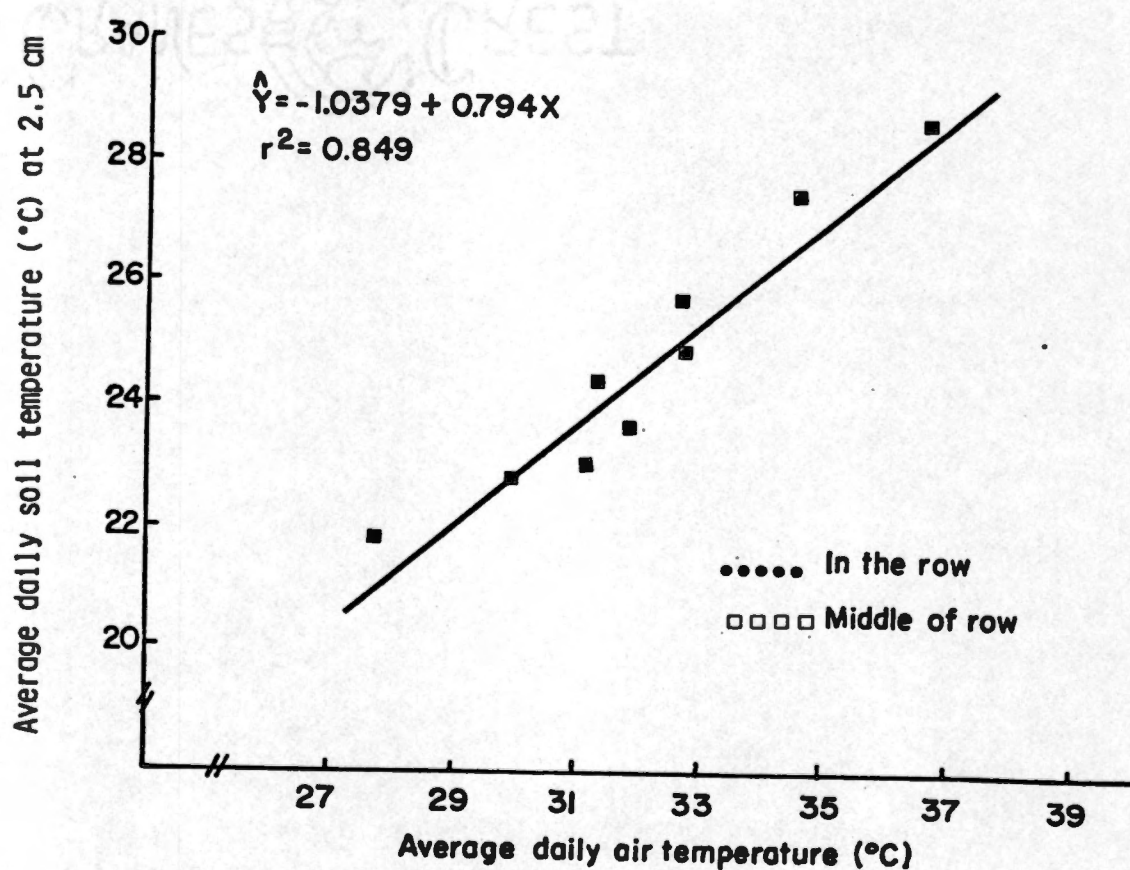


Figure 13. Relation Between Average Daily Air Temperature and Average Daily Soil Temperature at 2.5 cm in Middle and in the 25-cm Row Spacing During Growing Season.

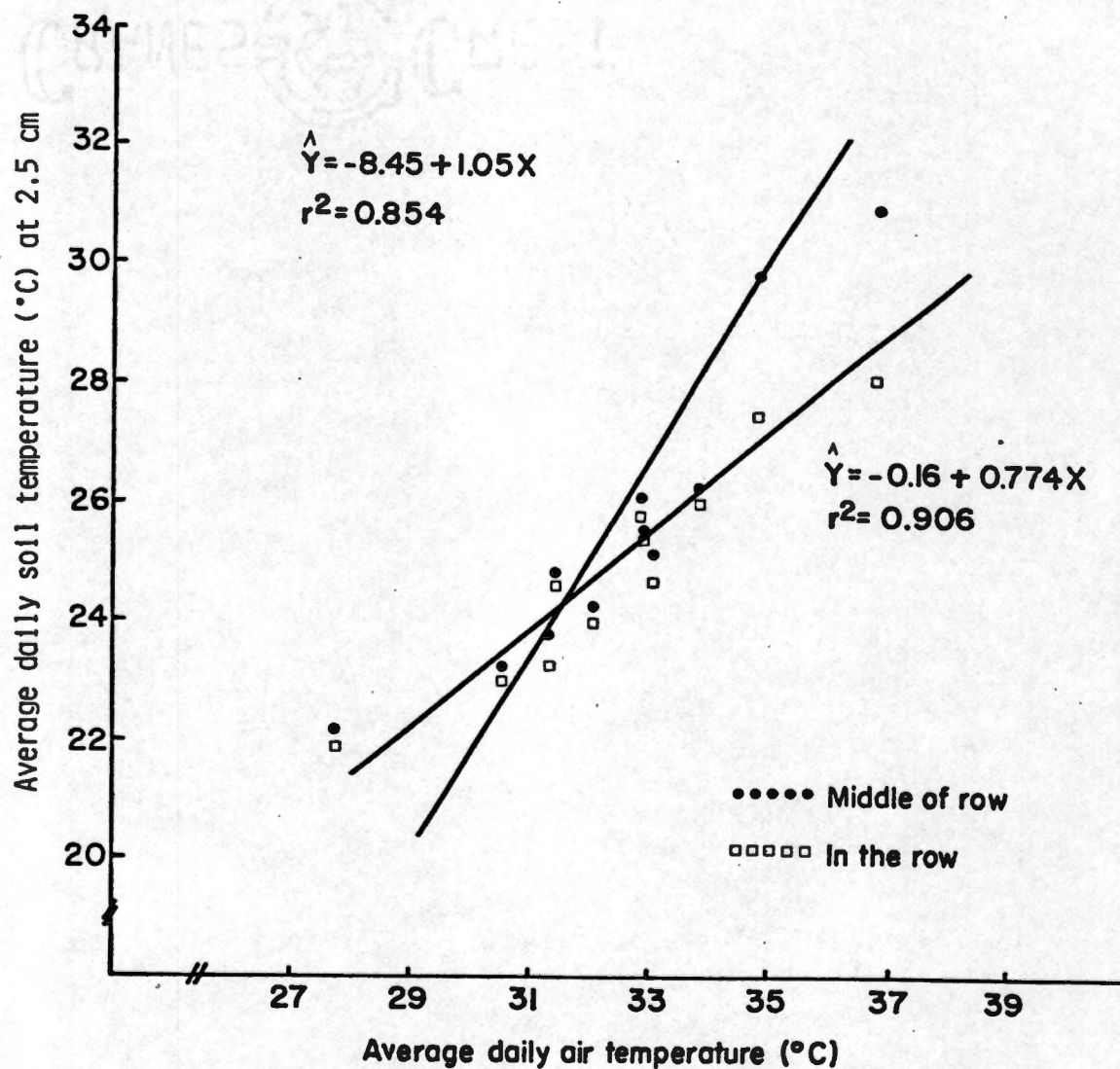


Figure 14. Relation Between Average Daily Air Temperature and Average Daily Soil Temperature at 2.5 cm in Middle and in the 76-cm Row Spacing During Growing Season.

CHAPTER V

SUMMARY AND CONCLUSION

Results of many experiments have shown that radiation is the major factor controlling photosynthesis production. However, there are periods during the life of a crop when water stress and high temperature can make photosynthesis less responsive to radiation.

Basically the amount of solar radiation intercepted is determined by the leaf area of the crop. The leaf area can be altered by increasing the number of plants per unit area. This objective has been achieved by different planting patterns, 4 row spacings (25, 51, 76, and 102 cm) and different plant populations in 30 cm of the row (2, 4, 6, 8, 10, and 12 plants).

The rate of leaf area expansion is strongly dependent on water availability, temperature, and radiation. Therefore, water energy balance at the soil surface, measured at different sites showed that there was a relation between yield and these planting patterns.

Results clearly indicated that Essex soybeans grown in 25-cm rows with 4-10 plants/30 cm of the row, had an appreciable higher yield compared with other planting patterns. Light interception in this range was maximum, and soil temperature was around 27C. Surface soil moisture was used more efficiently by 25 and 51-cm row spacings.

While the results from this experiment present some interesting suggestions, there should be some reservation for firm field recommendations.

Precipitation amount during early periods of growth was lower

than in previous years. Irrigation was used at different critical stages of growth when water was limiting, but lodging under high population (10 and 12 plants per 30 cm of row for 25 and 50-cm rows) probably have lowered the response of these planting patterns.

The availability of surface soil moisture, light interception and cooling effect of plant canopy on soil temperature, appear to be the major environmental factors in determining soybean yield.

High air temperature during the flowering stage probably influenced potential yields.

From the data which were obtained, the combination of light and moisture rather than their independent effect contributed to the high yielding superiority of the narrow rows (25 and 51 cm).



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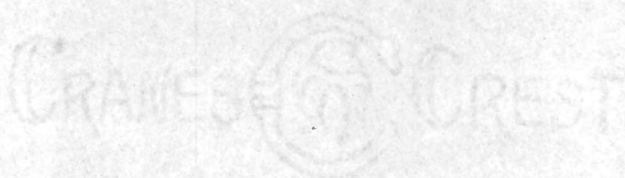
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CRAWFORD ST. REST



APPENDICES



APPENDIX A

TABLE 6
SURFACE SOIL MOISTURE AS INFLUENCED BY DIFFERENT PLANTING PATTERNS ON JUNE 23 AND 27

Row Spacing	Number of Plants/30-cm of Row											
	2	4	6	8	10	12	I.R.	M.R.	I.R.	M.R.	I.R.	M.R.
Date: June 23	M.R.	I.R.	M.R.	I.R.	M.R.	I.R.	M.R.	I.R.	M.R.	I.R.	M.R.	I.R.
25 cm	14.2	9.4	10.3	9.9	8.4	9.4						
	9.3	8.9	9.8	12.8	10.4	13.0						
Ave.**	11.8	9.2	10.1	11.4	9.4	11.2						
51 cm	14.4	12.7	14.3	13.0	11.6	11.2	11.4	11.6	11.4	11.6	11.4	8.4
	10.2	9.9	14.6	13.6	15.6	15.1	11.9	12.1	10.2	12.1	10.2	10.1
Ave.	12.3	11.3	14.5	13.3	13.6	13.2	11.7	11.9	10.8	11.9	10.8	9.3
76 cm	13.1	15.9	13.1	12.9	11.4	12.2	12.4	12.2	11.2	12.2	11.2	10.3
	13.8	13.8	10.4	11.0	14.5	13.2	13.9	11.7	13.4	11.7	13.4	15.1
Ave.	13.5	14.8	11.8	11.9	13.2	12.7	13.2	12.0	12.3	12.0	12.3	12.7
102 cm	13.1	10.1	12.9	11.8	12.6	11.8	13.7	13.1	14.2	13.1	14.2	11.8
	13.8	10.1	11.7	11.0	14.5	12.6	11.2	12.6	11.3	12.6	11.3	8.2
Ave.	13.5	10.1	12.3	11.4	13.6	12.2	12.5	12.9	12.8	12.9	12.8	10.0
Date: June 27												
25 cm	13.8	12.9	12.3	13.1	12.3	12.3	14.3	14.2	34.2	14.7	34.2	14.7
	12.6	11.8	13.1	12.7	33.1	33.1	14.2	26.6	26.6	12.6	26.6	12.6
Ave.	13.2	12.4	12.7	12.7	22.7	22.7	14.3	30.4	30.4	13.7	30.4	13.7
51 cm	35.3	32.0	15.8	15.1	14.9	14.0	11.0	14.2	14.7	14.7	14.7	14.7
	13.5	13.1	16.8	17.0	16.3	32.5	15.9	13.9	12.6	12.6	12.6	12.6
Ave.	24.4	22.6	16.3	16.1	15.6	23.3	13.5	14.1	13.7	13.7	13.7	13.7
76 cm	15.6	15.5	16.2	15.3	12.7	26.2	16.4	14.3	13.0	13.0	13.0	13.0
	18.3	16.1	14.4	13.7	14.1	37.5	17.4	33.1	34.4	34.4	34.4	34.4
Ave.	17.0	15.8	15.3	14.5	14.4	31.9	16.4	23.7	23.7	23.7	23.7	23.7
102 cm	16.6	15.3	16.9	17.9	15.6	31.2	12.9	17.5	15.5	15.5	15.5	15.5
	14.2	12.6	14.8	13.5	13.3	24.8	16.6	14.6	11.3	11.3	11.3	11.3
Ave.	15.4	14.0	15.9	15.7	13.1	28.0	14.8	16.1	21.2	21.2	21.2	21.2

* IR = Soil moisture in middle of the row.

IR = Soil moisture in the row.

** For 25-cm row one measurement is taken in M.R.

TABLE 7

For 25-cm row one measurement is taken in H. R.

TABLE 8
SURFACE SOIL MOISTURE AS INFLUENCED BY DIFFERENT PLANTING PATTERNS ON AUGUST 4 AND 8

Row Spacing	Number of Plants/30cm of Row											
	2	4	6	8	10	12						
	M.R.	I.R.*	M.R.	I.R.	M.R.	I.R.	M.R.	I.R.	M.R.	I.R.	M.R.	I.R.
Date: August 4												
25 cm	9.1		35.9		26.2		9.6		39.9		43.2	
	7.9		7.9		10.5		40.0		10.3		36.7	
Ave.**	8.5		21.9		18.4		24.8		25.1		40.0	
51 cm	41.2	40.2	12.3	11.5	39.7	40.6	12.3	12.6	10.4	11.7	10.4	10.0
	9.5	7.9	14.0	12.7	10.8	9.2	40.4	40.9	33.2	31.6	9.9	9.2
Ave.	25.4	24.1	13.2	12.1	25.3	24.9	26.4	26.8	21.8	21.7	10.2	9.6
76 cm	12.3	11.7	11.1	10.6	38.2	39.5	40.6	39.3	42.9	43.6	39.1	37.8
	10.1	8.4	11.6	11.4	13.6	10.8	43.1	41.1	10.8	9.5	12.9	12.1
Ave.	11.2	10.1	11.4	11.0	25.9	25.2	41.9	40.2	26.9	26.6	26.0	25.0
102 cm	13.0	9.1	12.3	10.4	12.1	11.1	41.4	37.2	42.9	43.1	13.0	10.4
	13.0	11.6	14.7	9.7	14.7	12.5	40.4	44.0	15.8	10.5	11.3	10.2
Ave.	13.0	10.4	13.5	10.1	13.4	11.8	40.9	40.6	29.4	26.8	12.2	10.3
Date: August 8												
25 cm	10.2		29.1		22.7		12.2		33.2		35.1	
	12.2		11.6		12.2		34.1		12.6		30.7	
Ave.	11.2		20.4		17.5		23.2		22.9		32.9	
51 cm	32.5	32.8	11.7	11.1	35.8	31.9	12.2	13.0	11.3	11.5	14.1	14.3
	12.4	11.1	15.0	15.8	10.9	10.9	32.8	33.9	29.8	28.6	12.0	13.7
Ave.	22.5	22.0	13.4	13.5	23.4	21.4	22.5	23.5	20.6	20.1	13.1	14.0
76 cm	15.2	13.6	13.1	11.3	34.0	34.3	32.8	37.1	38.6	35.1	34.0	33.6
	11.1	11.5	13.0	13.0	13.9	13.3	33.1	31.8	14.1	13.7	18.9	17.1
Ave.	13.2	12.6	13.1	12.2	24.0	23.8	33.0	34.5	26.4	24.4	26.5	25.5
102 cm	12.2	10.0	12.1	10.7	14.1	11.3	33.2	30.8	31.2	33.0	12.6	9.8
	13.5	12.0	15.2	11.1	18.4	14.8	34.3	38.0	21.2	15.2	15.9	13.5
Ave.	12.8	11.0	13.7	10.9	16.3	13.1	33.8	34.4	26.2	24.1	14.3	11.7

*MR = Soil moisture in middle of the row.

IR = Soil moisture in the row.

**For 25-cm row one measurement is taken in M.R.

TABLE 9
SURFACE SOIL MOISTURE AS INFLUENCED BY DIFFERENT PLANTING PATTERNS ON JULY 18 AND 21

Row Spacing	Number of Plants/30cm of Row											
	M.R.	2	I.R.*	M.R.	4	I.R.	M.R.	6	I.R.	M.R.	8	I.R.
Date: July 18												
25 cm	8.1			7.5				6.2			6.4	
	8.8			12.8				7.2			39.1	
Ave.**	8.5			10.2				6.7			22.8	
51 cm	36.4											
	8.5	38.8	9.4		9.2	18.7	19.1	6.8	7.7	7.0		
Ave.	22.5	9.0	9.6		10.2	11.1	12.0	39.9	37.4	34.1		
76 cm	10.7	23.9	9.5		9.7	14.9	15.6	23.4	22.6	20.6		
	22.3	10.3	9.2		9.7	8.3	8.4	36.6	34.7	12.0		
Ave.	16.5	20.1	10.7		9.0	11.3	10.3	38.7	38.0	36.9		
102 cm	12.2	15.2	10.0		9.4	9.8	9.4	37.7	36.4	24.5		
	11.8	10.5	12.6		10.7	11.4	7.5	37.9	40.2	14.0		
Ave.	12.0	7.3	11.6		9.6	9.0	8.8	38.4	36.1	24.9		
		8.9	12.1		10.2	10.2	8.2	38.2	38.2	19.5		
Date: July 21												
25 cm	13.1			14.7				15.3			14.6	
	14.0			20.6				11.1			30.3	
Ave.	13.6			17.7				13.2			22.5	
51 cm	30.4											
	14.2	31.5	15.7		14.2	28.9	28.0	14.9	13.5	14.9		
Ave.	22.3	14.4	13.3		13.3	13.7	14.0	33.4	30.5	29.9		
76 cm	17.5	23.0	14.5		13.8	21.3	21.0	24.2	22.0	22.4		
	29.3	15.9	16.8		15.9	16.2	14.2	30.2	31.7	28.5		
Ave.	23.4	29.5	19.4		21.9	15.5	15.5	31.2	32.1	30.5		
102 cm	15.5	22.7	18.1		18.9	15.9	14.9	30.7	31.9	29.5		
	12.7	13.6	17.0		14.9	14.9	12.0	29.6	34.1	24.6		
Ave.	14.1	11.2	25.8		22.6	14.6	11.8	31.0	28.2	28.6		
		12.4	21.4		18.8	14.8	11.9	30.3	31.2	26.6		

*MR = Soil moisture in middle of the row.

IR = Soil moisture in the row.

** For 25-cm row one measurement is taken in M.R.

TABLE 10

*MIR = Soil moisture in middle of the row.
IR = Soil moisture in the row.

65

TABLE 11
SURFACE SOIL MOISTURE AS INFLUENCED BY DIFFERENT PLANTING PATTERNS ON JULY 11 AND 14

Row Spacing	Number of Plants/30-cm of Row															
	2	4	6	8	10	12	I.R.	M.R.	I.R.	M.R.	I.R.	M.R.	I.R.	M.R.	I.R.	M.R.
Date: July 11	M.R.	M.R.	I.R.*	I.R.	M.R.	M.R.	I.R.	M.R.	I.R.	M.R.	I.R.	M.R.	I.R.	M.R.	I.R.	M.R.
25 cm	11.7 18.4	19.4 22.1	13.9 12.8	11.7 25.2	19.0 19.3	24.9 21.5										
Ave.**	15.1	20.8	13.4	18.5	19.2	23.2										
51 cm	24.8 14.5	14.8 13.4	23.3 15.6	15.5 14.7	26.8 12.5	11.1 30.8	10.9 23.8	14.1 25.2	13.1 25.4	17.9 26.9	16.6 23.8					
Ave.	19.7	14.1	19.5	15.1	19.7	21.0	17.4	19.7	19.3	22.4	20.2					
76 cm	13.9 28.6	12.4 25.2	13.0 25.8	12.0 23.4	19.2 18.6	23.6 25.6	21.6 25.4	22.2 24.5	21.1 22.6	13.1 29.7	12.8 31.9					
Ave.	21.3	18.8	19.4	17.7	18.9	24.6	23.5	23.4	21.9	21.4	22.4					
102 cm	12.2 11.7	14.4 28.4	12.8 11.9	14.2 24.5	12.6 11.0	23.5 25.6	22.4 21.9	21.4 23.2	20.3 20.4	12.6 15.8	11.3 14.1					
Ave.	12.0	21.4	12.4	19.4	11.8	24.6	22.2	22.3	20.4	14.2	12.7					
Date: July 14	10.9 14.9	15.5 18.1	10.7 10.3	10.3 22.6	15.7 16.4	20.8 19.0										
Ave.	12.9	16.8	10.5	16.5	16.1	19.9										
51 cm	21.4 11.8	12.4 10.8	20.7 12.3	12.7 12.3	22.3 11.0	9.2 21.8	9.2 20.9	10.2 22.6	10.3 22.8	11.8 21.6	12.2 20.5					
Ave.	16.6	11.6	16.5	12.5	16.7	15.5	15.1	16.4	16.6	16.7	16.4					
76 cm	12.9 22.4	11.6 18.8	10.9 19.4	12.0 17.0	14.9 14.6	19.2 22.0	17.9 20.7	16.6 18.8	15.9 18.8	19.6 27.0	10.3 22.0					
Ave.	17.7	15.2	15.2	14.5	14.8	20.6	19.3	17.7	17.4	23.3	16.2					
102 cm	10.3 9.9	15.3 22.6	10.0 9.4	12.9 16.2	10.5 9.7	18.4 21.3	17.3 20.2	17.2 18.5	15.1 16.6	11.3 11.8	11.4 11.6					
Ave.	10.1	19.0	9.7	14.6	10.1	19.9	18.8	17.9	15.9	11.6	11.5					

*MR = Soil moisture in middle of the row

IR = Soil moisture in the row.

**For 25-cm row one measurement is taken in M.R.

TABLE 12
SURFACE SOIL MOISTURE AS INFLUENCED BY DIFFERENT PLANTING PATTERNS ON AUGUST 11 AND 15

Row Spacing	Number of Plants/30-cm of Row																	
	M.R.	2	I.R.*	M.R.	4	I.R.	M.R.	6	I.R.	M.R.	8	I.R.	M.R.	10	I.R.	M.R.	12	I.R.
Date: August 11																		
25 cm		13.0			15.2			9.5			19.1			14.8			16.1	
		9.2			13.3			9.2			9.0			14.8			16.7	
Ave.**		11.1			14.3			9.4			14.1			14.8			16.4	
51 cm		10.7		10.7	10.3		10.5	10.0		10.9	20.2		17.4	18.0		19.1	17.4	
		18.6		19.1	10.2		11.6	18.6		15.2	8.7		8.1	8.5		8.7	10.3	
Ave.		14.7		14.9	10.3		11.1	14.3		13.1	14.5		12.8	13.3		13.9	13.9	
76 cm		18.2		16.5	15.0		14.8	12.4		10.7	19.1		17.8	16.9		16.5	21.9	
		10.2		10.5	11.1		10.3	13.3		12.0	15.2		14.3	13.7		14.6	9.0	
Ave.		14.3		13.5	13.1		12.6	12.9		11.4	17.2		16.1	15.3		15.6	15.5	
102 cm		9.6		9.2	17.3		13.7	9.8		9.2	18.6		17.4	15.8		15.0	9.6	
		9.8		8.5	12.4		13.0	9.4		9.4	15.9		15.4	13.9		13.0	10.7	
Ave.		9.7		8.9	14.9		13.4	9.6		9.3	17.3		16.4	14.9		14.0	10.2	
Date: August 15																		
25 cm		13.4			23.4			16.0			13.4			26.9			31.5	
		24.2			24.7			19.1			33.0			28.3			33.9	
Ave.		18.8			24.1			17.5			23.2			27.6			32.7	
51 cm		32.8		30.8	17.3		18.8	31.2		29.3	14.9		14.5	17.3		16.5	21.0	
		21.0		22.7	17.6		18.6	13.9		15.9	34.8		31.5	31.1		30.9	30.0	
Ave.		26.9		26.8	17.5		18.7	27.6		22.6	24.9		23.0	24.2		23.7	25.5	
76 cm		16.5		15.2	17.8		17.6	20.2		20.4	33.0		29.9	26.2		29.4	16.3	
		31.3		29.0	29.6		29.4	23.6		23.6	34.3		36.5	33.1		30.9	35.9	
Ave.		23.9		22.1	23.7		23.5	21.9		22.0	33.7		33.2	29.7		29.7	26.1	
102 cm		16.9		14.3	18.9		19.9	18.4		15.8	35.4		35.8	28.8		28.2	14.3	
		13.3		13.5	31.3		28.6	13.3		15.6	33.9		31.5	32.8		30.2	18.6	
Ave.		15.1		13.9	25.1		24.3	15.9		15.7	34.7		33.7	30.8		29.2	16.5	

*MR = Soil moisture in middle of the row.
IR = Soil moisture in the row.

**For 25-cm row one measurement is taken in M.R.

TABLE 13
SURFACE SOIL MOISTURE AS INFLUENCED BY DIFFERENT PLANTING PATTERNS ON AUGUST 25 AND 29

Row Spacing		Number of Plants/30-cm of Row																	
		2		4		6		8		10		12							
M.R.		I.R.*	M.R.	I.R.	M.R.	I.R.	M.R.	I.R.	M.R.	I.R.	M.R.	I.R.	M.R.	I.R.					
Date:	August 25																		
25 cm		11.6		19.1		11.4			9.9		24.3			August 25, 1980					
		19.4		23.0		15.0			26.0		23.4			25.2					
Ave.**		15.5		21.1		13.2			18.0		23.9			24.7					
														25.5					
51 cm	28.2		25.2	14.6		15.0	29.1		24.7	10.7		11.4	11.8		13.7		14.2		
	16.5		17.0	13.3		15.2	11.4		12.6	26.5		25.4	26.2		27.8		27.7		
Ave.	22.4		21.1	14.0		15.1	20.2		18.7	18.6		18.4	19.0		19.7		21.0		
76 cm	13.3		12.7	13.3		12.9	17.2		17.0	25.4		22.6	22.4		22.1	11.8	12.0		
	26.2		26.5	25.4		24.1	16.7		17.0	26.9		25.8	25.8		24.5	30.1	26.3		
Ave.	19.8		19.6	19.4		18.5	17.0		17.0	26.2		24.2	24.1		23.3	21.0	19.2		
102 cm	11.6		12.0	15.0		15.3	14.4		12.0	29.1		24.9	21.7		22.8	12.6	12.0		
	11.4		11.2	26.2		23.7	10.9		10.7	26.2		22.8	26.0		22.6	14.0	14.4		
Ave.	11.5		11.6	20.6		19.5	12.7		11.4	27.7		23.9	23.9		22.7	13.3	13.2		
Date:	August 29																		
25 cm		16.7		28.7		21.0			19.1		31.6			August 29, 1980					
		28.9		29.3		23.0			35.2		32.4			33.4					
Ave.		22.8		29.0		22.0			27.2		32.0			35.0					
														34.7					
51 cm	34.4		34.6	18.0		19.1	32.0		29.8	22.1		22.3	24.8		25.4	23.7	23.0		
	29.5		28.4	21.9		22.7	23.0		23.4	35.7		34.5	34.8		33.4	32.6	32.4		
Ave.	32.0		31.5	20.0		20.9	27.5		26.6	28.9		28.4	29.8		29.4	28.2	27.7		
76 cm	18.6		18.4	24.6		22.4	28.1		26.3	35.7		33.1	31.4		31.4	22.6	21.5		
	32.1		30.2	28.2		29.1	20.5		24.1	35.9		36.5	33.5		33.5	37.2	37.0		
Ave.	25.4		24.3	26.4		25.8	24.3		25.2	35.8		34.8	32.5		32.5	29.9	29.3		
102 cm	24.5		23.2	25.6		25.4	27.6		23.7	38.1		36.8	31.4		31.6	20.1	17.5		
	19.2		18.8	33.2		31.5	21.6		20.8	34.8		34.5	34.8		32.8	24.1	25.1		
Ave.	21.9		21.0	29.4		28.5	24.6		22.3	36.5		35.7	33.1		32.2	22.1	21.3		

* MR = Soil moisture in middle of the row.

IR = Soil moisture in the row.

** For 25-cm row one measurement is taken in M.R.

TABLE 14
SURFACE SOIL MOISTURE AS INFLUENCED BY DIFFERENT PLANTING PATTERNS ON AUGUST 22 AND 20

Row Spacing	Number of Plants/30cm of Row											
	M.R.	2	I.R.*	M.R.	4	I.R.	M.R.	6	I.R.	M.R.	8	I.R.
Date: August 22												
25 cm	12.6	25.3	22.8	25.8	15.2	19.4	11.5	31.3	12.5	16.0	27.5	27.3
Ave.**	19.0	24.3	17.3	28.9	12.3	31.5	21.9	20.9	23.3	26.4	15.4	34.1
51 cm	29.7	30.8	15.8	16.2	17.5	18.8	31.2	13.7	22.5	21.5	28.7	30.0
Ave.	25.7	26.8	16.0	15.6	18.2	15.6	22.1	21.9	22.0	21.7	30.0	27.5
76 cm	16.0	14.5	15.4	28.9	27.1	27.1	21.9	31.3	27.5	30.4	30.4	29.1
Ave.	30.2	22.0	22.2	14.2	14.5	14.2	14.2	14.2	14.2	14.2	14.2	14.2
102 cm	15.6	15.6	14.5	14.2	15.4	15.4	16.1	13.8	19.9	16.9	27.4	28.9
Ave.	14.9	14.4	19.8	19.6	16.9	15.5	27.5	27.4	28.9	28.9	15.0	15.9
Date: August 20												
25 cm	18.9	30.3	29.1	30.7	22.1	25.0	17.5	36.6	19.3	23.8	32.3	33.5
Ave.	24.6	29.9	23.8	23.7	33.2	18.2	35.3	26.8	32.2	33.4	34.5	34.8
51 cm	36.5	35.1	22.1	22.4	23.8	33.8	19.1	26.5	33.2	18.2	35.3	27.1
Ave.	32.1	21.5	22.3	21.5	26.5	26.4	30.9	35.8	34.8	34.5	34.7	35.1
76 cm	22.8	20.2	21.9	27.0	21.5	26.5	28.7	35.3	32.2	33.4	33.4	29.2
Ave.	27.9	26.9	24.5	24.5	29.5	21.4	35.8	34.2	35.0	34.8	34.8	20.8
102 cm	21.7	21.5	21.1	22.3	24.1	20.4	22.3	19.9	35.0	34.8	34.8	20.8
Ave.	19.5	19.8	26.8	26.2	22.3	17.5	36.6	27.1	19.3	23.8	32.3	33.5

*MR = Soil moisture in middle of the row.
IR = Soil moisture in the row.

**For 25-cm row one measurement is taken in M.R.

TABLE 15
SURFACE SOIL MOISTURE AS INFLUENCED BY DIFFERENT PLANTING PATTERNS ON SEPTEMBER 3 AND 5

Row Spacing		Number of Plants/30cm of Row																	
		M.R.	2	I.R.*	M.R.	4	I.R.	M.R.	6	I.R.	M.R.	8	I.R.	M.R.	10	I.R.	M.R.	12	I.R.
Date:	September 3																	September 3, 1980	
25 cm		14.1			24.2			15.9			14.8			29.2				29.7	
		25.2			29.0			21.6			31.2			30.5				29.9	
Ave.**		19.7			26.6			18.8			23.0			29.9				29.8	
51 cm	31.8		29.4	15.2		15.9	28.8		26.8	17.7		17.4	20.0		20.5	16.1		16.5	
	26.4		26.2	19.0		20.2	20.5		21.4	34.1		31.2	31.8		33.2	32.7		31.4	
Ave.	29.1		27.8	17.1		18.1	24.7		24.1	26.1		24.3	25.9		26.9	24.4		23.4	
76 cm	17.9		16.8	21.1		20.0	26.8		23.6	31.8		27.5	27.7		28.1	18.7		19.2	
	31.0		30.8	26.5		27.1	21.0		20.4	30.7		30.8	29.9		30.1	33.4		34.2	
Ave.	24.5		23.8	23.8		23.5	23.9		22.0	31.3		29.2	28.8		29.1	26.1		26.7	
102 cm	23.8		22.9	19.0		21.2	23.6		20.2	32.9		30.8	27.2		27.3	16.1		14.2	
	16.8		17.9	28.0		27.8	16.6		18.1	27.1		29.0	29.4		30.3	27.7		23.1	
Ave.	20.3		20.4	23.5		24.5	20.1		19.2	30.0		29.9	28.3		28.8	19.4		18.7	
Date:	September 5																	September 5, 1980	
25 cm		12.5			20.5			12.7			12.2			24.5				26.5	
		23.1			25.7			16.7			29.4			28.8				27.9	
Ave.		17.8			23.1			14.7			20.8			26.6				27.2	
51 cm	28.0		26.7	13.8		14.0	26.7		24.1	13.3		13.7	16.0		15.9	12.9		12.5	
	23.2		22.9	16.5		16.9	15.4		17.4	30.2		27.5	30.7		30.9	30.9		30.5	
Ave.	25.6		24.8	15.2		15.5	21.1		20.8	21.8		20.6	23.4		23.4	21.9		21.5	
76 cm	15.1		12.5	17.0		16.8	24.0		20.2	26.2		23.2	24.7		24.5	14.9		14.6	
	27.9		26.8	28.5		27.0	18.8		18.4	29.6		28.1	26.8		26.8	31.8		31.5	
Ave.	21.5		19.7	22.8		21.9	21.4		19.1	27.9		25.7	25.8		25.7	23.4		23.1	
102 cm	19.9		17.5	16.0		17.2	19.7		16.8	28.3		26.7	23.2		23.8	13.1		12.9	
	13.5		15.0	24.1		22.9	14.6		15.0	26.7		25.8	28.6		27.5	17.8		19.9	
Ave.	16.7		16.3	20.5		20.0	17.2		15.9	27.0		26.3	25.9		25.7	15.5		16.4	

*MR = Soil moisture in middle of the row.

IR = Soil moisture in the row.

** For 25-cm row one measurement is taken in MR.

TABLE 16
SURFACE SOIL MOISTURE AS INFLUENCED BY DIFFERENT PLANTING PATTERNS ON SEPTEMBER 9 AND 12

Row Spacing	Number of Plants/30-cm of Row																	
	M.R.	2	I.R.*	M.R.	4	I.R.	M.R.	6	I.R.	M.R.	8	I.R.	M.R.	10	I.R.	M.R.	12	I.R.
Date: September 9																		
25 cm		10.7			15.9			10.3			9.8			20.6			23.1	
		24.6			21.8			26.0			26.0			22.9			24.6	
Ave.**		17.7			18.9			18.2			17.9			21.8			23.9	
51 cm	26.4		23.6	12.2		13.0	23.2		19.1	11.3		12.0	11.8		12.2	10.9		10.9
	17.6		18.5	26.8		24.0	27.2		28.3	26.8		24.0	27.2		28.3	27.2		27.2
Ave.	22.0		21.1	19.5		18.5	25.2		23.7	19.1		18.0	19.5		20.3	19.1		19.1
76 cm	13.5		10.9	14.8		13.5	19.1		17.1	21.9		21.6	21.7		20.6	12.6		11.8
	25.1		21.8	28.1		27.2	25.1		23.5	25.1		23.5	23.5		21.8	28.1		27.2
Ave.	19.3		16.4	21.5		20.4	22.1		20.3	23.5		22.6	22.6		21.2	20.4		19.5
102 cm	15.0		13.3	15.2		15.6	13.9		12.2	26.0		23.4	20.6		20.2	12.0		12.0
	23.8		21.8	25.3		23.1	24.8		23.8	23.8		21.8	24.8		23.8	15.9		15.5
Ave.	19.4		17.6	20.3		19.4	19.4		18.0	24.5		22.6	22.7		22.0	14.0		13.8
Date: September 12																		
25 cm		15.9			18.8			15.5			15.9			26.2			28.8	
		23.9			26.5			18.5			28.3			25.6			28.7	
Ave.		19.9			22.7			17.0			22.1			25.9			28.8	
51 cm	29.0		26.8	15.7		16.5	26.4		24.0	16.3		16.6	18.7		17.0	13.0		13.5
	20.9		23.3	20.6		22.2	18.0		20.2	30.2		29.6	29.8		31.1	30.5		30.2
Ave.	25.0		25.1	18.2		19.4	22.2		22.1	23.3		23.1	24.3		24.1	21.8		21.9
76 cm	20.2		18.1	19.8		19.8	25.7		22.0	26.2		24.2	24.6		25.9	17.6		17.9
	28.0		26.3	26.8		25.4	18.7		17.2	26.8		26.7	25.7		26.1	31.7		31.8
Ave.	24.1		22.2	23.3		22.6	22.2		19.6	26.5		25.5	25.2		26.0	24.7		24.9
102 cm	22.9		20.7	17.9		22.4	19.0		18.7	26.8		26.2	24.2		24.0	16.3		17.0
	14.5		17.2	28.3		26.8	15.9		15.9	27.2		27.6	27.4		27.2	19.1		20.9
Ave.	18.7		19.0	23.1		24.6	17.5		17.3	27.0		26.9	25.8		25.6	17.7		19.0

*MR = Soil moisture in middle of the row.

IR = Soil moisture in the row.

** For 25-cm row one measurement is taken in M.R.

TABLE 17

SURFACE SOIL MOISTURE AS INFLUENCED BY DIFFERENT PLANTING PATTERNS ON SEPTEMBER 15 AND 19

Row Spacing	Number of Plants/30-cm of Row																	
	M.R.	2	I.R.*	M.R.	4	I.R.	M.R.	6	I.R.	M.R.	8	I.R.	M.R.	10	I.R.	M.R.	12	I.R.
Date:	September 15, 1980																	
25 cm		17.5			24.5			20.7			18.3			29.5			31.3	
		27.1			28.2			19.4			31.0			30.2			31.1	
Ave.**		22.3			26.4			20.1			24.7			29.9			31.2	
51 cm	31.0		28.7	17.0		18.3	28.6		27.3	21.0		20.8	23.2		23.2	19.5		19.4
	27.6		28.7	20.8		23.4	22.3		22.7	32.3		32.3	30.8		32.6	32.6		30.2
Ave.	29.3		28.7	18.9		20.9	25.5		25.0	26.7		26.6	27.0		28.0	26.1		24.8
76 cm	21.0		20.5	23.6		22.9	26.7		24.9	26.4		25.6	27.8		28.2	21.2		21.4
	30.2		29.8	28.4		27.6	17.3		18.1	27.3		28.0	28.6		28.7	32.4		32.4
Ave.	25.6		25.2	26.0		25.3	22.0		21.5	26.9		26.8	28.2		28.5	26.8		26.9
102 cm	24.9		20.7	24.1		25.3	24.3		22.1	29.8		28.9	25.1		25.1	18.6		17.5
	18.6		19.7	29.3		29.1	20.1		18.4	28.2		28.2	31.0		30.6	24.1		23.4
Ave.	21.8		20.2	26.7		27.2	22.2		20.3	29.0		28.6	28.1		27.9	21.4		20.5
Date:	September 19, 1980																	
25 cm		17.2			24.9			19.4			20.5			27.7			29.4	
		28.2			29.1			22.1			31.7			29.7			31.9	
Ave.		22.7			27.0			20.8			26.1			28.7			30.7	
51 cm	30.8		30.5	18.5		20.0	27.3		27.0	22.4		24.0	23.3		23.5	19.4		19.8
	30.6		28.7	22.0		24.8	23.6		24.8	34.0		31.2	32.9		33.6	32.7		32.1
Ave.	30.7		29.6	20.2		22.4	25.5		25.9	28.2		27.6	28.1		28.6	26.1		25.6
76 cm	26.0		22.2	24.9		22.9	27.7		26.0	28.3		25.5	28.8		29.7	22.4		21.8
	30.8		30.6	30.2		29.3	22.1		18.5	27.2		28.9	29.7		32.1	34.0		34.2
Ave.	28.4		26.4	27.6		26.1	24.9		22.3	27.8		27.2	29.3		30.9	28.2		28.0
102 cm	26.8		23.5	24.2		25.1	23.3		22.9	29.5		26.0	26.8		26.4	18.1		20.0
	18.2		19.9	31.6		30.6	20.8		22.5	30.4		30.1	31.7		31.2	24.4		26.3
Ave.	22.5		21.7	27.9		27.9	22.1		22.7	30.0		28.1	29.3		28.8	21.3		24.2

*MR = Soil moisture in middle of the row.

IR = Soil moisture in the row.

** For 25-cm row one measurement is taken in M.R.



APPENDIX B

TABLE 18
PERCENT OF RADIATION REACHING TO SOIL SURFACE DURING JULY 14 AND 16 AT DIFFERENT PLANTING PATTERN

Plants/30-cm of Row		Row Spacing (25-cm)							
Date: July 14		9:00 a.m.		12:00 a.m.		3:00 p.m.			
		T ^a	R ^b	T ^a	R ^b	T ^a	R ^b		
2	4,300	40.0	40.0	8,900	64.0	54.5	8,800	50.0	60.1
4	3,600	15.0	13.3	9,000	21.1	25.0	9,150	31.7	43.8
6	4,000	7.5	7.5	8,900	12.4	23.6	9,500	22.1	22.1
4	4,250	11.8	21.2	(51-cm)					
6	3,850	13.0	13.5	8,800	33.0	79.0	9,000	52.2	58.9
8	4,300	8.3	14.7	8,950	16.8	28.0	9,800	25.5	36.8
				8,800	13.6	26.0	9,000	29.2	22.7
6	3,800	14.5	28.7	(76-cm)					
12	4,100	25.4	36.6	8,900	14.5	71.4	9m400	18.1	75.5
				8,950	11.4	70.1	9,200	30.4	80.1
8	4,400	24.1	38.7	(102-cm)					
12	4,250	11.8	22.4	9,000	9.1	82.8	8,900	17.1	67.4
				9,000	13.3	85.6	8,900	25.3	87.6
Plants/30-cm of Row		Row Spacing							
Date: July 16									
2	4,100	15.6	26.8	(25-cm)					
4	4,300	8.3	9.3	8,800	48.8	46.6	9,600	57.3	36.4
6	4,250	5.1	5.9	8,700	23.0	48.3	9,400	47.9	23.4
				9,000	23.3	37.8	9,300	26.9	36.6
4	3,900	21.0	25.6	(51-cm)					
6	4,200	13.3	15.5	8,700	39.0	79.3	9,500	57.9	56.8
8	4,000	10.0	11.3	8,900	32.6	21.3	9,000	23.3	20.0
				8,600	17.4	39.5	9,100	30.1	41.7
6	4,200	7.4	20.0	(76-cm)					
12	4,000	9.5	20.0	8,600	6.5	58.2	9,250	9.1	34.6
				8,600	15.1	52.3	9,500	28.4	43.2
8	4,000	9.8	27.5	(102-cm)					
12	3,900	10.3	38.5	8,800	6.8	56.8	9,050	6.3	59.6
				8,400	17.8	83.5	9,400	17.0	85.1

^aT = Top, ^bR = Row, ^cM = Middle

^aT = Top, ^bR = Row, ^mM = Middle

TABLE 19
PERCENT OF RADIATION REACHING TO SOIL SURFACE DURING JULY 25 AND 30 AT DIFFERENT PLANTING PATTERN

Plants/30-cm of Row		Row Spacing (25-cm)							
		9:00 A.M.		12:00 A.M.				3:00 P.M.	
		T*	R*	T*	R*	T*	R*	T*	R*
Date: July 25									
2	4,000	9.0	9.8	6,900	21.5	20.3	9,700	25.8	19.6
4	4,000	3.0	4.0	6,900	5.4	8.0	8,900	6.1	7.0
6	4,000	3.0	3.1	7,000	5.4	9.2	9,300	2.8	17.8
(51-cm)									
4	4,000	11.0	1.6	6,900	12.3	24.3	9,600	31.3	20.9
6	4,000	7.8	6.8	9,000	3.9	7.4	9,200	13.0	8.9
8	3,900	3.6	5.6	6,500	7.7	8.0	9,200	5.2	7.6
(76-cm)									
6	4,000	3.8	9.3	7,000	3.6	17.1	9,200	8.0	19.6
12	4,000	3.8	9.5	7,000	5.6	11.6	9,500	3.7	13.7
(102-cm)									
8	3,900	8.5	25.9	8,900	17.4	50.0	9,300	14.0	32.3
12	3,900	9.5	21.0	6,600	7.8	60.0	9,500	20.0	53.7
Plants/30-cm of Row									
Date: July 30									
2	4,200	6.2	7.8	9,200	11.3	11.4	8,800	10.2	12.5
4	4,500	2.7	2.9	9,000	4.4	7.4	8,800	5.4	3.5
6	4,200	3.2	4.0	9,100	3.0	3.9	9,200	3.8	4.9
(25-cm)									
4	4,200	7.1	10.0	9,300	8.6	28.0	9,000	23.0	50.0
6	4,300	3.3	4.2	9,300	4.7	13.3	9,000	5.5	5.5
8	4,000	2.4	3.0	9,000	2.7	7.4	8,800	4.5	6.3
(51-cm)									
6	4,300	2.1	5.1	9,000	4.2	20.0	9,100	27.5	13.2
12	4,100	2.7	3.4	9,000	2.3	4.6	9,300	4.5	12.7
(76-cm)									
8	4,500	4.9	11.0	9,100	6.6	21.0	8,600	15.1	43.0
12	4,100	6.6	20.0	9,000	4.4	4.1	8,800	21.6	43.2
(102-cm)									

* T = Top, R = Row, M = Middle

TABLE 20
PERCENT OF RADIATION REACHING TO SOIL SURFACE DURING AUGUST 4 AND 6 AT DIFFERENT PLANTING PATTERN

Plants/30-cm of Row											
Date: August 4											
2	4	6	9:00 a.m.			12:00 a.m.			3:00 p.m.		
			T*	R*	M*	T*	R*	M*	T*	R*	M*
4	6	8	2,800	5.0	2.2	8,200	5.2	6.5	8,000	6.7	6.3
			2,700	2.3	2.5	7,300	3.6	6.4	7,600	2.2	3.3
			2,800	2.5	2.2	7,600	1.6	2.0	8,000	1.2	1.6
4	6	8	3,000	5.3	8.3	8,200	8.5	7.8	8,800	5.2	6.8
			2,900	3.4	5.3	7,600	2.9	3.8	7,500	2.1	2.8
			2,800	1.6	2.4	2,100	2.5	2.1	6,900	1.7	1.5
4	6	8	2,700	2.6	6.3	6,600	3.6	5.7	7,300	3.6	4.1
			2,600	1.4	6.1	8,000	2.7	5.7	9,400	3.3	4.0
			2,900	4.8	13.8	7,100	4.6	16.9	5,600	7.8	17.8
8	12	12	2,800	4.5	4.6	8,600	4.1	4.9	9,500	17.9	15.8
			2,900	1.9	2.1	8,600	1.2	1.7	9,300	8.1	2.1
			3,800	1.4	1.6	8,800	0.90	1.1	9,200	1.3	1.3
4	6	8	3,000	4.7	5.3	8,400	11.7	6.5	9,400	4.1	6.2
			3,100	2.9	3.5	9,000	1.7	2.6	9,200	3.3	2.7
			2,700	0.92	1.5	8,600	1.4	1.5	9,300	1.4	1.5
6	12	12	2,900	2.2	4.8	8,500	1.4	3.2	9,500	2.0	2.2
			2,900	1.5	3.4	8,500	3.1	2.8	9,500	4.4	2.5
			2,600	3.8	14.1	8,400	1.9	6.8	9,100	3.8	7.1
8	12	12	2,600	3.8	5.5	8,500	3.2	11.2	9,300	40.0	27.8
			2,900	3.8	14.1	8,400	3.2	11.2	9,300	40.0	27.8
			2,600	3.8	14.1	8,400	3.2	11.2	9,300	40.0	27.8

Plants/30-cm of Row
Date: August 6

Row Spacing

(25-cm)

Row Spacing

* T = Top, R = Row, M = Middle

TABLE 21
PERCENT OF RADIATION REACHING TO SOIL SURFACE DURING AUGUST 8 AND 11 AT DIFFERENT PLANTING PATTERN

Plants/30-cm of Row		Row Spacing (25-cm)							
		9:00 a.m.		12:00 a.m.		3:00 p.m.			
Date: August 8		T ^a	R ^a	T ^a	R ^a	T ^a	R ^a		
2	4	3,400	2.0	8,500	4.1	8,800	14.8	14.8	
4	6	3,400	1.3	8,400	1.4	9,200	1.4	1.5	
6	8	3,500	1.4	8,500	1.3	9,300	1.5	2.1	
4	6	3,600	3.3	8,500 (51-cm)	11.8	8,100	25.6	19.8	
6	8	3,800	1.4	8,500	8.2	8,900	7.3	6.7	
8		3,800	0.66	8,300	2.3	8,700	2.6	2.6	
6	12	3,400	1.5	8,200 (76-cm)	13.4	9,500	1.5	3.0	
12		3,400	1.2	8,200	10.3	9,400	2.4	2.8	
8	12	3,700	1.6	8,300 (102-cm)	1.7	8,800	6.3	6.3	
12		3,400	2.9	8,800	4.6	7,700	25.3	15.6	
Plants/30-cm of Row									
Date: August 11									
2	4	2,900	3.8	8,400 (25-cm)	5.9	8,000	10.5	10.0	
4	6	3,000	1.5	8,200	2.4	7,500	2.0	2.4	
6	8	3,000	1.3	8,200	2.2	7,100	3.4	3.3	
4	6	2,900	4.8	8,200 (51-cm)	6.7	8,100	11.4	11.7	
6	8	3,400	2.1	8,300	3.1	6,500	4.3	5.1	
8		2,700	1.6	8,100	2.6	7,300	4.0	4.3	
6	12	3,000	4.0	8,200 (76-cm)	2.3	7,500	2.3	3.0	
12		2,800	2.0	7,800	2.9	8,300	5.0	6.7	
8	12	3,100	4.5	8,200 (102-cm)	2.7	6,200	8.0	16.1	
12		2,900	4.8	8,200	5.7	7,600	17.1	30.2	

^aT = Top, ^aR = Row, ^aM = Middle

TABLE 22
PERCENT OF RADIATION REACHING TO SOIL SURFACE DURING SEPTEMBER 3 AND 6 AT DIFFERENT PLANTING PATTERN

Plants/30-cm of Row	Row Spacing (25-cm)											
	9:00 a.m.				12:00 a.m.				3:00 p.m.			
	T*	R*	M*		T*	R*	M*		T*	R*	M*	
Date: September 3												
2	3,300	4.8	4.5		8,400	5.7	4.0		8,500	3.5	4.7	
4	3,700	2.6	2.6		8,400	2.1	2.4		8,550	1.9	1.9	
6	3,700	1.2	1.2		8,400	1.9	1.7		8,600	1.0	1.1	
Date: September 6												
4	3,500	6.3	6.4		8,500 (51-cm)	8.6	7.2		8,400	5.0	13.1	
6	3,800	3.9	4.7		8,100	2.6	4.0		8,500	2.7	2.7	
8	3,200	3.8	3.6		8,400	4.6	4.1		8,400	2.4	3.6	
Date: September 6												
6	3,700	2.8	2.7		8,400 (76-cm)	2.4	7.5		8,800	10.4	3.9	
12	3,500	5.1	6.0		8,400	2.6	3.8		8,600	16.0	4.0	
Date: September 6												
8	3,500	5.1	10.3		8,300 (102-cm)	5.0	13.0		8,500	7.0	5.8	
12	3,400	6.2	9.7		8,200	4.5	10.6		8,700	38.0	13.7	
Plants/30-cm of Row												
Date: September 6												
2	1,300	5.2	5.1		6,200 (25-cm)	5.8	6.0		8,400	3.6	3.8	
4	1,500	2.1	2.5		5,700	5.0	5.2		8,600	2.1	2.3	
6	1,400	1.3	1.6		7,300	1.9	2.7		8,700	1.1	1.4	
Row Spacing												
4	1,400	6.8	7.2		7,500 (51-cm)	8.0	8.3		8,500	5.2	5.3	
6	1,600	3.9	3.2		6,500	6.1	6.9		8,600	5.8	4.3	
8	1,700	3.5	4.4		6,300	4.3	7.1		8,500	2.1	3.1	
Date: September 6												
6	1,450	3.6	3.9		5,500 (76-cm)	8.7	10.1		9,000	3.9	7.8	
12	1,500	5.6	6.9		6,200	7.7	8.7		9,200	4.7	4.2	
Date: September 6												
8	1,650	6.1	15.7		6,300 (102-cm)	12.1	23.1		8,200	6.2	8.6	
12	1,550	9.2	13.5		6,750	16.5	7.3		8,700	14.0	12.6	

* T = Top, R = Row, M = Middle

TABLE 23
PERCENT OF RADIATION REACHING TO SOIL SURFACE DURING SEPTEMBER 8 AND 19 AT DIFFERENT PLANTING PATTERN

Plants/30-cm of Row		Row Spacing (25-cm)											
		9:00 A.M.				12:00 A.M.				3:00 P.M.			
		T*	R*	M*		T*	R*	M*		T*	R*	M*	
Date: September 8													
2	4	3,400	3.3	3.2		4,900	7.5	7.6		4,700	6.4	6.8	
4	6	3,600	2.6	2.4		5,100	5.5	5.7		5,400	3.3	3.3	
6		3,600	1.5	1.3		5,200	2.7	2.7		4,700	2.0	2.1	
Date: September 19													
4	6	3,500	5.7	6.6		5,000	10.0	14.0		5,000	10.0	9.4	
6	8	3,800	3.9	4.5		5,000	7.4	7.4		4,600	6.3	7.2	
8		3,800	5.1	9.4		5,900	5.1	9.5		6,500	6.6	5.7	
Row Spacing (51-cm)													
6	12	3,400	4.6	4.7		5,300	7.6	8.9		5,600	8.0	8.9	
12		3,400	3.8	4.7		5,400	8.7	9.6		5,300	9.4	9.0	
Row Spacing (76-cm)													
8	12	3,400	4.1	11.1		5,200	11.5	30.1		7,250	24.8	13.8	
12		3,300	8.3	12.1		5,800	10.0	31.0		6,000	10.6	11.7	
Row Spacing (102-cm)													
Plants/30-cm of Row													
Date: September 19													
2	4	2,000	12.0	15.0		7,000	29.7	22.8		3,800	17.4	18.1	
4	6	2,000	7.5	7.3		7,100	10.3	10.4		3,800	10.3	10.8	
6		2,000	6.1	5.1		7,300	5.7	7.9		3,850	5.4	6.0	
Row Spacing (25-cm)													
4	6	2,400	15.1	22.0		6,500	18.6	24.0		3,800	22.9	23.2	
6	8	2,600	9.8	9.6		7,700	11.7	18.2		4,000	16.1	16.5	
8		2,200	6.4	6.6		4,700	13.0	14.9		4,000	10.2	13.3	
Row Spacing (51-cm)													
6	12	2,400	9.6	12.5		6,600	28.8	30.3		3,800	18.9	18.4	
12		2,400	10.4	14.2		7,250	26.2	44.1		3,800	20.6	23.2	
Row Spacing (76-cm)													
8	12	2,300	12.5	16.4		4,700	15.7	57.4		3,800	18.7	42.0	
12		2,300	16.9	28.7		6,500	22.3	58.5		3,900	31.3	48.7	
Row Spacing (102-cm)													

* T = Top, R = Row, M = Middle

APPENDIX C

TABLE 24

SOIL TEMPERATURE (C) AT 2.5-CM AS INFLUENCED BY 8 PLANTS PER 30-CM OF THE ROW
FOR 25 AND 76 CM ROW SPACING DURING JULY 14, 16, AND 30

75

Time	25-cm Row		76-cm Row		Air Temperature
	M*	R**	M*	R**	
Date: July 14, 1980					
8:00 a.m.	25.0	25.0	25.5	25.5	28.5
10:00 a.m.	26.0	26.0	27.0	26.5	33.0
12:00 noon	28.0	27.8	29.4	28.0	36.0
2:00 p.m.	29.0	29.0	35.5	29.0	37.5
4:00 p.m.	29.5	29.5	32.0	29.0	37.5
Date: July 16, 1980					
8:00 a.m.	25.0	25.0	25.0	26.0	27.0
10:00 a.m.	27.0	26.7	27.3	27.0	35.0
12:00 noon	29.0	28.5	29.0	28.0	37.5
2:00 p.m.	31.0	30.5	39.0	29.3	42.0
4:00 p.m.	28.6	28.4	34.0	30.0	42.0
Date: July 30, 1980					
8:00 a.m.	22.0	22.0	22.4	22.5	26.0
10:00 a.m.	23.0	23.0	23.5	24.0	30.5
12:00 noon	24.8	24.8	27.0	28.0	36.0
2:00 p.m.	26.0	26.0	29.5	28.0	39.5
4:00 p.m.	27.0	27.5	28.5	28.0	37.0

*Temperature in middle of the row; **Temperature in the row.

TABLE 25

SOIL TEMPERATURE (C) AT 2.5-CM AS INFLUENCED BY 8 PLANTS PER 30-CM OF THE ROW
FOR 25 and 76 CM ROW SPACING DURING AUGUST 4, 6, AND 8

Time.	25-cm Row		76-cm Row		Air Temperature
	M*	R**	M*	R**	
Date: August 4, 1980					
8:00 a.m.	23.5	23.5	23.5	23.5	24.5
10:00 a.m.	24.0	24.0	25.0	24.8	32.5
12:00 noon	25.0	25.0	25.5	25.5	33.0
2:00 p.m.	26.0	26.0	27.2	26.5	38.0
4:00 p.m.	26.0	26.0	27.0	27.0	36.0
Date: August 6, 1980					
8:00 a.m.	23.5	23.5	23.5	23.7	28.5
10:00 a.m.	24.0	24.0	24.5	24.3	32.0
12:00 noon	25.0	25.0	26.0	25.8	37.5
2:00 p.m.	26.0	26.0	27.8	27.0	38.0
4:00 p.m.	26.8	26.5	28.0	27.5	40.5
Date: August 8, 1980					
8:00 a.m.	23.0	23.0	23.0	23.0	27.0
10:00 a.m.	24.0	24.0	25.0	24.5	37.5
12:00 noon	25.8	26.0	26.5	26.0	40.0
2:00 p.m.	26.5	26.5	28.0	27.0	41.5
4:00 p.m.	27.0	26.5	28.0	27.5	41.0

*Temperature in middle of the row; **Temperature in the row.

TABLE 26

SOIL TEMPERATURE (C) AT 2.5-CM AS INFLUENCED BY 8 PLANTS PER 30-CM OF THE ROW
FOR 25 AND 76 CM ROW SPACING DURING AUGUST 11, 13, AND 15

Time	25-cm Row		76-cm Row		Air Temperature
	M*	R**	M*	R**	
Date: August 11, 1980					
8:00 a.m.	24.3	24.3	24.5	24.5	27.5
10:00 a.m.	24.8	25.0	25.0	25.0	30.0
12:00 noon	26.0	26.0	27.0	26.5	36.0
2:00 p.m.	27.0	27.0	28.5	27.8	37.5
4:00 p.m.	27.0	27.0	26.7	26.4	34.0
Date: August 13, 1980					
8:00 a.m.	22.5	23.0	22.8	23.0	21.0
10:00 a.m.	23.5	23.5	24.0	23.8	29.0
12:00 noon	25.0	25.0	26.0	25.2	34.0
2:00 p.m.	26.0	26.0	27.0	26.8	34.0
4:00 p.m.	26.2	26.2	27.2	27.0	35.0
Date: August 15, 1980					
8:00 a.m.	24.0	24.0	24.0	24.0	24.0
10:00 a.m.	24.0	24.0	24.5	24.5	30.0
12:00 noon	25.5	25.3	27.0	25.7	35.0
2:00 p.m.	26.2	26.3	27.0	27.0	36.0
4:00 p.m.	26.5	26.5	27.0	27.0	37.5

*Temperature in middle of the row; **Temperature in the row.

TABLE 27

SOIL TEMPERATURE (C) AT 2.5-CM AS INFLUENCED BY 8 PLANTS PER 30-CM OF THE ROW
FOR 25 AND 76 CM ROW SPACING DURING AUGUST 20, 25, AND SEPTEMBER 3

Time	25-cm Row		76-cm Row		Air Temperature
	M*	R**	M*	R**	
Date: August 20, 1980					
8:00 a.m.	24.2	24.2	24.3	24.3	23.5
10:00 a.m.	24.8	24.8	25.0	24.8	27.0
12:00 noon	25.5	25.5	26.5	25.5	35.0
2:00 p.m.	26.5	26.5	26.8	27.0	39.5
4:00 p.m.	26.8	27.0	28.0	27.3	39.0
Date: August 25, 1980					
8:00 a.m.	22.0	22.0	22.0	22.0	23.0
10:00 a.m.	22.5	22.5	23.0	23.0	29.5
12:00 noon	24.0	24.0	25.0	24.5	35.0
2:00 p.m.	24.5	24.5	25.5	25.0	36.0
4:00 p.m.	25.0	25.0	26.0	25.5	36.5
Date: September 3, 1980					
8:00 a.m.	22.8	22.8	22.8	22.8	24.5
10:00 a.m.	23.5	23.5	24.0	23.8	29.0
12:00 noon	25.0	24.8	25.5	25.0	31.0
2:00 p.m.	25.8	25.5	26.5	26.0	37.0
4:00 p.m.	26.0	25.8	27.0	26.0	35.5

*Temperature in middle of the row; **Temperature in the row.

TABLE 28

SOIL TEMPERATURE (C) AT 2.5-CM AS INFLUENCED BY 8 PLANTS PER 30-CM OF THE ROW
FOR 25 AND 76 CM ROW SPACING DURING SEPTEMBER 6, 8, AND 15

Time	25-cm Row		76-cm Row		Air Temperature
	M*	R**	M*	R**	
Date: September 6, 1980					
8:00 a.m.	23.5	23.5	23.5	23.5	24.5
10:00 a.m.	23.8	23.8	24.0	23.8	29.0
12:00 noon	24.3	24.2	25.0	24.5	31.0
2:00 p.m.	25.0	25.0	26.0	25.2	37.0
4:00 p.m.	25.8	25.6	26.0	26.2	35.5
Date: September 8, 1980					
8:00 a.m.	21.5	21.5	22.0	22.0	26.0
10:00 a.m.	22.5	22.5	23.0	22.8	28.0
12:00 noon	23.0	23.0	24.0	23.0	32.5
2:00 p.m.	24.0	24.0	25.0	24.0	33.0
4:00 p.m.	24.0	24.0	25.0	24.5	36.0
Date: September 15, 1980					
8:00 a.m.	21.0	21.0	21.0	21.0	25.0
10:00 a.m.	21.8	22.0	22.0	22.0	30.0
12:00 noon	23.0	23.0	23.5	23.0	31.5
2:00 p.m.	24.0	24.0	25.0	24.5	32.5
4:00 p.m.	24.0	23.5	25.0	24.5	32.5

*Temperature in middle of the row; **Temperature in the row.

TABLE 29

SOIL TEMPERATURE (C) AT 2.5-CM AS INFLUENCED BY 8 PLANTS PER 30-CM OF THE ROW
FOR 25 AND 76 CM ROW SPACING DURING SEPTEMBER 19

Time	25-cm Row		76-cm Row		Air Temperature
	M*	R**	M*	R**	
.					Date: September 19, 1980
8:00 a.m.	20.0	20.0	20.0	20.0	19.0
10:00 a.m.	21.0	21.0	21.0	21.0	27.0
12:00 noon	22.0	22.0	23.0	22.5	32.5
2:00 p.m.	23.0	23.0	23.5	23.0	29.5
4:00 p.m.	23.0	23.0	23.5	23.0	30.0

*Temperature in middle of the row; **Temperature in the row.

VITA

Hamid Shahandeh was born in Bodjnurd, a city east of the Caspian Sea in the northern part of Iran on January 3, 1952. He attended elementary school at Farrokhei School, Bodjnurd, and high school at Amir Kabir. He received a mathematical diploma from Danosh-Honar in Mash-had in 1970.

In 1971 he entered the University of Shiraz where he obtained a Bachelor of Science degree in Soil Science in June 1975. From 1975 to 1977 he was in the military service. In the spring quarter of 1978, he entered The University of Tennessee, Knoxville, and began his graduate study in Plant and Soil Science in the spring of 1979. He received the Master of Science degree with a major in Plant and Soil Science in March 1981.