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Growth and microclimate of "Essex" soybeans as affected by rowspacing

Paul Brewer Francis

To the Graduate Council:

I am submitting herewith a dissertation written by Paul Brewer Francis entitled "Growth and microclimate of "Essex" soybeans as affected by rowspacing." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Plant, Soil and Environmental Sciences.

W. L. Parks, Major Professor

We have read this dissertation and recommend its acceptance:

Otto Schwarz, John Reynolds, Russel Lewis

Accepted for the Council:

Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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GROWTH AND MICROCLIMATE OF "ESSEX" SOYBEANS AS AFFECTED BY ROWSPACING

A Dissertation

Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

Paul B. Francis

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ABSTRACT

"Essex" variety of soybeans, [Glycine max, L. (Merr.)], were planted on Sequatchie loam, (fine-loamy, siliceous, thermic Humic Hapludult), in rowspacings of 25-, 38-, and 51-cm with or without a wheatstraw mulch in 1983, and 13-, 25-, 38-, 51-, and 76-cm with no mulch treatment in 1984 with irrigation being used both years. Microclimate, plant growth, and water use data were collected throughout the growing season.

Canopy CO_2 concentrations, ([CO_2]), in the upper half of canopy were around 320 $\mu L \cdot L^{-1}$ at midday as compared to 340 $\mu L \cdot L^{-1}$ at a reference height, six meters above ground. At night, the [CO_2] exceeded 500 $\mu L \cdot L^{-1}$. Lower [CO_2] were observed in the narrow rows (13 and 25cm) at midday and higher levels were present for short periods after dusk. This was thought to be due to leaf density, which was higher in the upper strata of the narrower rows. In the narrower rows, no horizontal deviations in [CO_2] were observed. The [CO_2] was 5 to 15 $\mu L \cdot L^{-1}$ lower between the row middles at midday than over the row of the 76cm treatment. Mulching had no effect on the [CO_2]. Soil CO_2 emissions among treatments were similar and averaged around 144 $kg \cdot ha^{-1} \cdot day^{-1}$.

Soil temperatures across treatments were similar except during midday, (1500 to 1900 hour), where it was in excess of 32C in the row middle of the widest rowspacing. After mid-pod fill growth, rowspacing effects on soil temperatures were absent. Mulching cooled the top 5cm of soil two to five degrees at midday up to the pod-filling stage of growth, thereafter no differences were observed.

Apparent evapotranspiration was significantly lower in the narrowest rowspacings at canopy closure. Prior to and after, there were no treatment effects. Values ranged from 0.50 to 0.70cm $H_2O \cdot day^{-1}$.

Rowspacing had no effect on average seed weights or seeds per pod. Total seed production per plant increased with rowspacing. Net assimilation rate and relative growth rate decreased proportionally with rowspacing and the leaf area ratio was constant across treatments. After early pod fill, the leaf area index across treatments was similar.

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CHAPTER I

INTRODUCTION

The soybean has become a very popular and profitable seed crop for American farmers. Worldwide demand for soybeans has increased dramatically and has sparked interest on behalf of researchers to discover the intricate workings of the soybean plant so that this knowledge might be used to increase productivity. Many new varieties have been developed and work continues to discover new ones that will yield higher and be more resistant to insects and diseases. Chemical companies have developed various pesticides that reduce crop stress and increase yields. Development of new, more effective, and environmentally safe pesticides continues. New soil and crop management systems, such as no-till, carry hope of reducing soil erosion losses and production costs, while at the same time maintaining high yields.

One management technique that is gaining in popularity is to reduce row widths. Most soybeans in the past were grown in wide row-spacings, (defined here as greater than 76cm). Emphasis is now being made on narrowing rowspacings because in most instances, the result is higher yields. Studies have been conducted to discover the reasons why narrower rows induce higher yields. Narrow rows allow for more efficient use of solar radiation, reduce competition from most weeds due to shading, and show varietal differences in yield response. Rowspacing effects on water use have generally been shown not to differ by any great magnitude, but some results are conflicting. Additionally, there has not been enough research done to explain the CO_2 and light interactions within the plant canopies in terms of seed yield and variety response. With the rapid rise of CO_2 in the atmosphere there is interest in this area. Studies have been performed on light and CO_2 interactions in greenhouse or field chambers but data is lacking from undisturbed field environments, primarily because of the need for quick responding, inexpensive, and accurate instruments. Knowing how the microclimate and growth response of soybeans is affected by rowspacing is essential for guiding plant breeders and producers to higher yields in this new era of crop management.

Field microclimate data encompassing the growing seasons of 1982-1984 are reported here. The 1982 season was spent getting acquainted with the available instrumentation and collecting some preliminary data. This information was helpful in designing systems for extensive studies in the 1983 and 1984 growing seasons.

The objectives were to:

1. observe what effects rowspacing has on canopy microclimate, particularly the CO_2 concentration;

2. study the water use by the different rowspacings and relate this to canopy growth, soil temperature, stage of growth, and climate;

3. observe how rowspacing alters the podding and seed distribution; and

4. relate observed crop yields to any or all of the above.

The 1983 season study included three rowspacing treatments of 25-, 38-, and 51-cm, with and without a wheatstraw mulch, and the 1984 season encompassed rowspacings of 13-, 25-, 38-, 51-, and 76-cm and no mulch treatment.

CHAPTER II

LITERATURE REVIEW

1. THE SOYBEAN

Soybeans, (Glycine max. L. (Merrill)), originating from eastern Asia, were introduced into the United States around 1800 (80) and initially used primarily as a hay crop. Around 1900, the world-wide popularity of soybeans increased dramatically as other by-products were developed for use, among them vegetable oil and animal feed. Today, the soybean is the leading world source of vegetable oil for human consumption, protein for animal feed, and has recently been in demand for use as soy-protein for human consumption.

The United States leads the world in soybean production, harvesting 48,772,000 metric tons, or 60 percent of the world total in 1981-82, (138). The midwest was the largest producing area of the United States in 1982 followed by the south, harvesting 58 percent and 40 percent of the total respectively. Tennessee alone accounted for roughly 3 percent of the total soybean harvest of the United States. Through the years of 1979-81, the states producing consistently higher yields were Iowa, Indiana, and Illinois, with average yields ranging from 2240 to 2500 kg/ha. Tennessee farmers averaged around 1560 kg/ha for the years 1979-81.

Classification

The soybean is a member of the family Leguminosae and subfamily Papilionoideae. The genus is agreed to be Glycine but due to genetic diversity, confusion among taxonomists has resulted in the assigning of three subgenera; Glycine Willd.; Bracteata Verdc.; and Soja (Moench), F. J. Herm, (140). The most economically important species, Glycine max, L. (Merr), is a member of the subgenus Soja.

Water Use

By far, the most important factor related to high yields in soybeans is water availability. Water is essential for germination, growth, nutrient uptake, nodulation and nitrogen assimilation, and seed development. In terms of yield, water limitations impose the greatest reductions when present during the pod set and pod fill growth stages, (121).

The unsaturated conductivity of the soil was thought to be the dominant factor influencing water movement in the soil-plant system (31, 44). Hillel, (pp. 94-113 of 58), discusses in detail the movement of water in soil. However, the movement of water through the soil-plant system is now thought to be more of a function of the plant, (64,94,151).

Resistance to water flow occurs in the soybean plant through the root, xylem, and leaf and has been shown to increase with plant age, (64,66). The resistance of water flow out of the leaf has been found to be the major factor associated with plant water use, (129, 134). The dynamics of soybean water use has been studied by measuring plant transpiration, (64,105,108), evapotranspiration, (20,110,134), and leaf properties such as leaf water potential, stomatal conductance, and temperature, (15,41,65,127). High yielding soybeans are associated with lower water deficits at midday, particularly during pod-fill (15,81,99,109). Characteristics of soybean varieties exhibiting lower water deficits at midday include dense leaf pubescence (5,43), lower stomatal diffusive resistance, (5,53,126), increased root densities for more efficient water uptake, (15,43), and the elevation of their leaves to erect positions, which exposes the more reflective abaxial leaf surface, (68,83,142).

Photosynthesis and Photorespiration

Assimilation of carbon from carbon dioxide by the soybean plant has been found to be a complex process involving the interaction and coupling of several photo- and biochemical processes. Soybeans have been shown to assimilate CO_2 via the C3 or Calvin cycle, (27). Akazawa, (2), has described in detail the photo- and biochemical reactions of the Calvin cycle. Basically, CO_2 reacts with ribulose-1,5-diphosphate, (RuDP), in the presence of light, Mg^{+2}, and the most abundant plant enzyme, RuDP-carboxylase, forming two molecules of the three carbon compound, 3-phosphoglyceric acid, (hence the denotion C3 pathway). The Calvin cycle continues, regenerating RuDP and forming various carbon compounds used for the synthesis of sucrose, starch, celluose, pectins, and other polysaccharides.

Probably the most important factor in terms of plant production efficiency was the discovery of the light induced loss of carbon through a process known as photorespiration. A detailed description on the reactions involved in photorespiration can be found in an article by Tolbert, (137). The enzyme found responsible for photorespiration was RuDP-oxygenase, a component of RuDP-carboxylase, (14). Early studies with soybeans discovered inhibition in apparent photosynthesis by oxygen due in part to photorespiration, (42). Ogren, (96), stated that for soybeans, the ratio of O_2 to CO_2 fixed at standard atmospheric conditions, (300 ppm CO_2, 21 percent O_2, and 25C), was about 1:4 and the CO_2 compensation point, (CO_2 concentration at which photosynthesis equals photorespiration), was around 40 ppm.

Due to the nature of the RuDP-carboxylase/oxygenase enzyme and its naturally high content in plants, photorespiration is inevitable, (76). Therefore, research with soybeans has been primarily on the interactions of light and CO_2 concentrations on photosynthetic production. A classic study by Brun and Cooper, (22), looked at the photosynthetic response of soybeans at various CO_2 concentrations and light intensities. At light intensities above 5380 lux, the photosynthetic rates were limited by the CO_2 concentration. Their findings were supported by the work of Egli et al., (39), and Sionit et al., (125), who also noted a decrease in transpiration with increased CO_2. The effects of increased CO_2 of soybean leaf and canopy apparent photosynthetic rates has been found to vary among cultivars, (22,39,51,61,144). These differences are thought to be due to leaf orientation, (11,61), the age of plant, (8), sink demand, (23,135), or the ability to supply CO_2 to the chloroplast, (39,139), which has been related to leaf pubescence, (5).

The effect of increased CO_2 concentrations on increasing canopy photosynthesis would naturally lead one to think that a subsequent seed yield increase would follow. Research in this area is conflicting. In several studies, little correlation was found between leaf or canopy apparent photosynthesis and crop yield, (9,34,36), while others have discovered some relationship, (32,51,144). However, the data collected for most of these studies compared just a few cultivars and the techniques involved measuring photosynthesis during very short time intervals for a single leaf or an area of the canopy in the field using a chamber, which involved mixing the air and disturbing naturally developed profiles. Pallas, (98), warned that diurnal trends in photosynthesis and transpiration were present in soybeans and that short-term photosynthetic measurements may not account for these changes. Net assimilation rate, an indication of long-term plant photosynthetic product accumulation, (55), was measured among several cultivars in one study and found to have little relationship with final seed yield, (25).

Soybean seed yields are significantly increased when plants are grown in CO_2 enriched environments, (30,54). Researchers have stressed the importance of favorable photosynthetic conditions during the pod fill growth period for higher seed yields, (39,51,79). Hardman and Brun, (48), studied the effect of an enriched CO_2 environment of 1200 ppm during vegetative, flowering, and pod-filling stages and noticed significant seed yield enhancements in the pod-filling treatment only. They attributed this to a slight increase in pod number and a marked increase in pod weight and seed yield. In a similar study, Ackerson et al., (1), found that seed yield increased 27 percent for soybeans grown in enriched CO_2 environments from early pod development to maturity as compared to a control and attributed this to increased pods per plant rather than greater seed size. These discrepancies may be due to the leaf:pod ratio of the plants studied. Peet, (102), found significantly greater total and pod weights for plants having 5:1 pod/leaf ratios when grown in a CO_2 enriched environment, but did not see the increase for plants having 15:1 pod/leaf ratios. She suggested that the increased pod/leaf ratio shifts the plant more to being source limited, since the rates of photosynthesis per unit area leaf were found to be the same in their study.

Diurnal trends and seasonal shifts in the photosynthetic capability of soybeans are evident, (12,67,92,139). Soybean leaves assimilating CO_2 in optimum photosynthesis environments accumulate starch, (92), which has been seen to cause a reduction in the net photosynthetic rate, (92,139). The increase in soluble carbohydrate level in the chloroplast is thought to reduce net photosynthesis by increasing the diffusion pathways, (21,135). Seasonally, the net canopy carbon exchange rate was seen to be highest during late reproductive growth, (67).

Assimilate demand also creates shifts in net photosynthesis, (135). Using radioactive carbon-14 as a tracer, Latimore et al., (72), noticed a virtual halt of assimilated ^{14}C from the leaves to the root nodules and subsequent translocation to the pods at the onset of pod-fill. Photosynthetic rate has been seen to increase with an increase in sink demand brought about by shading leaves, (decreasing source), (135), or decrease with a decrease in sink demand, accomplished by pod removal, (23,45,88). The clear relationship between photosynthetic activity and the pod-filling process is hypothesized as due to either a nutrient concentration gradient, (23,88), or the filling pod acting as a sink for abscisic acid, (23), a plant hormone produced in stressed leaves which has been shown to cause stomatal closure and thus, a reduction in photosynthesis, (84).

Canopy Microclimate

Microclimate investigations have been initiated on several field crops to study the transfer of energy and mass within the canopy, (7,18,33,46,50,149). The information obtained is helpful in the understanding of crop efficiency and can be used to plan profitable soil and crop management systems, (89). Most of the research has been focused on measuring the CO_2 flux above a crop canopy because of its high relationship to crop growth and yield.

All these techniques rely on the principle that the flux of CO_2 above a field crop can be estimated from measuring the vertical gradient of CO_2 and calculating an eddy transfer coefficient, obtained from measurements of momentum, sensible heat, or water vapor, (95). Mathematically, this has been expressed in an equation analogous to that used for molecular diffusion, (89):

$$F_c = -\rho_c K \frac{\alpha c}{\alpha z}$$

where F_c is the flux of CO_2, ρ_c the density of CO_2, K the turbulent transfer coefficient, and $\frac{\alpha c}{\alpha z}$ the concentration gradient. The turbulent transfer coefficient has been assumed to be similar to the turbulent transfer diffusion coefficient for momentum, heat, and mass. Using this assumption, Brown and Covey, (18), found an exponential decay of K with depth in a corn canopy.

The flux of CO_2 has been estimated by measuring the gradient of CO_2 along with the flux and gradient of some other known quantity such as wind, sensible heat, or water vapor. These methods rely on the assumption that carbon dioxide, sensible heat, and water vapor are carried by similar turbulent transfer eddies, (113). These techniques have gained in popularity among researchers and are usually in conjunction with evapotranspiration and/or transpiration studies, (17,69,95,118).

Aerodynamic methods have been employed in the estimation of CO_2 flux above a crop canopy. Using a logarithmic law of wind movement, (78), estimates of the eddy diffusion for momentum have been determined from vertical wind speed data. Assuming that shearing stress is constant with height and that the turbulent transfer diffusion coefficients for CO_2 and momentum behave similarly, the turbulent carbon dioxide exchange was determined in a corn field by Lemon, (74), and Wright and Lemon, (149); a barley field by Biscoe, (10); and an oat field by Verma and Rosenberg, (141).

Micrometeorlogical investigations used to monitor fluxes of CO_2, water, and energy through a crop require an extensive amount of accurate and expensive equipment, (106,114). Errors in calculation may arise from lack of sufficient measurements, (150), incomplete accountability for CO_2 respired from the soil and plant, (60,89), lack of recognition for horizontal divergences, (149), or sudden changes in environmental conditions, such as wind or temperature, which may not be accounted for by the model, (143). In the future, the direct measurement of CO_2 fluxes in the canopy by eddy correlation techniques may be feasible with development of new CO_2 and wind velocity sensors that have accurate and rapid response, and are affordable, (95).

2. SHIFTS TO NARROWER ROWSPACING

Researchers began to notice higher seed yields from narrower row widths as early as 1939, (146). The advantages obtained from narrower rows have been stated as due to a more efficient interception of solar radiation, reduction of soil-water evaporation loss, more uniform root density, protection of soil from raindrop impact, and more efficient harvesting due to higher fruiting, (100). Disadvantages may be the difficulty of controlling problem weeds and increased lodging, (100).

Solar Radiation Interception

Probably the greatest advantage of reduced rowspacing comes from a more efficient arrangement of the canopy for the interception of photosynthetically active radiation. The interception of light downward through the canopy is exponential, (115), and it has been clearly shown that to a certain point the relative amount of percent solar radiation interception and dry matter production increases with leaf area index, LAI, (16,24,61,122,145). Shibles and Weber, (122), found that soybeans have a critical LAI where the maximum amount of dry matter is produced. They proposed that the rate of dry matter production at this critical LAI levels off rather than decreases. Jeffers and Shibles, (61), continued their studies and noted that the critical LAI was proportional to the amount of solar radiation, other factors being equal.

It has been found that the apparent canopy photosynthesis reaches a maximum in the early reproductive stages and then declines, (115, 144). Narrowing rowspacing helps develop a higher LAI during reproductive growth, (57), thus enabling the crop to take full advantage of intercepting solar radiation at this critical stage when nearly all of the photosynthate is translocated to the seed, (56,63). Wiegand and Richards, (145), stated that high yields are not possible unless canopies develop fully enough to intercept nearly all the photosynthetically active radiation during the reproductive stage. Studies have shown that around 90 percent of the intercepted solar radiation and most of the photosynthate produced occur in the upper 20 percent of the canopy, (53,115). Rowspacing arrangement in terms of maximizing leaf area and solar radiation interception by the onset of the reproductive period is especially important for determinate varieties, where the cessation of vegetative growth occurs earlier than in indeterminate varieties, thus enabling more photosynthates to go for seed development, (123).

Growth Response

Overall, it has been shown that increasing plant population by decreasing rowspacing reduces the total number of seeds per plant, (57,59,62,73,101). However, the response of soybean yield components to narrow rospacing differs among varieties, (47,82,101,147). Some cultivars have shown the tendancy for lower weight/seed in narrower rows, (73,120,147), while other varieties show no rowspacing effects, (62,73,147). No common trait, (i.e., lodging, branching patterns, reproductive types, leaf shape, etc.), among the varieties showing no rowspacing influence on average weight/seed was obvious in the literature.

Increasing plant populations in narrower rows amplifies competition for light resulting in higher plant heights and lodging, (59,120,147). Lodging can reduce seed yields up to 20 percent or more, (28). Varieties differ in their lodging characteristics when grown in narrower rows, (59,101,121). The high statured varieties grown in wider rowspacings have a tendency to develop more nodes with longer internode lengths and thinner, much longer stems in comparison to shorter statured varieties, (59). There is a tendency for soybeans showing indeterminate growth to lodge, (47,52). In the midwest, crossing northern U.S. indeterminate varieties with southern U.S. determinates to obtain semi-determinate soybeans, which emphasize short stature and high yields, has been undertaken by Cooper, (29), as one attempt to increase production.

Water Use

The results of research on soybean water-use in narrow rows are conflicting. Data by Timmons et al., (136), was taken on evapotranspiration rates at various rowspacings and plant populations over a two-year period in western Minnesota and revealed no significant differences among treatments. Doss and Thurlow, (35), discovered that water use by soybeans was influenced more by soil water regime than by row width or variety and Reicosky et al., (110), found similar relationships between leaf water potentials and evapotranspiration among rowspacing treatments.

The soybean root systems are concentrated primarily in the upper 30cm of soil, (43,87), and appear not to be affected as much by changes in intrarow plant density, (93,110). Concerning interrow density, Reicosky et al., (110), and Bohm, (13), found higher root densities in the upper layer for narrow rows in some years due in part to a more uniform distribution across rows, the wider rows having lower root densities in the row middles, which is probably due to the growth reaction to higher temperatures encountered there before canopy closure, (131). It has been found that over one-fourth to one-half of the moisture loss from soybean plots occurs as evaporation from the soil surface, (105). Therefore, significant differences in water-use between rowspacing treatments has been seen only during times when the narrower rows had reached canopy closure prior to other treatments. Reicosky et al., (110), for instance, saw higher evapotranspiration rates in 25cm rows after canopy closure, but found no significant rowspacing differences at any other time. The increase in water use was attributed to an increase in plant transpiration rate.

Microclimate

Research on the soybean microclimate as affected by rowspacing is limited. Livingston, (75), observed the effect of skip-row planting patterns of York soybeans on a Sequatchie loam at Knoxville, TN. He found 90 percent of the incoming light, (measured with a photometer), absorbed in the upper 30cm of canopy and that isothermal layers followed the contour of the canopy surfaces. CO_2 measurements from vertical and horizontal locations in the canopies revealed distinct isolayers where shapes were affected by canopy arrangements, light, and wind. Singh et al., (124), looked at net and spectral radiation of two varieties, (Harosoy and Wayne), in rowspacings of 102-, 76-, and 51-cm after canopy closure. The transmission of solar radiation through the canopy in the spectral range, (380-780 mu), did not vary among rowspacings, within any one variety, but a greater transmission through the canopy occurred in the Harosoy-63, which had narrower leaves and a lower LAI. The differences in canopy light distribution among varieties may account for some of the cultivar variations in canopy apparent photosynthesis observed by Wells et al., (144), who measured only light interception, not distribution.

Sojka and Parsons, (128), studied the canopy microclimate in terms of water status as affected by rowspacing. The relationship between leaf and air temperature, and the xylem pressure potential was similar among rowspacings. However, the slope of atmospheric vapor pressure deficit and change in air temperature was altered at canopy closures due to the reduction in heat reflected off the exposed soil. Other microclimate data shows that canopy closures reduce wind eddy diffusivity, (3,104). This causes less movement of air within the canopy which would tend to promote a higher humidity. A search through the literature revealed little work on the interactions of cultivar and rowspacing effects on canopy microclimate.

CHAPTER III

THE 1983 STUDY

1. MATERIALS AND METHODS

Field Design

"Essex" variety soybeans were planted 10 May 1983 on a Sequatchie loam, a fine-loamy, siliceous, thermic, Humic Hapludult, in rowspacings of 25-, 38-, and 51-cm adjacent to an air conditioned shed used to house instruments needed in different moisture and climatic measurements. A diagram of the field layout is shown in Figure 1. Soil preparation consisted of fall moldboard plowing, double disking, and rolling. Phosphorus and potassium fertilizers were broadcast in April prior to disking according to soil test results. Treflan, (trifluralin), was applied prior to final disking at a rate of 1.09 kg ai$\cdot$ha^{-1}. On 21 June a mixture of 0.55 kg ai$\cdot$ha^{-1} Basagran (bentazon) and 0.27 kg ai$\cdot$ha^{-1} Blazer (sodium salt of acifluorfen) herbicides were applied with a hand-held spray boom for control of weed infestations. A population count was made on 22 June when the plants were at V4 growth, (for growth terminology refer to Table 1), by counting the number of plants per meter row at 10 random locations within each rowspacing treatment. Final populations were 478,000, 319,000, and 282,000 plants$\cdot$ha^{-1} for the 25-, 38-, and 51-cm rowspacings respectively. A wheatstraw mulch was applied at a rate of 4,500 kg$\cdot$ha^{-1} on 23 June to half of the north and south end of the field.

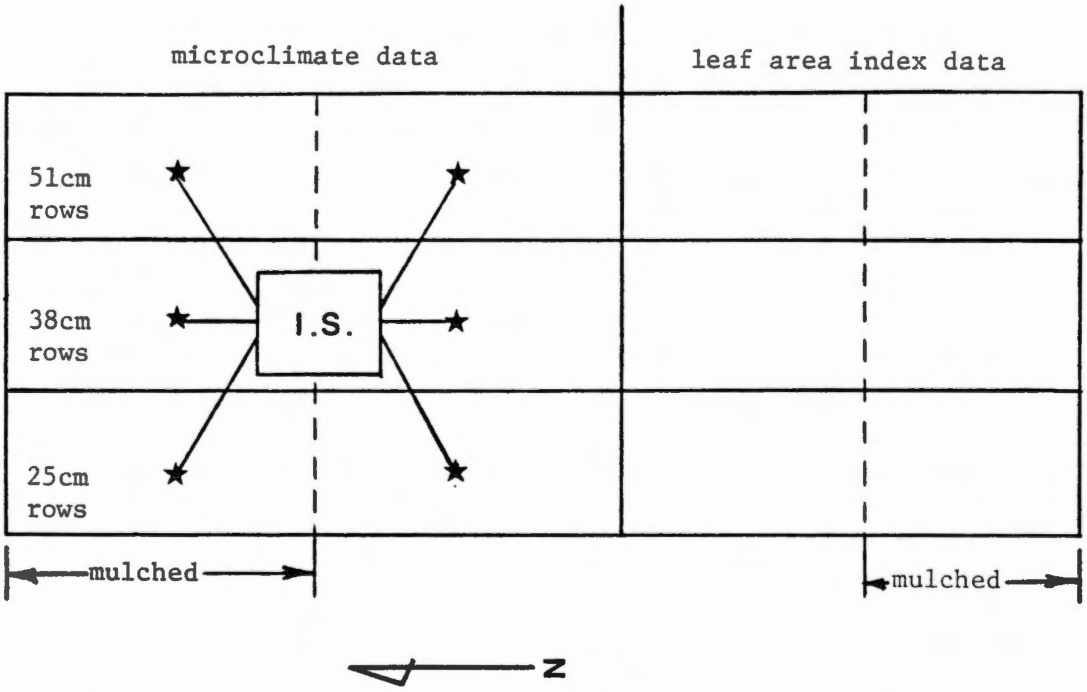


Figure 1. Field layout for 1983. I.S. is the instrument shed.

Table 1. Soybean growth terminology as adopted by the American Society of Agronomy (40)

Stage no.	Description
V1	Completely unrolled leaf at the unifoliate node.
V2	Completely unrolled leaf at the first node above the unifoliate node.
V3	Three nodes on main stem beginning with the unifoliate node.
V(N)	N nodes on the main stem beginning with the unifoliate node.
R1	One flower at any node.
R2	Flower at node immediately below the uppermost node with a completely unrolled leaf.
R3	Pod 0.5cm long at one of the four uppermost nodes with a completely unrolled leaf.
R4	Pod 2cm long at one of the four uppermost nodes with a completely unrolled leaf.
R5	Beans beginning to develop (can be felt when the pod is squeezed) at one of the four uppermost nodes with a completely unrolled leaf.
R6	Pod containing full size green beans at one of the four uppermost nodes with a completely unrolled leaf.
R7	Pods yellowing; 50% of leaves yellow. Physiological maturity.
R8	95% of pods brown. Harvest maturity.

Canopy Carbon Dioxide

Figure 2A shows the inlet arrangement for measurement of the average vertical CO_2 concentration in the upper four layers of the canopy in addition to the soil level, inlets were mounted on permanent masts erected adjacent to the instrument shed (refer to Figure 1 for most locations). The masts were steel fenceposts that were installed on 10 June when the plants were about 40cm tall. All CO_2 measurements taken throughout the remainder of the growing season were from the same location in each plot.

The canopy gas sampling inlets were made from thin walled polyvinyl chloride plumbing pipe, 3.8cm inside diameter, and 51cm long. Small holes, 0.3cm diameter, were drilled along the inlet in 4 offset rows and were spaced 2.54cm apart. The inlet used to measure CO_2 at the soil level was designed to obtain air samples as close to the soil as possible. Two rows of holes, drilled 2.54cm apart at a 90 degree angle, were positioned in such a way as to offset with the soil surface at a 45 degree angle.

The inlets were connected to the masts using steel packing bands as shown in Figure 2C. This allowed easy positioning vertically as the canopy grew, and horizontally, across the rows to obtain an average gas sample, (Figure 2B). A No. 6 rubber stopper with a glass tube through its center was inserted in one end of the inlet and the sample hose, which ran to the instrument shed , was connected to the glass tube. The other end of the inlet was open. Glass wool was placed over the inlet side of the stopper to filter the air entering the

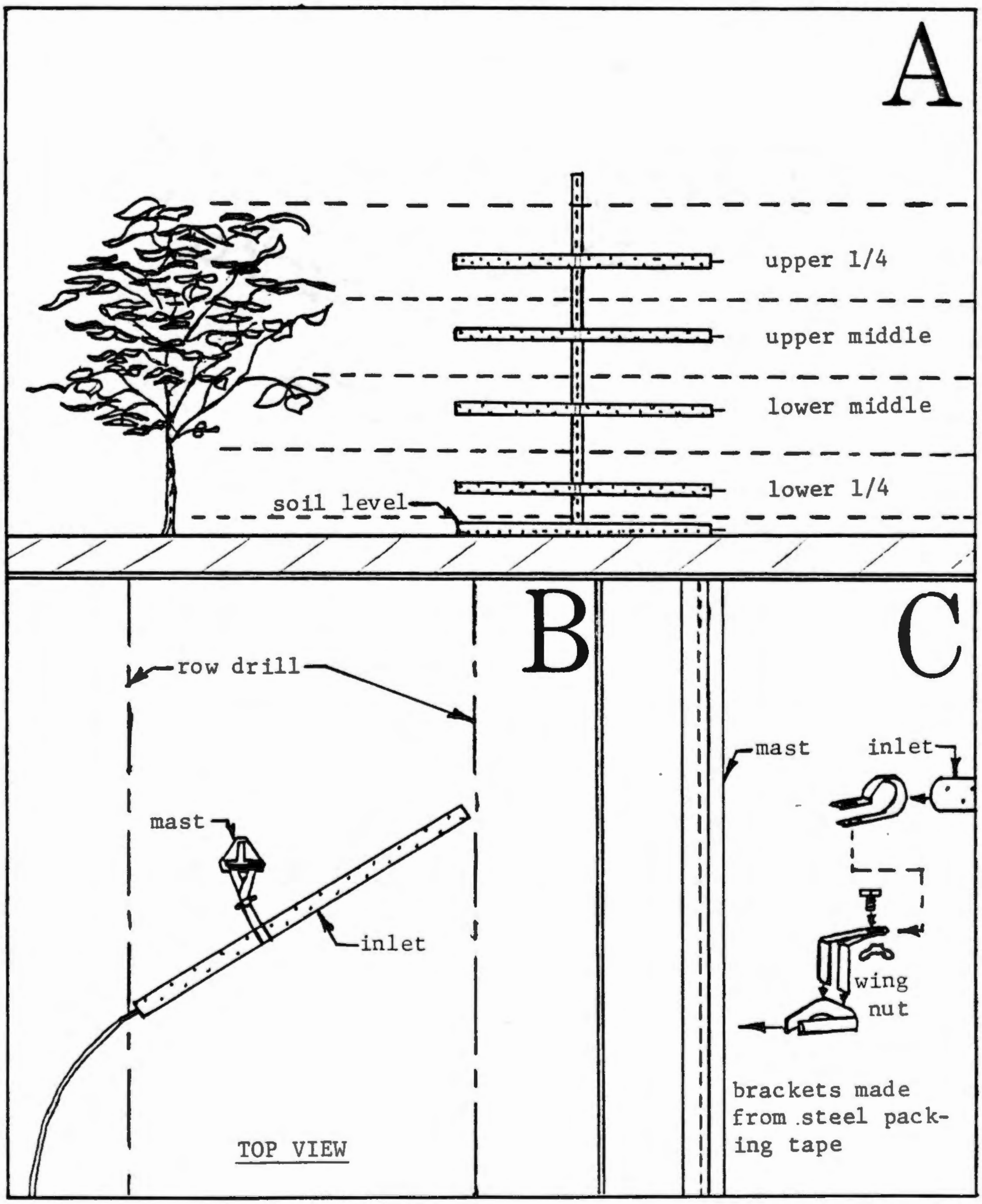


Figure 2. Inlet arrangement for 1983, A), vertical placement, B), horizontal placement, and C), mounting bracket.

sample hose. The sample hose was made of nylon tubing, 0.64 cm inside diameter with 0.15 cm thick walls and was approximately 910 cm long for each inlet. A nylon hose does not readily absorb CO_2 and has been recommended and used extensively by other researchers, (17,49,149). The sample hoses were suspended above the ground by wooden stakes to reduce excessive moisture buildup on the outside, which could possibly cause condensation inside the hose and errors in the CO_2 measurements.

The CO_2 concentration, (CO_2), of the air samples was measured with a Beckman 215B infrared gas analyzer. The Model 215B measures CO_2 by detecting differences in the amount of infrared light, which is absorbed by the CO_2 passing through two cells within the instrument. The detector unit consists of two sealed compartments separated by a thin, flexible metal diaphragm mounted below a stationary metal button. A rotating chopper blade blocks the light passing through the cells 9.25 times per second. With the instrument in a differential set-up, air from a reference source is pumped through one of the cells and the sample stream through the other cell at equal and constant flow rates. Deviations of the CO_2 in the sample from ambient CO_2 were recorded on a Sargent-Welch Model SRG recorder.

Carbon dioxide gas and water vapor absorb infrared light within the 2.7 μm waveband. The Beckman 215B cannot differentiate between the two so the air streams moving through the instrument's cells were dried using columns containing indicating drierite that were 4.6 cm in diameter and 28 cm long. Indicating drierite absorbs some CO_2, (70), and this created additional delays in obtaining CO_2 estimations. The sample air stream passed through the flow meter, and then into the Model 215B where it was exhausted at atmospheric pressure. The best flow rate found through testing was 800 $cm^3 \cdot min^{-1}$. Flow rates any faster than this did not allow the gas ample time for sufficient drying through the drierite column. The flow meters used for both the reference and sample airstreams were from Fisher Scientific Co. and had a working range of 0 to 1000 $cm^3 \cdot min^{-1}$. The pump used for the sample airstream was a Neptune Dyna-Pump, Model 2, 0.62 amp, and a Thomas Industries Inc., Diaphragm Pump, Model 907CA18, 3.0 amp was used to pump the reference gas. A wooden mast was erected atop an adjacent utility pole and designed to allow a gas line to be raised and lowered, much like a flag pole, to obtain air for the reference height, 6 meters above the ground.

In a typical days sampling, the canopy inlets were installed at about 0730 hours (EDST) and the instruments turned on and warmed up for about 45 minutes. The reference pump was then turned on and allowed to pass air through the reference cell for about 12 minutes before calibration. The instrument was calibrated using standard gases of 160, 322, and 560 $\mu L \cdot L^{-1}$. These standard gases were obtained from Matheson Gas Company and were accurate to within 1 percent. It was important to pass the calibration gases through the cell at the identical flow rate as the sample stream in order to reduce errors caused by differences in pressure between the calibration and sample gases within the instrument. Changes in pressure within the cell would cause differences in the gas concentration and thus result in errors in the CO_2 measurements. The gain control settings on both the gas analyzer and chart recorder were adjusted to give maximum scale between 150 and 600 $\mu L \cdot L^{-1}$ CO_2.

After calibration, air samples were analyzed from the treatments under study. Samples were obtained beginning with the top inlet and ending with the soil inlet. Measurements compiled from all five inlets within a given treatment constituted a "run." Air from the reference height was also measured for CO_2 and sampling continued throughout the day until around 2200 hour. Because of instrument drift and changes in [CO_2] at the reference height, the instrument had to be calibrated nearly every hour.

Due to the length of the sample gas lines and the absorption of CO_2 by the drierite, it took around 5 to 8 minutes to obtain an accurate estimate of CO_2 for each inlet. With five inlets positioned within each treatment, this amounted to about 35 to 40 minutes per run. To study all six treatments in the same day, it would take a minimum delay of around three and one-half hours between each run for a given treatment. This was considered too long a delay and so it was decided to sample a maximum of four treatments in one day and to spread the sampling times out as evenly as possible. Wind was another sampling problem. It was desirable to sample during times of negligible wind, defined as little or no leaf movement in the uppermost canopy leaves. However, on some days the wind would periodically be in excess of this defined threshold and gas measurements would cease. After the wind calmed enough to sample again, which usually occurred in the late afternoon if at all, measurements would begin after a 20 minute delay, which was observed to be sufficient enough to allow a representative vertical CO_2 profile to develop. A sufficient days data collection for a given treatment was defined as one having at least five good runs spaced out between 0800 and 2400 hour. On some days, insufficient data were collected due to unfavorable weather conditions. However, the summer of 1983 had many favorable days of sampling CO_2 under this system which resulted in a good spread of treatment observations, (refer to Figure 3).

The temperature and humidity in the upper and lower half of the canopy were recorded during each run. This was accomplished using an aspirated psychrometer constructed from the same PVC piping used for the gas inlets and two Yellow Springs Instrument Co., YSI 401 temperature probes, (Figure 4). The wet bulb was made of cotton and cotton thread and was wetted with distilled water prior to use. The temperature probes were mounted in front of the glass tubing insert which was connected with tygon tubing to a Thomas Industries Inc., Diaphragm Pump, Model 907AC18, 3.0 amp operated at full capacity. The aspirated psychrometer produced identical readings to a sling psychrometer under various environmental conditions. Other data recorded for a days CO_2 sampling were total incoming radiation measured at the adjacent Class A weather station with a Science Associates Inc. No. 653 bimetallic recording pyranometer (actinometer). This instrument measured solar radiation from the sun and sky for all wavelengths between 360 to 2000 nm.

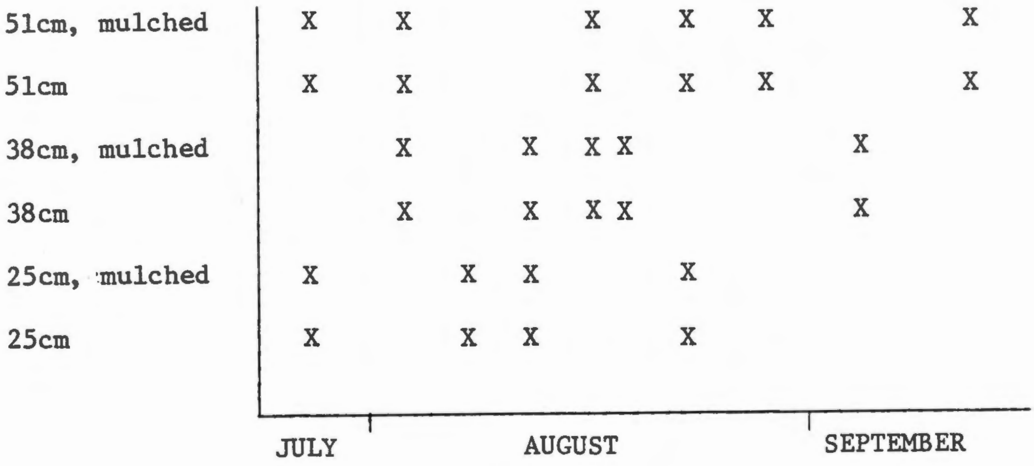


Figure 3. Dates of CO_2 data collection for 1983.

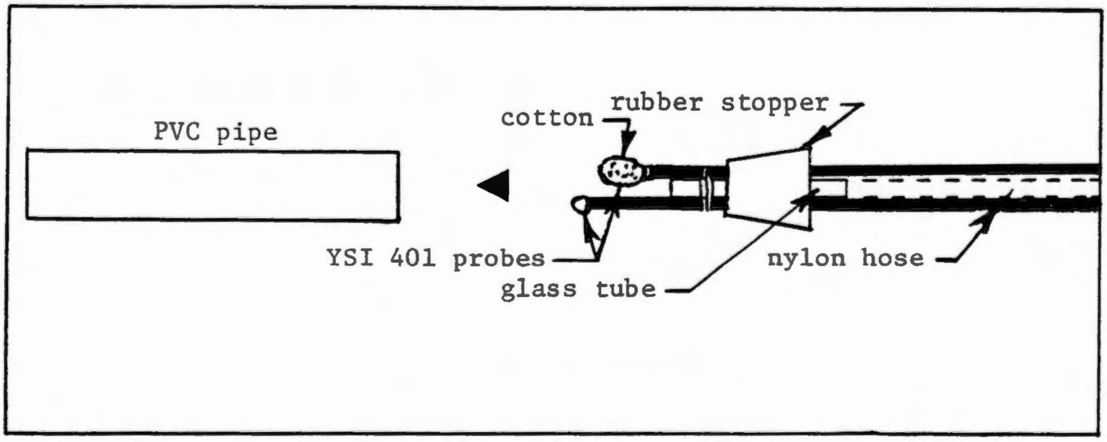


Figure 4 . Psychrometer used in the 1983 study.

Soil Carbon Dioxide Emission

A dynamic system was developed for the measurement of short term soil CO_2 emissions. The technique involved using the Beckman 215B infrared gas analyzer to detect increases in CO_2 within a closed system over the soil and calculating CO_2 evolution using the universal gas law.

The system developed is shown schematically in Figure 5. An inverted tin canister, 15.5cm diameter by 17.5cm length, served as a soil chamber and was inserted 3cm into the soil with the aid of a knife. The inlet and outlet of the soil chamber were made from glass tubing and designed to circulate air thoroughly. The outlet tube ran from the soil chamber to a six liter mixing chamber, constructed from two tin canisters, then to the drying column, the pump, flow meter, and into the CO_2 analyzer. The mixing chamber was necessary to "smooth" out any bursts of CO_2 given off from the soil which sometimes occurred. The temperature of the airstream passing into the CO_2 analyzer was recorded with a YSI 401 temperature probe.

After the system was set up in the field, nitrogen gas was added if needed until the gas passing through the analyzer was within the 300-500 $\mu L \cdot L^{-1}$ CO_2 range, which was within the linear range of recorder output and in the range of the observed concentrations in the canopy. The air flow was set at 1200 $cm^3 \cdot min^{-1}$ and allowed to circulate for about 15 minutes. The rise in CO_2 concentration over the next 10 minutes was recorded and converted to $cm^3 \cdot CO_2^{-1}$ released using the ratio:

$$cm^3\ CO_2/10\ \ cm^3\ ::\ cm^3\ CO_2/\text{total}\ cm^3\ \text{system}.$$

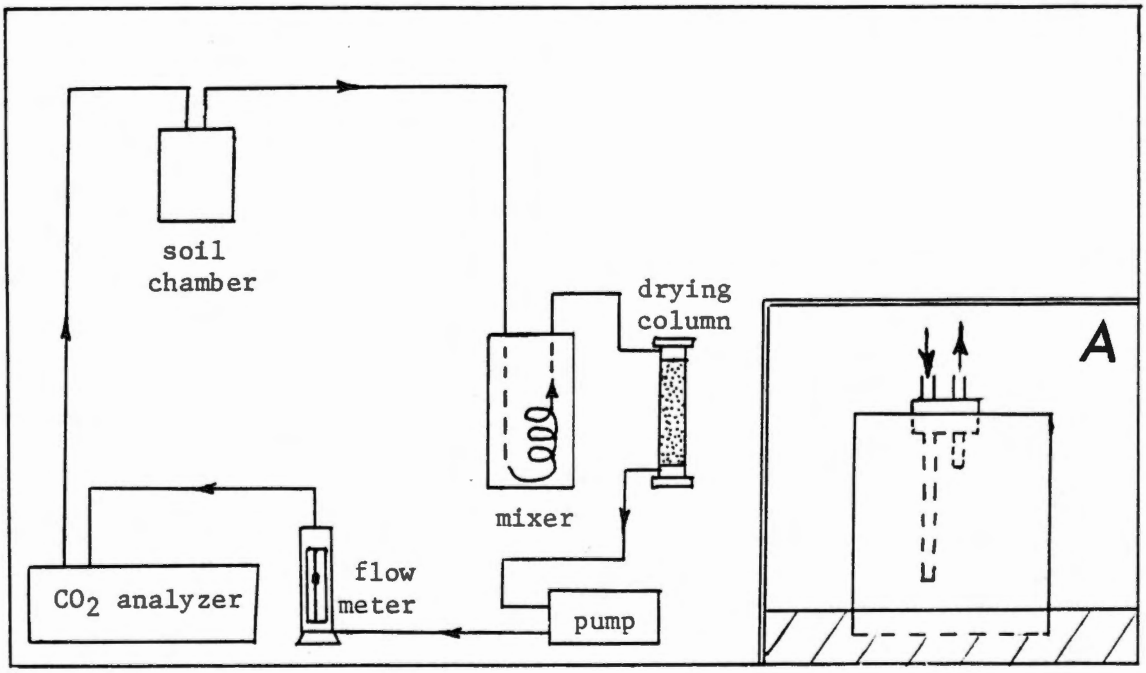


Figure 5. Schematic drawing of short-term soil carbon dioxide evolution measurement. Inset A is detailed view of soil chamber.

The moles of CO_2 released in 10 minutes was calculated from the equation:

$$n = \frac{RT}{VP} ,$$

where n is moles CO_2, R is the universal gas constant, (1.987 $cal \cdot deg^{-1} \cdot mol^{-1}$), T is temperature, (K), V is the volume of the system, which was calculated to be $9093 cm^3$, and P is atmospheric pressure, assumed to be 1.0132 x 10 $dyn \cdot cm^{-2}$. From knowing the density of CO_2 with temperature and the surface area covered under the soil chamber, the value for n was converted to $kg \cdot CO_2 \cdot ha^{-1}$.

Soil CO_2 evolution measurements were initiated on August 22 and continued until September 20. Measurements were made throughout the day in conjunction with canopy CO_2 measurements, but due to time constraints only two treatments could be observed on a given day. This method is a modification of those used by other researchers, (37,38,148), and has some error due to creation of CO_2 and pressure gradients, which may cause overestimation of CO_2 evolution, (86).

Leaf Area Index

Leaf area index, (LAI), was determined five separate times during the growing season beginning at R1 growth, (initial flowering). Four replications per treatment were made at each sampling time except for the 51cm mulched treatment. A very poor stand in the area designated for LAI measurements for the 51cm mulched treatments, located in the far south end of the field, was not representative of the remaining field area. Therefore, the results of LAI determinations for the 51cm nonmulched treatment were assumed to be the same as the mulched treatment, (this assumption was later supported by statistical tests of significance, see page 43).

A destructive method of measuring LAI was used which involved removal of leaves within a $2500cm^2$ area. An aluminum conduit, 0.64cm diameter, was bent into a 50x50cm square and mounted on a mast so that it could be adjusted to different levels in the canopy, (refer to Figure 6). Leaves within this area were excised at the pulvinis and partitioned into the upper four layers of the canopy. Any partial area of a leaf within the sampling zone was excised as close as possible along the zone boundary. Leaf area was determined by dividing the oven-dry weight of the leaves by the average leaf dry surface density, (LDSD).

Because of variations in LDSD over the growing season, (Figure 7), LDSD was determined at each sampling period. Fifteen leaves were randomly sampled from the canopy and their LDSD calculated from:

$$LDSD = \frac{\text{dry wt. leaf (g)}}{\text{leaf area (cm}^2\text{)}} \quad .$$

Individual leaf area was measured by carefully drawing the leaf's outline on notebook paper and then cutting it out with a razor blade. The paper outline was oven-dried, weighed and divided by the surface density of the notebook paper. The surface density of the notebook paper, (in $g \cdot cm^{-2}$), was determined by cutting out and weighing five squares of known area in similar manner.

Figure 6. Apparatus used in leaf area index determinations.

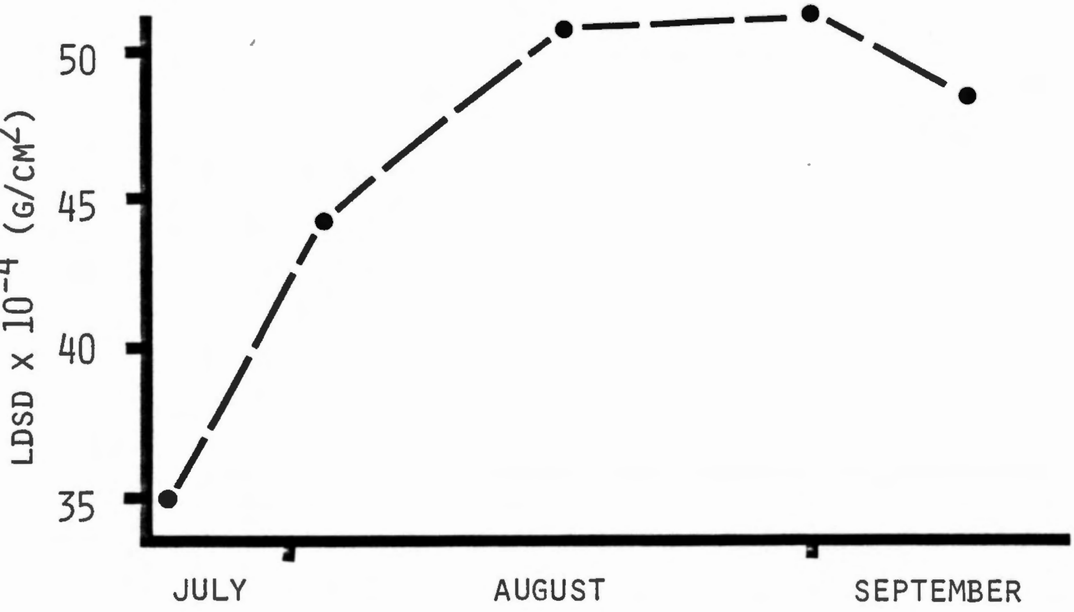


Figure 7. Variation in leaf dry surface density over time.

Bulk leaf samples were placed in brown paper bags which were vented using a hole puncher and dried in a forced air oven at 70C for at least 48 hours. The dry leaves were then weighed to the nearest 0.01 g and their area calculated from:

$$\text{area } (cm^2) = \frac{\text{oven dry wt. leaves (g)}}{\text{LDSD } (g \cdot cm^2)}$$

This method of determining LAI is reported to be accurate within 15 percent (p. 540 of 119).

Preliminary leaf inventory data from 1982 was taken from leaf area index sampling during the pod-fill stage. The data shows a tendency for larger leaves to have a greater LDSD and for yellowed leaves to be low in surface density. However, larger leaves dominated the canopy and accounted for over 90 percent of the total leaf area, (Table 2).

Table 2. Typical leaf inventory taken on 26 August 1982 from 38cm rowspacing.

leaf description[a]	LDSD($g \cdot cm^{-2}$)[b]	%number	%area
large	0.0046	75	93
small	0.0035	21	6
yellowed	0.0014	4	1

[a]Large = length + width > 11cm; small = length + width < 11cm; yellowed = greater than 50% chlorosis.

[b]LDSD is average leaf dry surface density.

Leaf Litter

An attempt was made to obtain a weekly estimate of leaf and stem drop from the canopies of the various treatments. Four squares 20x20 cm, were cut from plastic and placed randomly within the treatments. All plant material upon the squares was periodically removed, brushed free of soil, oven-dried, and weighed. The values were converted to $kg \cdot ha \cdot day^{-1}$ of plant foliage lost. It was important not to disturb the canopy above the squares during sampling because leaves would fall prematurely and induce errors of great magnitude due to the small area sampled.

Soil Temperatures

Soil temperature was measured at the surface, 3, 5, and 10cm depths in the soil using Yellow Springs Instrument Co., YSI 401 temperature probes. In addition, the temperature of the soil surface and of the air, 1 meter above the ground, was monitored with YSI 409B and YSI 405 probes respectively. Temperature probes were connected by cable leads to a YSI Model 47 scanning tele-thermometer, located inside the air-conditioned field instrument shed. The YSI Model 47 output was transferred to a YSI Model 80 laboratory recorder.

The YSI Model 47 has 11 channels and was set to scan all 11 channels every 5 minutes. Channel 11 was left open for calibration purposes. The accuracy of the Model 47 is listed as 1 percent of scale between 5 and 50C. The YSI Model 80 records the temperature on inkless paper using a recording stylus which responds to the input signal and is pressed against the carbon backed recording paper every 2 seconds. The result is a "tick mark" which appears as a straight line over time. The instrument was set at a chart speed of 2.54cm/hr. Instrument drift was a problem for about a week after initial start-up in the field and calibration was necessary nearly every day. Afterwards, frequent checks revealed that no calibrations were necessary except when changing the recording paper.

Due to a lack of temperature probes, soil temperatures were measured in the 51cm rowspacing only. The soil probes were situated 12.5cm from the row drill which was chosen in order to obtain temperatures somewhat of an average between the row drill and middle. The probes were installed on 22 June 1983 when the plants were at V5 growth and about 20cm tall. A small hole with a straight face was made in the soil with a spade and an ice pick used to form a tunnel for probe insertion. All thermister leads in the field were clearly marked to prevent accidents. Two air thermisters, (YSI 405 probes), were attached to the rain gauge stakes and shielded from direct radiation using a styrofoam drinking cup (Figure 8). On very hot, cloudless days, this radiation shield was inadequate--allowing daily maximum temperature values up to 5C greater than those recorded at the adjacent Class A weather station.

Apparent Evapotranspiration

Apparent evapotranspiration was calculated using a water balance approach. Weekly inventories were made of rainfall, any added

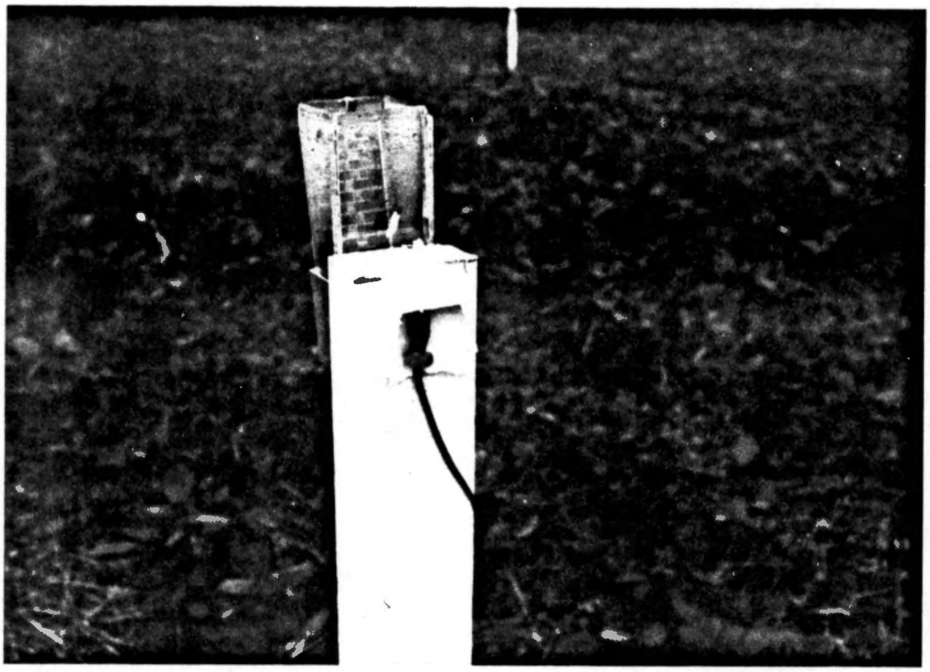


Figure 8. Tru-Test rain gauge and air temperature probe in field.

irrigation, and soil moisture down to a depth of 114 cm. Total soil moisture was measured at three locations within each treatment. Assuming that runoff and movement of water in or out of the measured soil zone was negligible, all water not accounted for between measuring dates was considered lost as apparent evapotranspiration.

Soil moisture was measured using a Troxler Model 3411-B surface moisture-density gauge and a Troxler Model 3222 depth moisture gauge, (Figure 9). These moisture meters are accurate, measuring within 0.1 percent of actual volumetric moisture content. It should be mentioned that high percentages of soil organic matter will cause erroneously high moisture readings, but the amount was considered negligible in this study due to the very low organic matter content of the Sequatchie loam.

Using a soil auger, an aluminum tube, 5 cm inside diameter and 183cm long was placed into the ground as an access tube to measure soil moisture with depth using the Model 3222 depth moisture gauge. The tube was plugged on the bottom end with a No. 10 1/2 rubber stopper to keep out moisture and buried leaving 15 cm extending above ground. The soil was carefully tamped along the top to prevent water infiltration down the gap between tube and soil. The tube was capped with an inverted aluminum can. A visual inspection down each tube before a measurement was made to check for water leakage was necessary to avoid immersing and damaging the Model 3222 probe. Although the land was nearly level, small dikes about 10cm in height were formed approximately 1.5 meters around each access tube to eliminate any potential water losses due to runoff.

Figure 9. Troxler Model 3411-B surface moisture-density gauge in foreground and Model 3222 depth moisture gauge in background.

The surface moisture meter, Model 3411-B, was used to measure the average soil moisture content in the upper 28cm. The soil surface was smoothed near each access tube so that the 3411-B could obtain good contact with the soil surface. After the surface moisture measurement, the Model 3222 depth moisture gauge was used to obtain average moisture contents through the remaining soil profile in 15cm intervals. The total soil moisture in the measured profile was calculated from:

$$TM(cm) = (22.86cm \times SM) + 15.24cm \times (M1+M2+M3+M4+M5+M6)),$$

where TM is the total soil moisture, SM is the volumetric moisture content detected with the Model 3411-B, and M1-M6 are volumetric water contents of the six measured intervals with the Model 3222.

Two Tru-test® rain gauges were mounted approximately 1.5 meters off the ground to record rainfall amounts. The Tru-test rain gauge measures rain to the nearest 0.0025cm and has a rectangular opening, 6.35 x 5.72cm, (Figure 8). The accuracy of measurement decreases for rainstorms exceeding 3cm or greater due to the scaling of the gauge. Rainfall values at the adjacent Class A weather station were used when storms exceeded 3cm in amount. Irrigation was measured by placing 6 tin cans, 15cm in diameter and 17cm in depth, near the locations of the soil moisture access tubes. After irrigation, the depth of water in the cans was measured in cm. It was estimated that this method of measuring irrigation amounts was accurate to within 0.2cm.

The apparent evapotranspiration was calculated from:

$$\underset{(\text{cm } H_2O\cdot\text{day}^{-1})}{\text{AET}} = \frac{SM_i + R + I - SM_f}{\text{number of days between measurements}} ,$$

where SM_i is initial soil moisture (cm), SM_f is final soil moisture, and R and I are rainfall and irrigation respectively (cm). Soil moisture measurements were planned every 7 days beginning at about 1000 hour in an attempt to ensure some uniformity, although weather or irrigation scheduling sometimes created delays.

2. RESULTS AND DISCUSSION

Canopy Carbon Dioxide

The canopy carbon dioxide concentrations ranged from midday lows of around 290 $\mu L\cdot L^{-1}$ in the upper layer to nighttime highs of over 600 $\mu L\cdot L^{-1}$ at the soil level. At the reference height, 6 m above the soil surface, (CO_2) ranged from 340 $\mu L\cdot L^{-1}$ at midday to nighttime highs of over 450 $\mu L\cdot L^{-1}$. The study site was located in a valley directly below a busy highway near a metropolitan area and settling of CO_2 emitted from automobiles and industry may well have contributed to high nighttime concentrations at the reference heights.

For each day and each treatment, the observed (CO_2) was fitted to a polynomial regression model as a function of the time of day and height above ground, (all statistics mentioned in this text were performed using software from the Statistical Analysis System, SAS, (177)). This was accomplished using a general linear model in SAS, (in polynomial curve fitting, no class variables are specified). The prediction of (CO_2) for a treatment on a given day, at any given height in the canopy, and at any given time from about 0900 to 2200 EDST, was very accurate as seen by the high coefficient of determination values, (Table 3). Basically, the (CO_2) during the day increased linearly downward in the canopy and showed a quadratic relationship over time at any given height. Some examples are presented in Table 3.

An overall correlation of the data is presented in Table 4. No strong relationships of CO_2, LEV, or TIME could be seen from the overall correlation. However, a correlation of the variables in Table 3, (shown in Table 5), revealed a possible relationship in the ability to predict canopy (CO_2), as inferred by rsq, (coefficients of determination), with SUN, DAY, and GRW, (r = .45, -.48, and -.49, respectively). It appeared that prediction of the canopy (CO_2), for a given day and treatment, decreased with plant age. This may be due to changes in photosynthesis and photorespiration that occur with plant age, (88,97), or to alterations in the canopy microclimate occurring with the drastic drop in LAI in the latter part of August and through September. Many more observations would be needed to predict the canopy CO_2 concentrations after mid-pod fill stage using polynomial regression.

Examples of some plotted models are shown in Figure 10, which shows the effect of wind on the canopy (CO_2). The wind on 24 August, which began around 1000 hour and averaged 21.3 $km \cdot hr^{-1}$, mixed the

Table 3. Some selected polynomial regression equations depicting the canopy CO_2 concentration as a function of height above ground, (H, (cm)), and time of day, (T, (EDST)).

rowspacing (cm)	date	CO_2 = equation	R^2	total incoming rad. (ly/day)	grwth	LAI
25	7/27	714.7-.34xT-.51xH+.000000051xTxTxT	0.79	786.7	R2	4.9
	8/8	951.8-.79xT-1.37xH+.00029xTxT+.00000024xTxTxT	.79	425.0	R4	4.9
	8/10	606.6-.51xT+1.61xH-.00013xTxH+.00023xTxT	.85	425.0	R4	4.9
	8/24	549.4-.13xT-8.5xH+.000043xTxT+.18xHxH -.0012xHxHxH	.78	329.0	R5	3.2
25, mulch	7/27	1198.6-1.13xT-5.4xH+.00038xTxT+.12xHxH +.00000098xTxHxH	.97	786.7	R2	4.9
	8/8	1253.74-1.13xT-3.35xH+.00038xTxT +.00000026xTxTxH=.018xHxH	.84	425.0	R4	4.9
	8/10	609.4+.033xT-.45xH-.00082xTxT+.000000xTxTxT	.93	425.0	R4	4.9
	8/24	478.8-.017xT-3.47xH+.027xHxH	.56	329.0	R5	3.2
38	8/3	570.5+.11xT-.72xH-.00047xTxT+.00000019xTxTxT	.94	507.2	R3	4.2
	8/10	1050.7-.96xT-3.35xH+.00035xTxT+.029xHxH	.89	425.0	R4	4.2
	8/17	610.7-.42xT+5.56xH-.0086xTxH+.00019xTxT +.0000027xTxTxH	.84	390.7	R5	3.8
	9/7	709.9-.45xT-.71xH+.00015xTxT	.78	349.6	R6	2.7
38, mulch	8/3	675.6-.31xT-.99xH-.00000xTxT+.000000049xTxTxT	.92	507.2	R3	4.2
	8/10	675.7+12.52xT-2.94xH-.0083xTxT+.00000018xTxTxT +.027xHxH	.87	425.0	R4	4.2
	8/17	624.7-.29xT+4.88xH-.013xTxH+.00013xTxT +.0000042xTxTxH+.034xHxH	.83	390.7	R5	3.8
	9/7	1485.3-.20xT-.19xH+.0011xTxT-.0000002xTxTxT +.016xHxH	.88	349.6	R6	2.7
51	7/27	605.9-.080xT-.14xH-.00030xTxT+.00000015xTxTxT	.98	786.7	R2	3.7
	8/15	577.1+.29xT-3.19xH+.0027xTxH-.00060xTxT -.00000072xTxTxH+.00000021xTxTxT	.74	445.5	R5	3.7
	8/29	242.3+.56xT-1.52xH-.00033xTxH-.00057xTxT -.00000016xTxTxT+.043xHxH-.0029xHxHxH	.98	315.3	R6	2.9
	9/20	552.7-.50xH-.00025xTxT-.00000012xTxTxH +.00000011xTxTxT+.000063xHxHxH	.78	212.5	R7	2.7
51, mulch	7/27	605.9-.018xT-.14xH-.0003xTxT+.00000015xTxTxT	.97	786.7	R2	3.7
	8/15	1405.6-1.35xT-.82xH+.00044xTxT	.81	445.5	R5	3.7
	8/29	567.0-.072xT-.50xH-.00013+.00000062xTxTxT	.88	315.3	R6	2.9
	9/20	370.9+4.18xH-.0066xHxT+.0000096xTxT +.0000020xTxTxH+.0075xHxH	.52	212.5	R7	2.7

Table 4. Overall correlation of 1983 canopy carbon dioxide study.

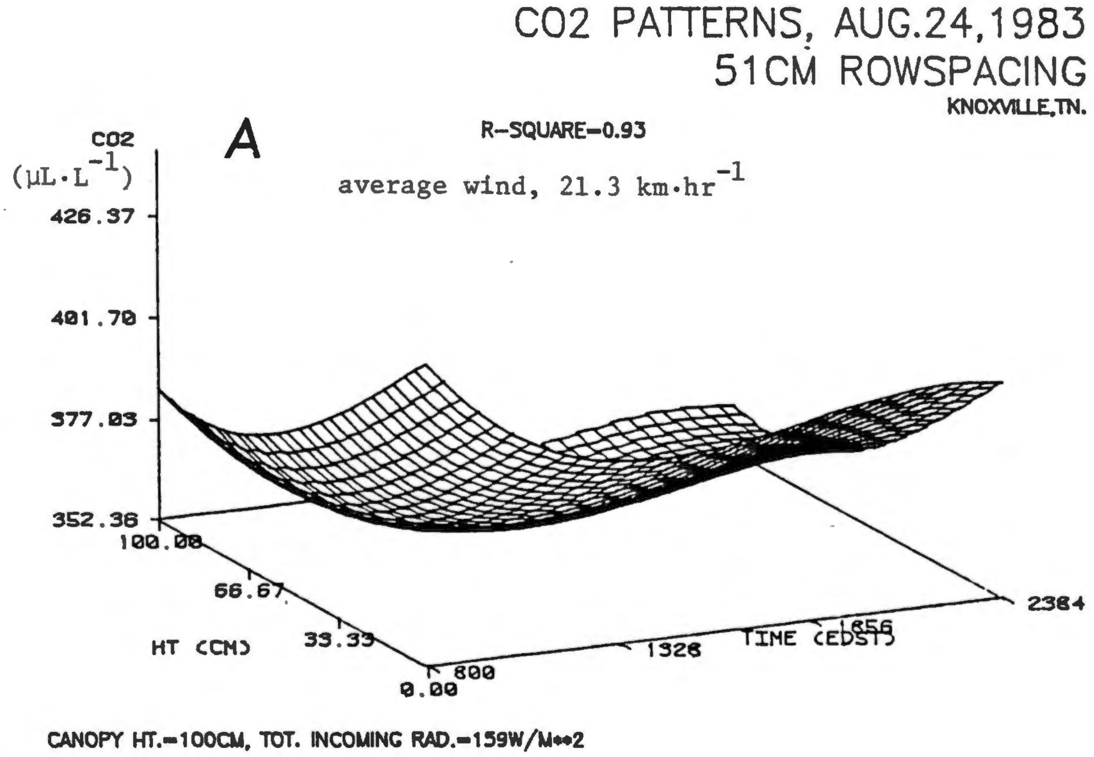
	TIME[a]	CO2	LEV	HUM	TEM
TIME	1.00				
CO2	-.03	1.00			
LEV	.01	-.05	1.00		
HUM	.02	.54	-.04	1.00	
TEM	-.03	-.56	.64	-.70	1.00

[a]TIME is time of day, CO2 is carbon dioxide concentration, LEV is height of measurement, and HUM and TEM are humidity and temperature respectively.

Table 5. Correlation coefficients for selected parameters in 1983.

	trt[a]	day	sun	grw	lai	rsq
trt	1.00					
day	.20	1.00				
sun	-.15	-.88	1.00			
grw	.25	.89	-.91	1.00		
lai	-.59	-.66	.53	-.69	1.00	
rsq	.19	-.48	.45	-.49	.29	1.00

[a]Where trt is treatment, day is day after germination, sun is total incoming radiation, grw is stage of growth, lai is leaf area index, and rsq is coefficient of determination from regression equations describing canopy carbon dioxide.



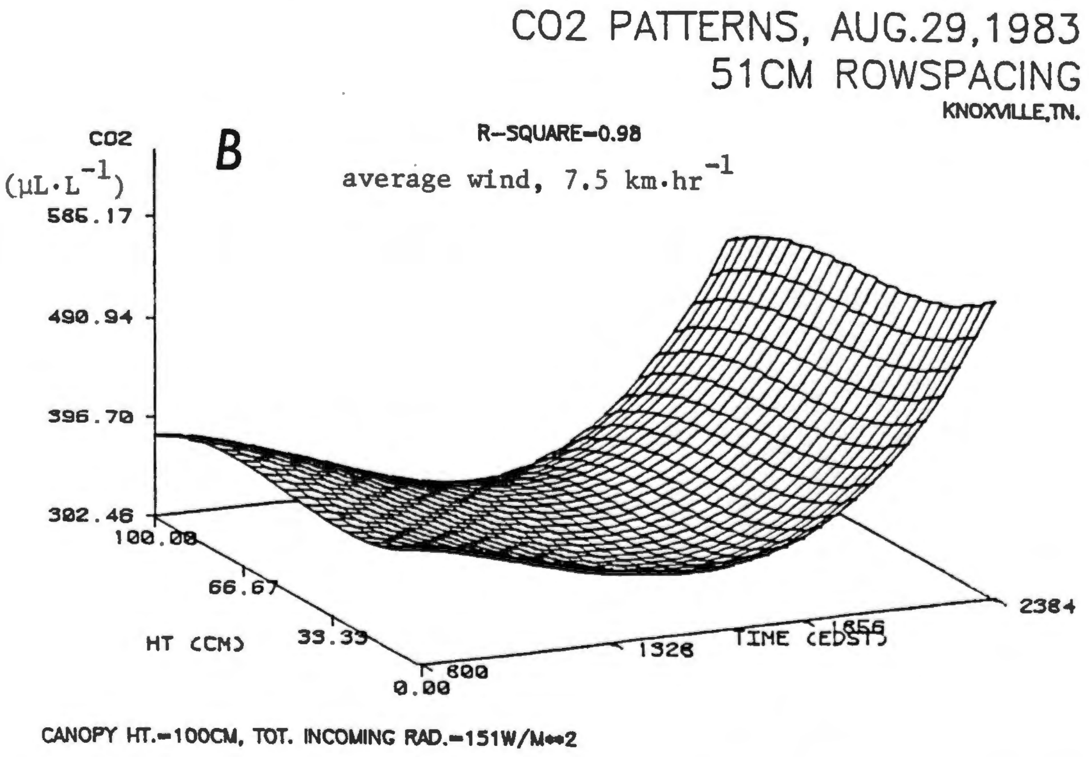


Figure 10. Comparison of canopy carbon dioxide concentrations for 51cm rowspacing on A, a windy day, B, a calm day.

air such that no large profiles developed as in 29 August, where average windspeed was only 7.5 $km \cdot hr^{-1}$. Wind data was obtained from the National Weather Service Station at McGhee-Tyson Airport, located only 3 km south of the study site. Note the rapid rise in canopy (CO_2) at sunset, (around 1930 hour). This CO_2 "bloom" is due in part to the release of CO_2 from the glycolate pathway. Carbon dioxide filtering through the various reactions is released in the mitochondria and has no chance of recapture by the plant due to the shutdown of the Calvin cycle in the absence of light. This was very evident on calm days, when the [CO_2] in the upper half of the canopy rose 100 $\mu L \cdot L^{-1}$ or more within 20 minutes.

Actual recorded CO_2 concentrations of 24 August are shown in Figure 11. Concentrations in the upper half of the canopy ranged from 300 to 500 $\mu L \cdot L^{-1}$. Some upward diffusion of CO_2 occurred around 1500 hour in the 25cm rowspacing as seen by the low values in the bottom strata. The soil level [CO_2] fluctuated among treatments. The concentration at the reference height, approximately 2 meters above the canopy, ranged from around 340 to 400 $\mu L \cdot L^{-1}$. The decrease in canopy photosynthesis with plant age can be seen in Figure 12. A distinct midday depression was present on 15 August and was virtually non-existant on 20 September. Some plant respiration was evident on 20 September as seen by the slight increase in all strata of around 30 $\mu L \cdot L^{-1}$ CO_2 in the early morning and late evening.

In order to obtain some statistical inferences on the canopy CO_2 relationships among treatments, all data collected from R1 to R4

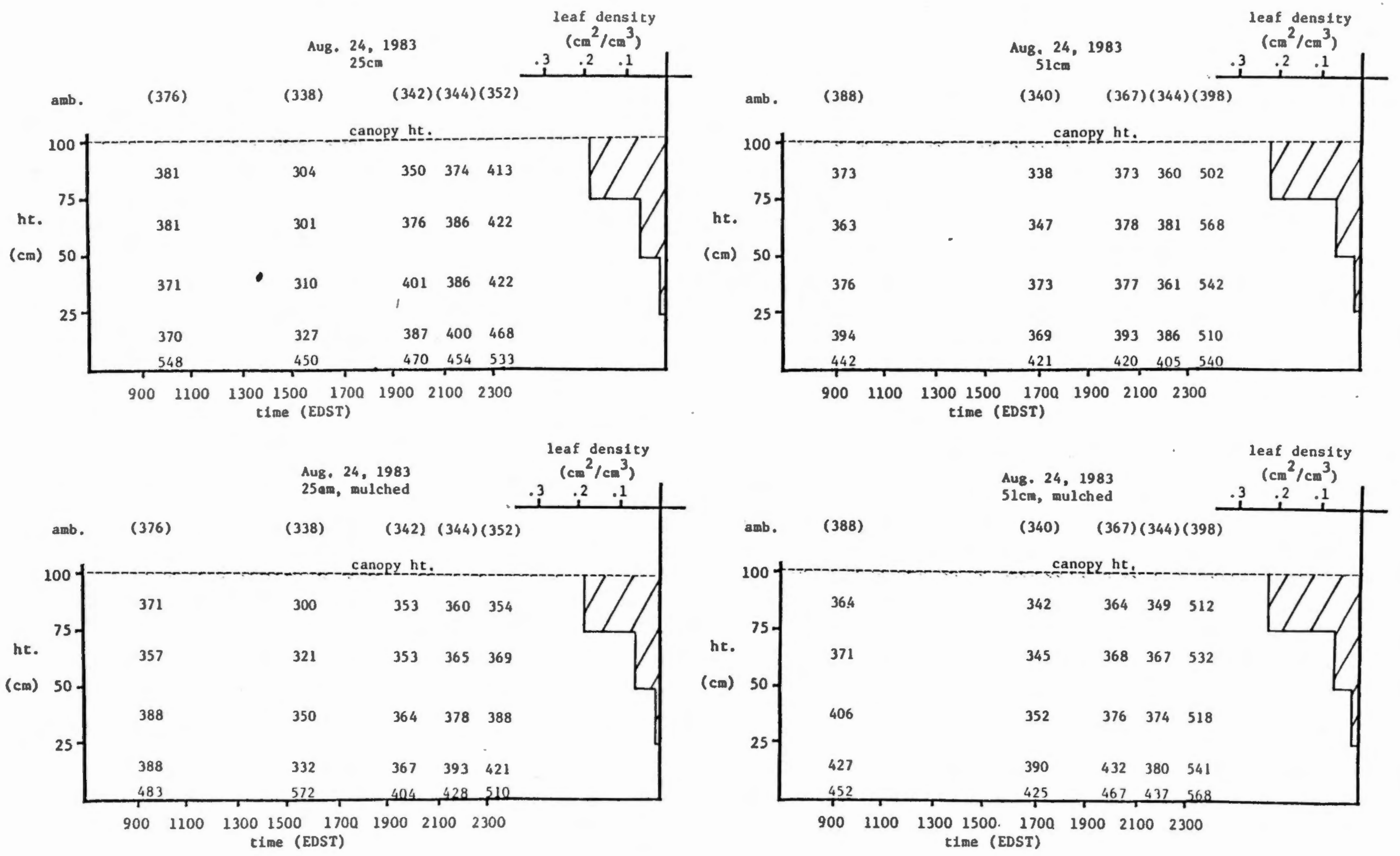


Figure 11. Observed canopy carbon dioxide concentrations, ($\mu L \cdot L^{-1}$), and leaf density on 24 August 1983.

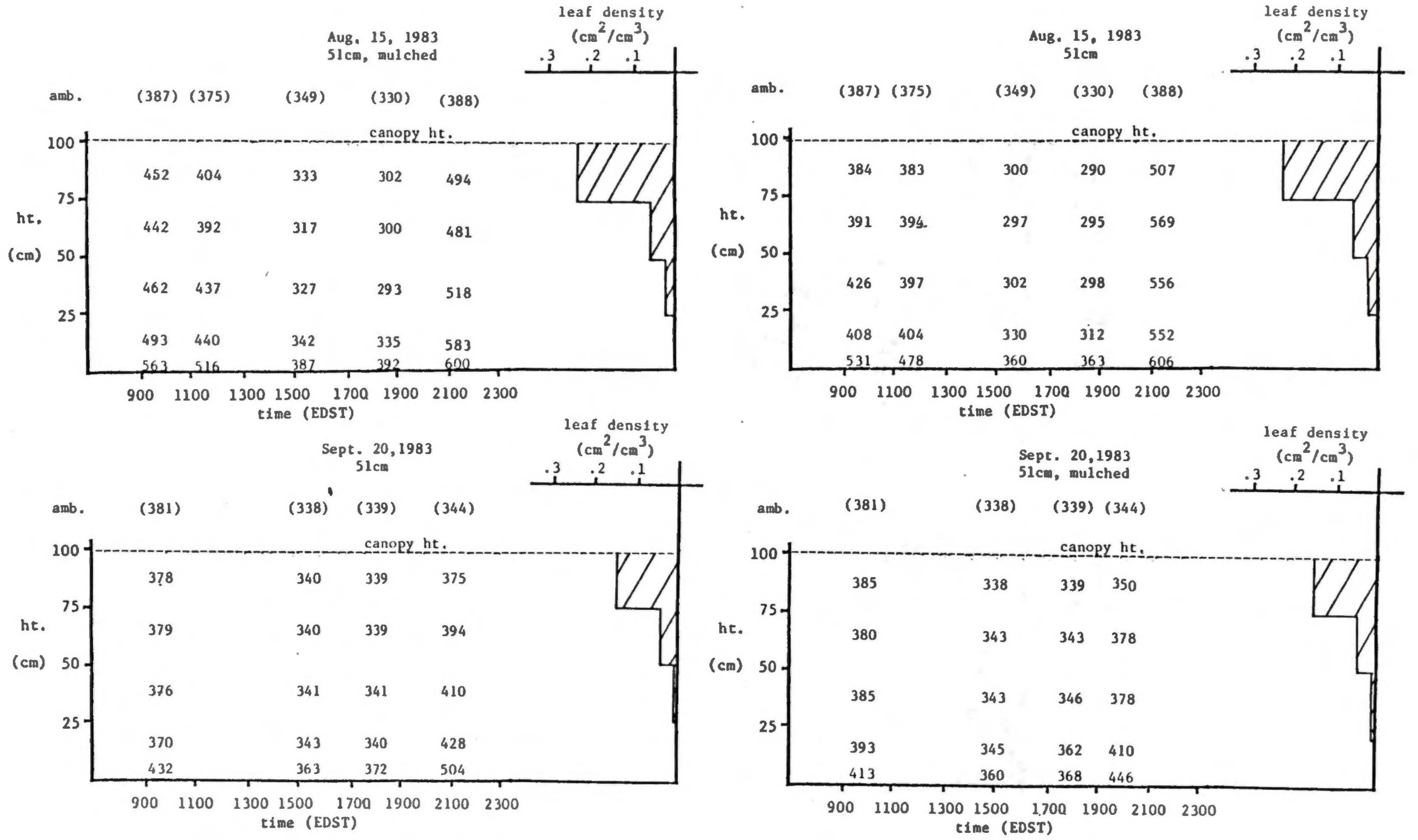


Figure 12. Observed canopy carbon dioxide concentrations, ($\mu L \cdot L^{-1}$), and leaf density for the 51cm rowspacing on August 15 and September 20, 1985.

growth, (27 July through 11 August), was pooled. These values were chosen due to the importance of this time of growth in terms of final seed yield and because the total data collected for all treatments were nearly equal. This included 3 days of data collection for each treatment and approximately 18 observations for each level sampled. A preliminary correlation matrix, (Table 6), showed little correlation of CO_2 concentrations with any other variable except temperature and humidity, the nighttime and early morning values being higher for all three. In order to obtain further information, the observed [CO_2] was treated as a dependant variable with treatment, date, and level as independant variables in a general linear model. The variable time, was used as a continuous covariate in the model. The analysis of covariance is shown in Table 7. Time of day was a significant covariate as expected. There were also significant differences among treatments and dates sampled. There were no significant differences among the CO_2 means at the sampling levels unless expressed as a function of time.

A similar analysis was performed separately at each sampling level to further identify the sources of variation. Specific one degree of freedom contrasts were used to test between rowspacings and mulched versus unmulched. A summary of the corresponding F-tests is shown in Table 8. At all levels, time was a significant covariate. However, there were no significant differences in the [CO_2] over time among treatments at the soil or lower fourth of the canopy levels, or between mulched and unmulched treatments at any level. Significant

Table 6. Correlation coefficients of 1983 variables between R1 and R4 growth.

	TIME	LEV	CO2	TEM	HUM
TIME	1.00				
LEV	.00	1.00			
CO2	-.01	-.02	1.00		
TEM	.00	.02	-.76	1.00	
HUM	.15	-.07	.68	-.75	1.00

[a]TIME is time of day, LEV is height in the canopy, CO2 is carbon dioxide concentration, and TEM and HUM are temperature and humidity respectively.

Table 7 . Analysis of covariance for 1983 data.

source[a]	df	sum of squares	F value	Prob F
t	1	26669.0	16.22	0.0001
t*t	1	45042.2	27.39	0.0001
t*t*t	1	192397.3	117.00	0.0001
trt	5	24522.0	2.98	0.0121
trt*t	5	33784.9	4.11	0.0014
trt*t*t	5	36819.1	4.48	0.0007
trt*t*t*t	5	37836.8	4.60	0.0005
lev	4	3546.0	0.54	0.7071
lev*t	4	18439.3	2.80	0.0260
lev*t*t	4	19025.4	2.89	0.0224
lev*trt*t	20	40342.4	1.23	0.2299
date	4	65716.4	9.99	0.0001
error	315	517975.7	-	-

[a]Where time, t , is the covariate, trt is treatment, lev is the sampling level in the canopy, and date is sampling date. Type III sum of squares.

Table 8. F-test results from analysis of covariance for carbon dioxide concentrations at each canopy level as a function of time of day pooled over R1 to R4 growth.

source[a]	df	SOIL P>F	LOW P>F	LM P>F	UM P>F	UP P>F
t	1	0.69	0.91	0.02	0.02	0.04
t*t	1	.00	.00	.74	.68	.92
t*t*t	1	.00	.00	.06	.07	.04
trt	5	.99	.64	.17	.05	.00
trt*t	5	.30	.28	.15	.09	.05
trt*t*t	5	.14	.26	.12	.11	.10
trt*t*t*t	5	.11	.27	.10	.12	.12
(25vs51cm)	(1)	.84	.89	.02	.02	.02
(25vs38cm)	(1)	.98	.18	.01	.01	.01
(mul.vs.unmul.)	(1)	.79	.88	.24	.18	.18

[a]Where t is time of day, trt is treatment, SOIL is soil surface, LOW is lower fourth, LM is lower middle, UM is upper middle, and UP is upper fourth of canopy. Type III sum of squares.

differences among rowspacings were evident in the top three canopy layers studied. This was attributed to differences in leaf density among rowspacings (see page 63). Leaf density alters sunlight penetration and photosynthesis in addition to turbulent transfer of CO_2 downward in the plant canopy, which may explain the different concentrations observed during the day. This can be seen in a plot of the 25 and 51-cm rowspacings, (Figure 13A). The 25cm showed a lower drop in [CO_2] than the 51cm rowspacing at midday, (around 1300 hour), in the upper fourth of the canopy. This was probably due to the increased leaf density of the 25cm rows resulting in greater CO_2 assimilation at peak irradiance. A higher leaf density in the 25cm rows may also be the reason why slightly higher [CO_2] were observed near dusk, (around 2100 hour), due to plant respiration. Although not significant, the 25cm rowspacing did show slightly higher [CO_2] values at the soil level in the mornings, (Figure 13B). This may be due in part to reduced turbulent transfer with the atmosphere that is promoted by a higher leaf density in the upper layer.

Soil Carbon Dioxide Emissions

The soil CO_2 emission data are listed in Table 9. Values ranged from 0.05 to 0.25 $kg \cdot CO_2 \cdot ha^{-1} \cdot min^{-1}$ evolved, (72 to 360 $kg \cdot CO_2 \cdot ha^{-1} \cdot day^{-1}$). The average amount of CO_2 evolved was around 0.10 $kg \cdot ha^{-1} \cdot min^{-1}$, (144 $kg \cdot CO_2 \cdot ha^{-1} \cdot day^{-1}$). These are very similar to those recorded by Lundegarth, (77), from a beet field in Sweden.

The density of CO_2 at 25C is reported to be 1.811 $kg \cdot m^{-3}$, (p. 32 of 119). Given a canopy height of one meter, and assuming

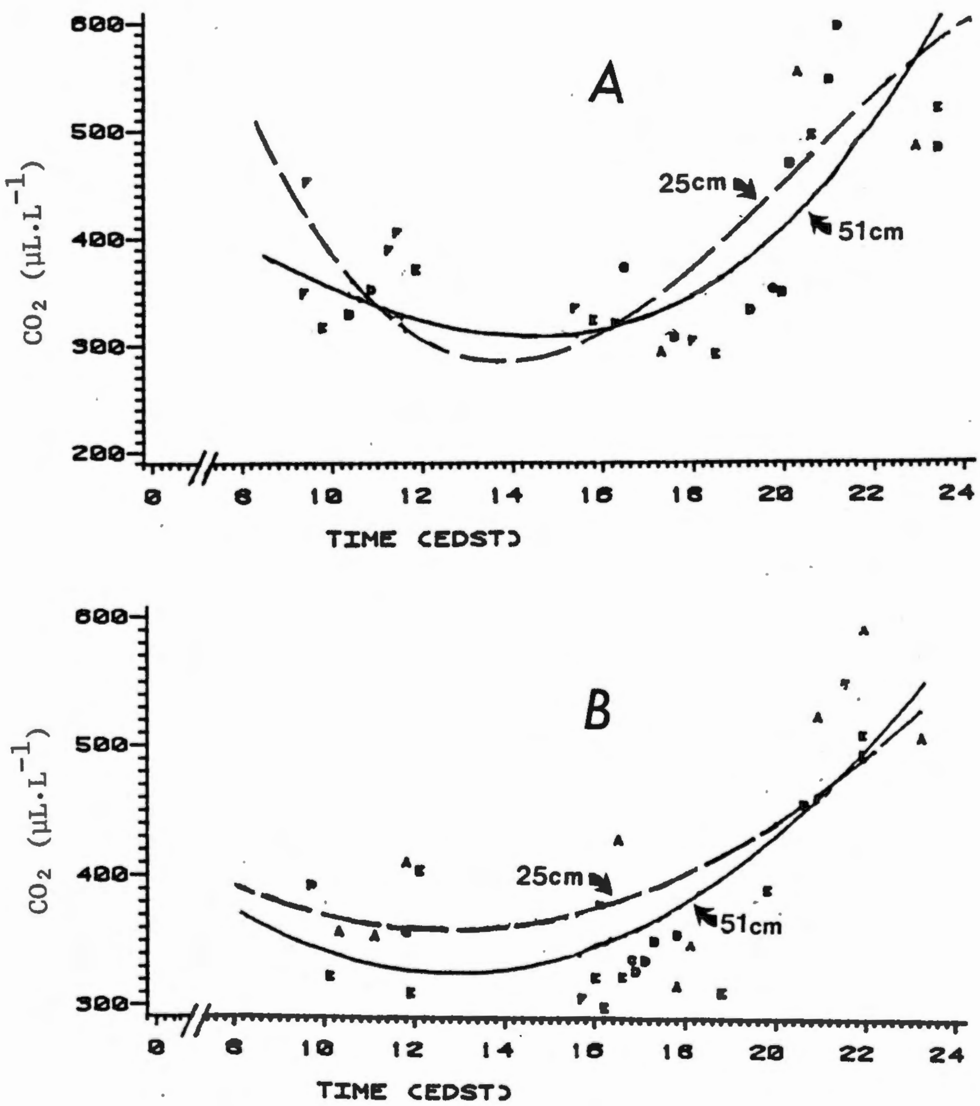


Figure 13. Comparison of pooled carbon dioxide measurements from R1 to R4 growth in A, the upper fourth canopy layer, and B, at the soil surface for the 25- and 51cm rowspacings.

Table 9. Soil CO_2 emission observations for 1983.

date	time (EDST)	treatment	air temp. (C)	CO_2 emission ($kg \cdot ha^{-1} \cdot min^{-1}$)	CO_2 emission ($kg \cdot ha^{-1} \cdot day^{-1}$)
8-22	1730	25cm, mulched	40.0	0.15	216
8-23	1600	25cm, mulched	40.0	.25	360
8-24	0915	25cm, mulched	25.0	.23	331
8-24	1130	25cm, mulched	35.0	.22	317
8-24	1945	25cm, mulched	26.0	.05	72
8-24	2355	25cm, mulched	25.0	.08	115
8-29	1730	51cm, mulched	29.0	.08	115
8-29	1800	51cm	29.0	.10	144
8-29	2110	51cm, mulched	25.0	.14	202
8-29	2130	51cm	25.0	.13	187
8-29	2320	51cm, mulched	20.0	.11	158
8-29	2335	51cm	20.0	.08	115
8-30	1030	51cm, mulched	28.0	.11	158
8-30	1048	51cm	28.0	.11	158
8-30	1225	51cm, mulched	32.0	.11	158
8-30	1240	51cm	32.0	.12	173
9-7	1030	38cm, mulched	24.5	.09	130
9-7	1055	38cm	24.5	.09	130
9-7	1600	38cm, mulched	31.0	.11	158
9-7	1630	38cm	31.0	.10	144
9-7	1955	38cm, mulched	25.0	.09	130
9-7	2015	38cm	25.0	.10	144
9-7	2215	38cm, mulched	22.0	.07	101
9-7	2230	38cm	22.0	.09	130
9-8	0025	38cm, mulched	21.0	.09	130
9-8	0040	38cm	21.0	.10	144
9-20	1120	51cm, mulched	27.0	.09	130
9-20	1145	51cm	29.0	.11	158
9-20	1648	51cm, mulched	29.0	.10	144
9-20	1713	51cm	29.0	.11	158
9-20	1905	51cm, mulched	22.5	.09	130
9-20	2133	51cm, mulched	22.5	.09	130
9-20	2203	51cm	22.5	.12	173

that CO_2 evolution is constant and diffuses evenly within the canopy only, a rise in $[CO_2]$ of 331 $\mu L \cdot L^{-1}$ per hour could be expected. This is substantial but is not observed in the field due to the diffusion of CO_2 out of the canopy, losses by turbulent mixing, absorption by water on the plant surfaces, assimilation by plants during active photosynthesis, readsorption by the soil, and reductions in evolution rate due to lower soil moisture and temperature, (37,71,85,90). These losses are significant. Moss et al., (91), reported that 95 percent of the CO_2 utilized by corn plants came from the atmosphere rather than from the soil due to these losses. Their findings were based on a micrometeorology study in which they found an average soil CO_2 emission rate of 0.6 $kg \cdot ha^{-1} \cdot min^{-1}$ in comparison to the 0.10 $kg \cdot ha^{-1} \cdot min^{-1}$ determined in this study.

A correlation analysis, (Table 10), was performed to study the relationships among variables. There was a high positive correlation of CO_2 evolved and air temperature, $(r = .70)$. The slight negative correlation of CO_2 emission with date and treatment $(r = -.41$ and $-.39$ respectively), may be due to the negative correlation of date and treatment with temperature, $(r = -.40$ and $-.39$ respectively). Temperatures were lower in September and the 25cm rowspacing was not sampled after 24 August. There was no obvious correlation of soil CO_2 emission with time, $(r = -.19)$, however there were probably not enough observations made in one day. Moss et al., (91), and Witkamp, (148), using many more daily observations, saw a predawn minimum and an afternoon maximum in soil CO_2 emissions.

Table 10. Correlation coefficients for 1983 soil carbon dioxide emissions.

	DATE[a]	T	TRT	TEMP	SCO2
DATE	1.00				
T	-.15	1.00			
TRT	.22	.14	1.00		
TEMP	-.40	0.18	-.39	1.00	
SCO2	-.41	-.19	-.39	.70	1.00

[a]Where DATE is date of measurement, T is time, TRT is treatment, TEMP is temperature, and SCO2 is soil carbon dioxide emission.

Soil Temperatures

Three dates were chosen to study the effect of mulching, soil depth, and time on soil temperatures in the 51cm rowspacing; 21 July, 29 July, and 13 August. An analysis of covariance was modeled for each day using the hour of measurement as a continuous covariate. The results are shown in Table 11. Specific contrast tests were used to study temperature differences over time between the four depths measured, (surface, 3-, 5-, and 10-cm). These included 3 versus 5-cm, 3 versus 10-cm, and 5 versus 10-cm, (Table 11).

On 21 July, a significant depth by hour relationship existed, but none of the contrast tests were significant. This is because the majority of the variance came from the surface temperature, which

Table 11. Analysis of covariance for soil temperatures on three dates in 1983.

source[a]	d.f.	sum of squares	F value	Prob>F
		21 July		
HR	1	76.7	22.93	0.0001
HR*HR	1	16.5	4.93	.0255
HR*D	3	150.7	15.01	.0001
HR*HR*D	3	111.1	11.06	.0001
(3cm vs 5cm)	(1)	0.8	0.24	.6274
(3cm vs 10cm)	(1)	4.5	1.33	.2502
(5cm vs 10cm)	(1)	0.4	0.12	.7297
HR*D*L	4	56.5	4.22	.0027
HR*HR*D*L	4	35.5	2.65	.0346
error	171	571.9		
		29 July		
HR	1	6.6	4.51	0.0352
HR*HR	1	0.4	0.30	.5876
HR*D	3	35.6	8.14	.0001
HR*HR*D	3	24.5	5.59	.0012
(3cm vs 5cm)	(1)	2.0	1.40	.2388
(3cm vs 10cm)	(1)	8.1	5.52	.0199
(5cm vs 10cm)	(1)	1.5	1.03	.3117
HR*D*L	4	15.1	2.59	.0383
HR*HR*D*L	4	7.9	1.35	.2519
error	171	249.5		
		13 August		
HR	1	22.3	9.79	0.0021
HR*HR	1	2.4	1.04	.3100
HR*D	3	66.6	9.73	.0001
HR*HR*D	3	46.1	6.75	.0003
(3cm vs 5cm)	(1)	24.9	10.93	.0012
(3cm vs 10cm)	(1)	50.8	22.29	.0001
(5cm vs 10cm)	(1)	3.3	1.43	.2337
HR*D*L	4	13.3	1.45	.2187
HR*HR*D*L	4	10.0	1.10	.3589
error	171	389.8		

[a]Where HR is hour (EDST), D is depth in soil, L is location (mulched or unmulched). Type III sum of squares.

was not listed on the analysis of covariance table but can be seen in Figure 14. On 29 July the temperature pattern was different between the 3cm and 10 cm depths, and the 3-, 5-, and 10-cm depths on 13 August. Mulching affected temperature patterns on 21 July and on 29 July, (note the interaction of HR, D, and L in Table 11), but showed no effects on 13 August.

This can be seen graphically in Figures 14 and 15. On 21 July, (Figure 14), mulching tended to buffer the midday temperature rise. On 13 August, (Figure 15), there was little difference in the temperature patterns between mulched or unmulched treatments. For instance, the temperature stayed fairly close to 22C at the 5- and 10-cm depths. Throughout most the day on 21 July, the temperature stayed near 25C at all depths, rising up to 30C at 3cm in the unmulched treatment between 1400 and 2000 hour.

The results show the effect of mulching on buffering soil temperatures before canopy closure. After canopy closure, the temperature patterns appeared similar with greatest changes occurring at the 3cm depth, particularly between 1400 and 2000 hour. Temperatures ranged between 25- and 32C at the 3 cm depth early in the season and from 20- to 25C in August. Surface temperatures peaked around 35C prior to canopy closure. The temperature differences between depths increased later in the season after canopy closure, mostly among the 3-cm and the 5- and 10-cm depths. The 5- and 10-cm depths were similar and rarely exceeded 27C.

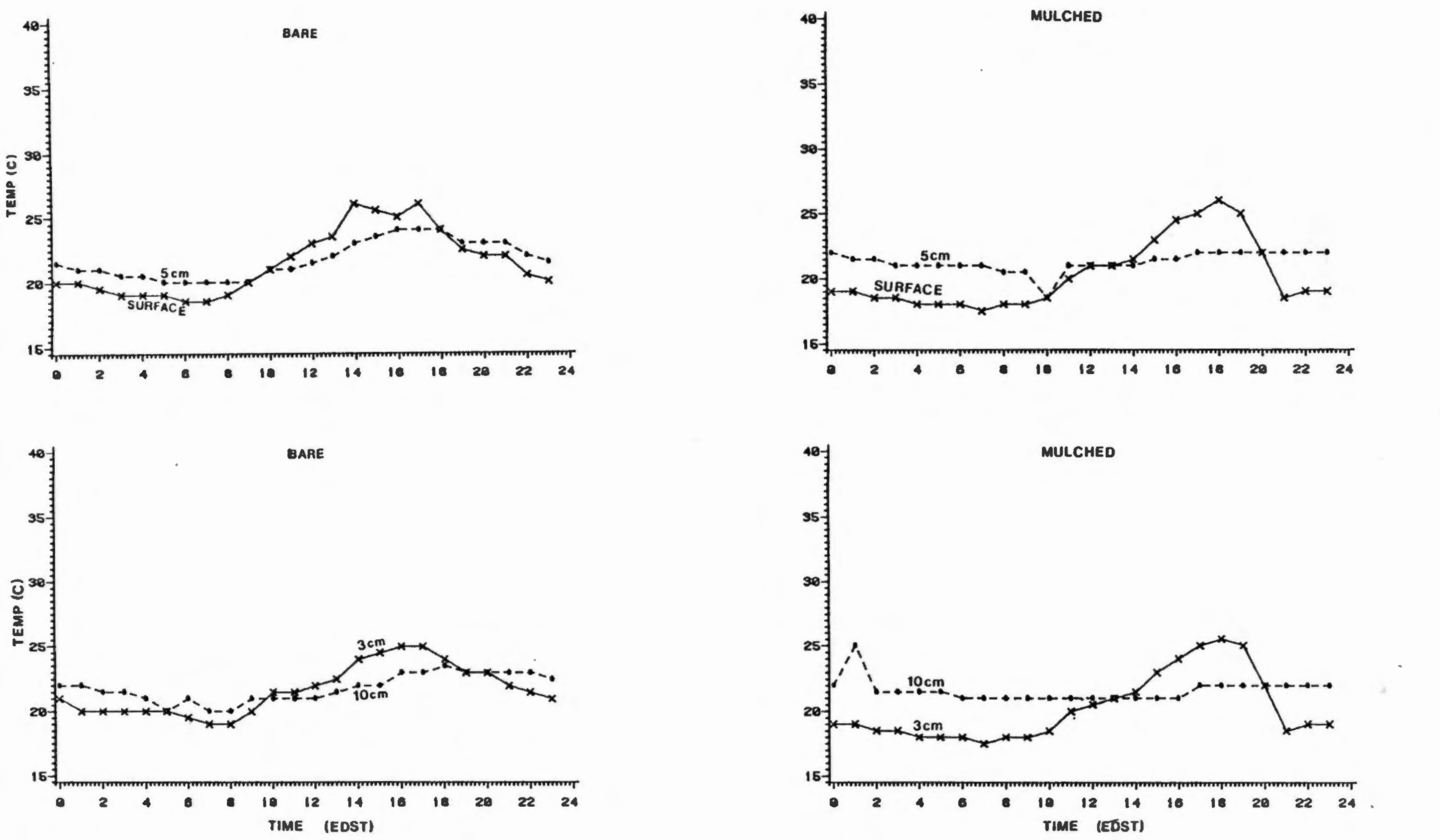


Figure 14. Soil temperatures in the 51cm rowspacing at the surface, 3-, 5-, and 10cm depths on 21 July.

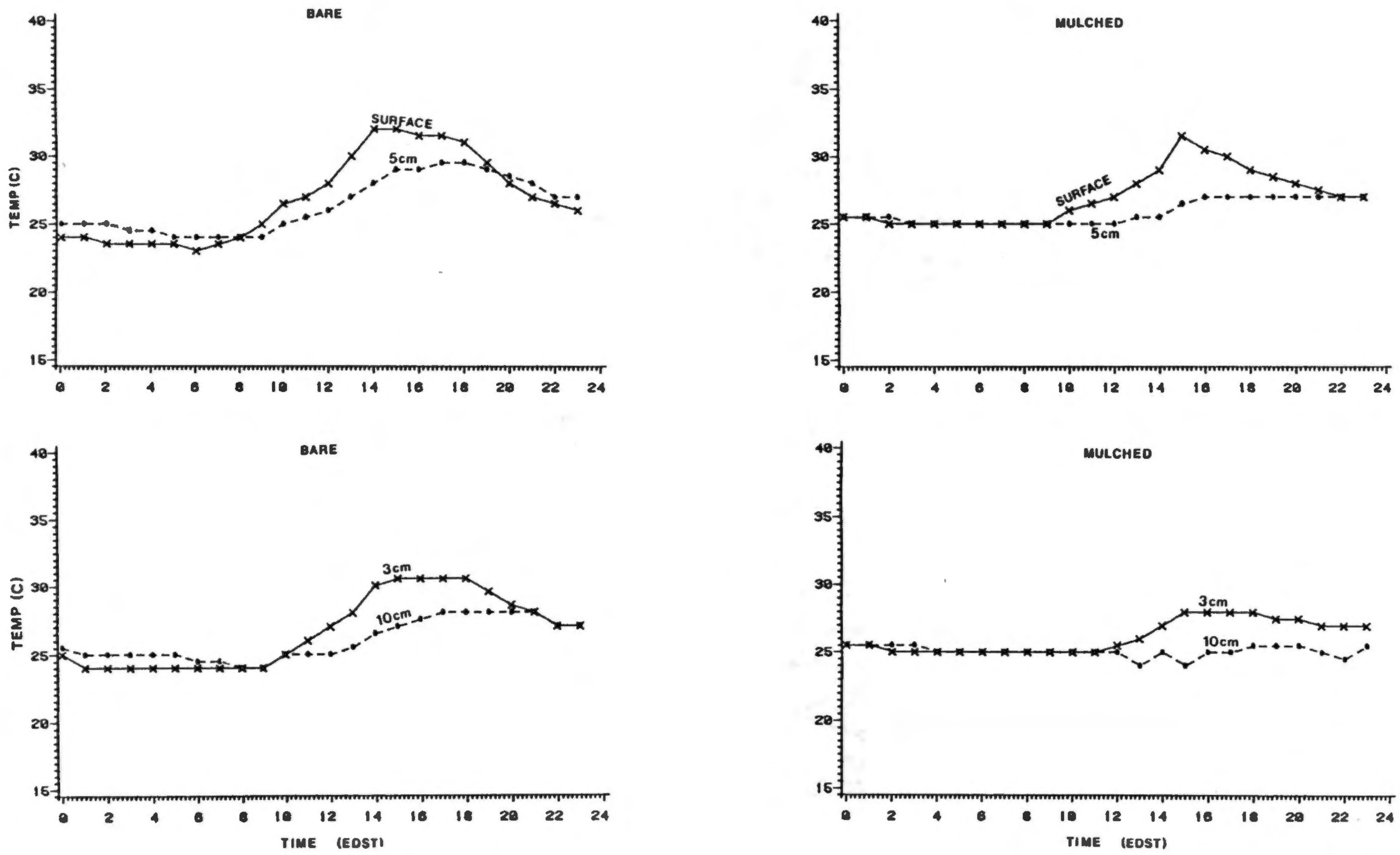


Figure 15. Soil temperatures in the 51cm rowspacing at the surface, 3-, 5-, and 10cm depths on 13 August.

Leaf Area Index

The LAI for the 25cm and 38cm rowspacings were similar throughout all sampling periods, (Table 12). However, the mean LAI for the 25cm rowspacing tended to be slightly higher, but not significantly higher than the 38cm rows. The variation in canopy leaf area in the field was large as seen by the somewhat high coefficients of variation, which ranged from about 10-20 percent (Table 12). The reasons for this may have been due to differences in plant emergence within a large runoff area midway through the LAI sampling zone, which had a poor stand due to excessive water runoff and surface crusting early in the season.

The LAI for the 25cm rows was significantly higher on 2 August than the 51cm rowspacing. At this time the plants were at the early pod fill stage, (R3). A high LAI at this stage of growth is beneficial in terms of final seed yield due to the increased photosynthetic potential. The total leaf area in the upper fourth layer of canopy was also higher for the 25cm rows on the 2 August sampling, (Figure 16). Since over 90 percent of the intercepted solar radiation is probably absorbed in the upper fourth layer, (53), a higher leaf area density in the 25cm rows sets the stage for higher yields at this critical stage.

The leaf area density in all layers began to decline in subsequent samplings after 2 August. The lower leaves abscissed because of shading and this was accelerated by a torrential thunderstorm that occurred on 12 August, which caused some plants to lodge in all

Table 12. Leaf area index values for 1983.

rowspacing (cm)	leaf area index[a]				
	sampling date				
	21 Jul	2 Aug.	20 Aug.	1 Sept.	12 Sept.
25	3.2a	4.9a	3.2a	3.2a	2.5a
25,mulch	3.5a	-	-	-	-
38	3.1a	4.2ab	3.8a	2.9a	2.4a
38,mulch	2.9a	-	-	-	-
51	2.8a	3.7b	3.7a	2.7a	2.7a
C.V.[b]	21.6	11.1	13.4	13.1	9.9

[a]Based on 2500cm^2 ground area and four replications per rowspacing. Means with the same letter are not significantly different at the 0.05 level of probability according to Duncan's New Multiple Range test.

[b]Coefficient of variation.

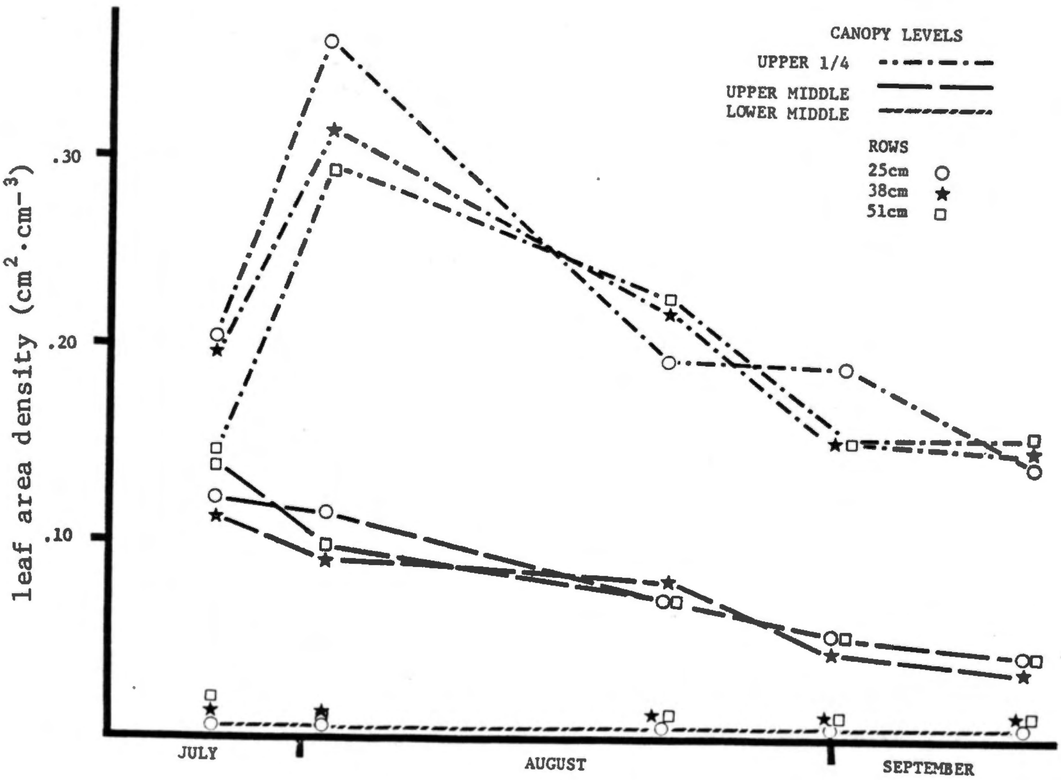


Figure 16. Leaf area density for 1983.

rowspacings. Because "Essex" soybeans are determinates, leaf regrowth after the pod filling process began was minimal. The foliage loss rates, (Table 13), coincide with the decline in LAI values. A tremendous jump in the foliage loss occurred around the first week of September after the plants had reached physiological maturity, (R7). There did not appear to be any significant differences in foliage losses among the treatments, indicating that most of the foliage loss was from the middle two zones, where the leaf density was very similar among treatments, (Figure 16). The lower one fourth strata was essentially devoid of leaves in all rowspacings.

Table 13. Foliage drop for 1983.

row-spacing (cm)	foliage loss rate $(kg \cdot ha^{-1} \cdot day^{-1})$[a] sampling date				
	11 May-22 July	22July-5 Aug.	5 Aug.-19 Aug.	19Aug.-1 Sept.	1Sept.-9 Sept.
25	0.88a	1.23ab	4.46a	5.55a	14.46a
25,mulch	1.27a	2.04ab	4.38a	6.91a	11.51a
38	1.42a	2.79a	7.30a	5.85a	16.67a
38,mulch	0.71a	1.99ab	8.66a	6.10a	11.20a
51	1.04a	0.90b	8.15a	6.43a	13.63a
51,mulch	1.04a	1.80ab	4.67a	7.74a	11.37a

[a]Means followed by the same letter are not significantly different at the 0.05 level of probability according to Duncans New Multiple Range Test.

Apparent Evapotranspiration

The apparent evapotranspiration of the treatments is summarized in Table 14. A Duncan's Multiple Range test was used at each sampling period for comparison of means in addition to a general linear model with specific treatment contrasts to study the variations among treatments and replications. An analysis of variance, (not shown), revealed no significant differences among replications for any treatment at any period and the contrast tests reflected the Duncan's Multiple Range tests. Generally, moisture use by the treatments was similar, (Table 14), but there were a few sampling periods where significant differences existed and reflected definite treatment effects.

The mulched treatments showed lower evapotranspiration rates early in the season up to R1 growth. The values were lower, but not significantly, at the first determination from V8 to V9 growth and clearly showed lower rates during the second determination at R1 growth, (initial flowering). These differences reflect mulching effects in reducing evaporation from the soil surface prior to canopy closure, the magnitude of moisture loss between mulched and bare treatments for any one rowspacing being greater with wider row widths, (note the R1 date, Table 14).

At R3 growth, (early pod fill), the 25cm rowspacing tended to have significantly lower evapotranspiration rates than the other treatments. This was probably related to canopy closure. Field notes during that period recorded canopy closure in the 25cm rows, a small

Table 14. 1983 soybean apparent evapotranspiration summary.

	average daily apparent evapotranspiration (cm-H_2O/day)[b,c]										
	7/11-7/15	7/15-7/22	7/22-7/28	7/28-8/5	8/5-8/13	8/13-8/19	8/19-8/26	8/26-9/2	9/2-9/9	9/9-9/16	9/16-9/22
	Growth										
trt[a]	V8-9	R1	R2	R3	R4-5	R5	R5	R5-6	R6	R6-7	R7
25	0.25a	0.20ab	0.25a	0.59bc	0.33a	0.41ab	0.20ab	0.31a	0.41a	0.51a	0.55a
25M	0.13a	0.15b	0.34a	0.53c	0.28a	0.41ab	0.18ab	0.36a	0.12a	0.53a	0.52a
38	0.20a	0.26a	0.18a	0.71ab	0.30a	0.23b	0.24ab	0.30a	0.21a	0.52a	0.51a
38M	0.17a	0.15b	0.24a	0.66ab	0.27a	0.37ab	0.21ab	0.33a	0.16a	0.67a	0.39a
51	0.28a	0.28ab	0.21a	0.66ab	0.32a	0.64a	0.16b	0.31a	0.19a	0.54a	0.43a
51M	0.24a	0.08c	0.15a	0.78a	0.21a	0.40ab	0.30a	0.36a	0.29a	0.63a	0.53a

[a] Treatment designations: 25, 25cm rowspacing: 25M, 25cm rowspacing, wheatstraw mulch added at 4500 kg$\cdot$ha^{-1}; etc.

[b] Values are average of three replications.

[c] Column means not followed by the same letter are significantly different at the 0.05 level of probability according to Duncan's New Multiple Range test.

gap between rows in the 38cm, and a 6 to 8cm gap between rows in the 51cm rowspacings. No significant difference in LAI was found, (Table 12, page 62). The closed canopy appeared to have reduced evaporation from the soil surface, which may account for up to 50 percent of total moisture use, (105). These results are in contrast to work done by Taylor, (133), who noticed a higher moisture use by 25cm rows compared to 100cm rows as determined from soil moisture tension data in the upper 30cm of soil. Taylor postulated this increase was due to greater transpiration rates as inferred by a higher LAI in the 25cm rows. The findings here do not support that and the discrepancies may be due to insignificant differences in LAI, or differences in humidity and wind, (Western Iowa is less humid and more windy than East Tennessee).

There does seem to be a relationship between LAI and apparent evapotranspiration, beginning around the first week of September. A slight increase in moisture use occurred for all treatments at this time and is thought to be due to an increase in evaporation from the soil surface. The LAI for all treatments decreased considerably prior to this period, (Table 12, page 62), which would allow more solar radiation to reach the soil surface and possibly increase evaporation.

These results indicate that there is not a significant difference in moisture use among the different rowspacings after full canopy closure. This is in support of conclusions reached by other researchers, (35,110,136). Moisture use appears to be influenced more by canopy closure early in the growing season and is related more to LAI later in the season when the leaves begin to abscise. Mulching helped to reduce moisture losses from the soil surface early in the season prior to canopy closure.

CHAPTER IV

THE 1984 STUDY

1. MATERIALS AND METHODS

Field Design

Essex variety soybeans were planted in row widths of 76-, 51-, 38-, 25-, and 13-cm in north-south rows on 16 May 1984 on a Sequatchie loam soil, (fine-loamy, siliceous, thermic, Humic Hapludult). The field layout consisted of three areas; one for obtaining canopy CO_2 observations, one for obtaining yield data from a completely randomized block experiment, and one for obtaining leaf area index and plant growth data. On 18 May a preemergence application of Lorax, (50w-lineuron), and Dual 8E, (metoachlor), was applied at rates of 1.68 and 2.24 $kg \cdot ha^{-1}$ ai respectively. Soybean emergence occurred on 21 May, five days after planting, and this was denoted as DAY 1 after emergence. Severe burning of lower leaves was noted after a heavy thunderstorm on 29 May, presumably from the Dual 8E being splashed on the plant by raindrop impact on the soil. The plants recovered from the herbicide damage within a week and no other damage was observed.

A population count was made on 10 June when plants were 10cm tall and at V2 growth stage, (two developed nodes). This was accomplished by counting the number of plants per linear meter of row at 10 random locations within each treatment. Final populations were 594,000, 393,000, 268,000, 209,000, and 145,000 plants per hectare for the 13-, 25-, 38-, 51-, and 76-cm rowspacings respectively. The plants in the 38cm rows directly south of the instrument shed died from a combination of herbicide burn and water ponding. These were replanted on 12 June but never attained the same stature as the soybeans in the unaffected areas. A combination of Basagran, (bentazon), and Blazer, (acifluorfen), at 0.56 and 0.28 $kg \cdot ha^{-1}$ ai respectively was applied with a hand sprayer for control of weed infestations on 20 June. Canopy closures occurred at 30, 37, 50, and 66 days after emergence for the 13-, 25-, 38-, and 51-cm rowspacings respectively. Canopy closure was defined as complete leaf overlap and did not occur in the 76cm rowspacing. Plots were combine harvested on 8 November.

Canopy Carbon Dioxide

The measurement of the canopy CO_2 concentrations in 1984 was done using the same technique as in 1983 with a few modifications. The pumps, set-up of the Beckman Model 215B gas analyzer in the differential mode using air from a height of six meters in the reference cell, tubing, drying columns, and flow rates were all the same. However, calibration of the gas analyzer was accomplished using standard gases of 300 and 500 $\mu L \cdot L^{-1}$. The standard gases were accurate to within $\pm$ 1 percent. The recorder output was linear between 300-500 $\mu L \cdot L^{-1}$ CO_2 and experience had shown that nearly all of the measured values for CO_2 were within this range.

The CO_2 concentration midway between the rows was added as a horizontal component giving 10 measurements in all. They were in the rows and row middles at the soil surface, lower one-fourth, lower middle, upper middle, and upper one-fourth of canopy, (Figure 17). A gas sample was taken from the reference height after canopy sampling and these 11 CO_2 observations encompassed one run. Because of the time required between each measurement, plus the time needed to recalibrate the analyzer, one hour was required to complete a run. Therefore, only one rowspacing treatment could be studied on any given day.

The CO_2 measurements continued in the presence of mild canopy disturbing winds. To quantify the wind, a scaling system was developed based on canopy response. This was thought to be more representative of the turbulent mixing action that the wind imposes within the canopy. The wind codings were as follows: 0, negligible; 1, top few leaves disturbed; 2, upper fourth of canopy leaves disturbed; 3, top half of canopy disturbed; and 4, more than top half of canopy disturbed. In all the canopy CO_2 observations, the wind was rarely greater than a coding of 2. The direction of the wind was measured using a vane made from aluminum tubing and zinc coated tin and recorded according to the following system: 0, negligible; and numbers 1 to 8 corresponding to N, NE, E, SE, S, SW, W, and NW directions respectively.

The air temperature and humidity were recorded in the upper and lower half of the canopy mid-way during a run. The psychrometers

Figure 17. Gas inlet arrangement used in 1984.

were similar to the ones used in 1983 with a few modifications. They were insulated from sensible heat within the inlet using a styrofoam block and a test tube of distilled water was attached to the inlet having a cotton wick to keep the wet bulb moist, (Figure 18).

Soil Carbon Dioxide Emission

Soil CO_2 respiration was estimated over a 24 hour period using a long-term NaOH adsorption method outlined by Anderson, (4), with a few modifications. The reagents were 1.0N fresh NaOH, 3.0N $BaCl_2$ solution, 1.0N HCl standardized, and phenolphthalein indicator. Materials used were metal cans, (15cm diameter and 17cm tall), 250ml beakers, 250 erlenmeyer flasks, a 20ml pipette, and small stands to support the beakers above the soil.

After placing the stand and beaker on the soil, 20ml of 1.0N NaOH was pipetted into the 250ml beaker and immediately covered with the can, and sealed by pushing about 3cm into the soil. Three random locations within each rowspacing were selected. An additional location was on bare soil, kept weed free and at least 2m from the soybeans. Two blank cans were set up likewise by sealing with a polyurethane sheet. The measurements were initiated on 11 July when the soybeans were 60cm tall at V7 growth and repeated every 7 days until 30 August. A separate can was placed on the bare soil surface in a similar fashion with a YSI Telethermometer 401 temperature probe inside to record temperatures during the 24 hour period. Maximum and minimum air temperatures and rainfall or irrigation amounts over the 24 hour period were also recorded.

Figure 18. Arrangement of aspirated psychrometers used in 1984.

After 24 hours, the NaOH solution was carefully transferred to the 250 ml flasks, stoppered, and transported to the laboratory for titrating. Any CO_2 released from the soil was assumed to be absorbed by the NaOH solution by the following reaction:

$$NaOH + CO_2 \longrightarrow NaHCO_3 + H_2O$$

Once in the laboratory, about 5 ml of 0.3N $BaCl_2$ solution was added to the flasks to precipitate the carbonate from Na_2CO_3 as $BaCO_3$. The flasks were then titrated with 1.0N HCl after adding a few drops of phenolphthalein. As mentioned by Anderson, (4), it was important to add and mix the HCl slowly to avoid contact with and possible dissolution of the precipitated $BaCO_3$. The color change was from white to pink. The CO_2 emission was calculated from:

$$CO_2\ (kg \cdot ha^{-1} \cdot day^{-1}) = (B-V) x N x 13.75,$$

where B is the mean ml HCl titrated in the blanks, V is ml HCl titrated in the sample, N is the normality of the acid and 13.75 is a conversion factor to obtain values in $kg \cdot ha^{-1} \cdot day^{-1}$.

Errors arise in this method from incomplete adsorption, increased air pressures within the can resulting in underestimations, transferring the NaOH, and titrating. Regardless, it has been recommended by Anderson, (4), as one method for allowing accurate measurements of the relative rates of soil CO_2 emission in situ.

Soil Temperatures

Soil temperatures were measured with the identical equipment used in 1983. Soil temperature probes were available to allow measurement of soil temperatures for three different set-ups:

1. at the 3cm depth in the row drill and middle for all row-spacings except 38cm,

2. at the 3, 5, and 10cm depth in the row drill and middle for the 51cm rowspacing, and

3. at the 3, 5, and 10cm depths in the row drill and middle for the 76cm rowspacing.

Soil temperatures were not measured in the 38cm rowspacing due to severe flooding and herbicide damage that produced a poor stand within the range of the extension cables.

The joints between the thermister leads and extension cables were suspended above the ground by wooden stakes and covered with plastic bags for easy changing. Leads were changed every two or three days to a new set-up. As in 1983, recalibration of the YSI Telethermometer was rare after about the first week of operation.

Leaf Area Index

The leaf area index was measured in a manner similar to that used in 1983. Determination of leaf area for leaf dry surface density, (LDSD), estimates was accomplished by drawing the leaf outline in 1mm grid paper and counting squares rather than cutting and weighing the leaf outline. Partitioning of the canopy into layers was omitted, the data being inferred from individual plant growth information. Four replications were used for each rowspacing. Sampling began on 25 June when plants were 45cm tall at V5 growth and repeated about every two weeks thereafter until 20 September.

Plant Growth

During LAI sampling, 10 representative plants were selected from random locations within each treatment for obtaining plant growth information. Plants were excised at the soil surface and immediately transported to the laboratory and placed into cold water. Data was collected on the plant height, number of petioles, length of petioles, and the stem weight, leaf weight, leaf area, pod number, pod weight, seed number, and seed weight in the upper four strata of canopy. The weights were dry weights obtained by drying at 70C in a forced air oven for 48 hours. It was important to process the plants immediately after collection because of the loss of turgor that occurred within two days.

Prior to final crop harvesting, five representative plants were selected from random locations within each treatment and data collected on height and stem weight, pod number, pod weight, seed number, and seed weight at each node.

In a comparison study, leaf area index was calculated by multiplying the average leaf area per plant by the number of plants per hectare and dividing by the hectare area. This method of determining LAI was inconsistent, giving lower values for the 51- and 76-cm rowspacings and higher values for the narrower rows when compared to the more accepted destructive sampling method, (Table 15). This may explain some of the high LAI values in the literature recorded for narrow rows using the individual plant method, (see 145 for example). Overestimation of LAI by individual plant analysis in the narrow rows may result from not compensating for the leaf area exceeding the hectare border.

Table 15. Leaf area index for 1984 for selected dates.

row-spacing (cm)	date					
	6/25		7/11		7/24	
	method[a]					
	DS	IP	DS	IP	DS	IP
76	0.4	0.4	2.1	1.5	2.9	2.9
51	0.6	0.4	1.7	1.6	3.1	2.8
38	0.5	0.6	1.8	2.5	3.0	2.8
25	0.3	1.0	2.2	2.5	2.8	4.8
13	0.4	1.0	2.5	2.7	3.1	6.7

[a]DS is destructive sampling and IP is the individual plant sampling method.

Apparent Evapotranspiration

Apparent evapotranspiration was estimated using the same technique employed in 1983. Three replications were used for each treatment.

2. RESULTS AND DISCUSSION

Canopy Carbon Dioxide

Canopy CO_2 measurements were made from late vegetative growth until physiological maturity. Because of the poor stand in the 38cm rowspacing, no measurements were taken. Five separate days of measurement were recorded for each of the remaining treatments. Winds were favorable, rarely reaching a coding of 2, (upper half of canopy disturbed). Obtaining accurate measurements past 2100 hour was difficult on some days because of low temperatures and high humidity, which resulted in high water contents in the airstream that were difficult to remove.

A distinct diurnal pattern was evident in the canopy CO_2 levels, (refer to pages 131 through 134 in Appendix A). Midday depressions were evident due to active photosynthetic assimilation, with concentrations around 330 $\mu L \cdot L^{-1}$ as compared with 340 $\mu L \cdot L^{-1}$ at 6 meter height. In 1983, midday depressions as low as 300 $\mu L \cdot L^{-1}$ were observed, but these were biased to days with little wind. As in 1983, a CO_2 "bloom" was noticed shortly after sunset, with most of the excess respired CO_2 thought to be coming from the glycolate pathway.

After adjusting for the diurnal effects, mean horizontal [CO_2] did not appear to be significantly different in an analysis of covariance, which was fitted to each days measurements, (Tables 16 through 19). To simplify some of the cumbersome statistics needed to observe horizontal divergences in [CO_2] at each strata and among treatments, measurements between R1 and R5 growth were pooled and a polynomial regression equation fitted to the data. This encompassed three days of measurement per rowspacing and approximately 15 observations per sampling location. Horizontal location was designated as 0cm in the row drill and 7.5-, 12.5-, 25.5-, and 38-cm for the row middles in the 13-, 25-, 51-, and 76-cm rowspacings respectively. The resulting equation, with a coefficient of determination of 0.73 was:

$$CO_2 = 586.1 - 7.89t - 1.65t^2 + 0.085t^3 - 0.16ht + 0.45hor + 0.0039(ht)(hor) + 0.030(t)(ht) - 0.0046(t^2)(ht) + 0.00015(t^3)(ht) - 0.058(t)(hor) - 0.0036(t^2)(hor) + 0.00024(t^3)(hor),$$

where hor is horizontal location, t is time of day, and ht is height. A computer plot of the resulting model for specific hours of the day revealed that the [CO_2] at midday in the row middles, (1400 hour), was lower for the 76cm rowspacing than the narrower rowspacings, (see page 135 in Appendix A). This can be observed by comparing pages 131 and 134 in Appendix A. Greater light penetration and a higher leaf density in the lower strata of the row middles for the wider rows may explain the lower [CO_2] observed at midday and the increased seed production in the lower strata, (see page 102

Table 16. Analysis of covariance for 13cm rowspacing. Time of day (T) is covariate and horizontal location, (H), is a class variable.

DAY [a]		Model	Error	T	T*T	T*T*T	H	T*H	T*T*H	T*T*T*H	R-SQUARE
	d.f.	7	42	1	1	1	1	1	1	1	
50	S.S.	299834.0	50349.5	31395.0	256278.5	11465.7	64.5	491.6	7.2	131.6	0.8562
	P>F	0.0001	-	0.0001	0.0001	0.0004	0.7790	0.4395	0.9254	0.6887	
		7	52	1	1	1	1	1	1	1	
66		167294.0	118690.4	86994.6	76825.8	1411.2	433.1	100.5	255.8	1273.7	0.5849
		0.0001	-	0.0011	0.0001	0.4353	0.6699	0.8340	0.7392	0.4584	
		7	52	1	1	1	1	1	1	1	
80		167934.2	157630.6	62777.6	101870.6	3253.6	4.8	14.9	0.5	12.3	0.5158
		0.0001	-	0.0001	0.0001	0.3050	0.9685	0.9443	0.9901	0.9495	
		7	52	1	1	1	1	1	1	1	
95		257995.5	52617.0	87015.4	118660.9	49865.4	917.7	289.4	1139.2	107.4	0.8306
		0.0001	-	0.0001	0.0001	0.0001	0.3450	0.5951	0.2936	0.7459	
		7	42	1	1	1	1	1	1	1	
115		42904.6	28049.6	5935.9	24338.8	12315.1	219.6	13.1	18.2	13.9	0.6047
		0.0001	-	0.0048	0.0001	0.0001	0.5693	0.8892	0.8698	0.8860	

[a]DAY is day after germination, d.f. is degrees of freedom, S.S. are Type I sum of squares, and P>F is the probability of a greater F-value.

Table 17. Analysis of covariance for 25cm rowspacing. Time of day, (T), is covariate and horizontal location, (H), is a class variable.

DAY [a]		Model		T	T*T	T*T*T	H	T*H	T*T*H	T*T*T*H	R-SQUARE
	d.f.	7	52	1	1	1	1	1	1	1	
60	S.S.	452623.7	36993.6	1461.9	425226.2	25606.1	39.6	48.7	179.3	61.9	0.9244
	P>F	0.0001	-	0.1577	0.0001	0.0001	0.8145	0.7947	0.6178	0.7691	
		7	52	1	1	1	1	1	1	1	
74		125449.6	86364.4	52871.6	67137.5	4760.6	423.4	66.3	87.3	103.0	0.5923
		0.0001	-	0.0001	0.0001	0.0964	0.6158	0.8424	0.8196	0.8044	
		7	52	1	1	1	1	1	1	1	
101		40939.0	12252.0	12742.2	25798.8	2218.1	120.8	5.4	10.7	43.1	0.7700
		0.0001	-	0.0001	0.0001	0.0037	0.7787	0.8815	0.8337	0.6738	
		7	42	1	1	1	1	1	1	1	
122		26655.5	8864.0	1151.5	17927.3	7395.6	70.3	74.6	0.6	35.7	0.7504
		0.0001	-	0.0243	0.0001	0.0001	0.5670	0.5554	0.9587	0.6830	

[a]DAY is day after emergence, d.f. is degrees of freedom, S.S. are Type I sum of squares, P>F is the probability of a greater F-value.

Table 18. Analysis of covariance for 51cm rowspacing. Time of day, (T), is covariate and horizontal location, (H), is a class variable.

DAY[a]		Model	Error	T	T*T	T*T*T	H	T*H	T*T*H	T*T*T*H	R-SQUARE
	d.f.	7	42	1	1	1	1	1	1	1	
57	S.S.	367964.1	41614.7	5420.2	359347.5	11523.1	233.2	368.7	63.9	61.9	0.8984
	P>F	0.0001	-	0.0242	0.0001	0.0014	0.6301	0.5451	0.8007	0.9314	
		7	52	1	1	1	1	1	1	1	
71		65368.7	65413.9	1973.9	30980.1	30383.1	1419.6	38.8	21.1	25.3	0.4998
		0.0001	-	0.2159	0.0001	0.0001	0.2812	0.8613	0.9875	0.8876	
		7	52	1	1	1	1	1	1	1	
85		42453.0	209869.4	1848.5	40138.1	213.8	142.3	57.0	11.1	42.3	0.1632
		0.1854	-	0.5016	0.0027	0.8189	0.8518	0.9059	0.9584	0.9188	
		7	52	1	1	1	1	1	1	1	
99		41063.7	67995.3	87114.2	216716.6	35608.1	462.6	726.0	435.6	0.7	0.8338
		0.0001	-	0.0001	0.0001	0.0001	0.5546	0.4596	0.5663	0.9822	
		7	42	1	1	1	1	1	1	1	
120		1501.4	7495.0	568.6	841.3	42.0	8.1	5.4	7.5	28.5	0.1669
		0.3230	-	0.0815	0.0356	0.6302	0.8324	0.8625	0.8390	0.6914	

[a]DAY is day after emergence, d.f. is degrees of freedom, S.S. are Type I sum of squares, P>F is the probability of a greater F-value.

Table 19. Analysis of covariance for 76cm rowspacing. Time of day, (T), is covariate and horizontal location, (H), is a class variable.

DAY[a]		Model	Error	T	T*T	T*T*T	H	T*H	T*T*H	T*T*T*H	R-SQUARE
	d.f.	7	42	1	1	1	1	1	1	1	
44	S.S.	370898.0	10997.2	119981.0	229283.8	21517.0	8.7	16.1	79.9	11.8	0.9712
	P>F	0.0001	-	0.0001	0.0001	0.0001	0.8562	0.8054	0.5836	0.8326	
		7	52	1	1	1	1	1	1	1	
64		343060.6	23887.7	195311.1	145033.6	2455.5	28.1	0.3	6.0	235.9	0.9346
		0.0001	-	0.0001	0.0001	0.0251	0.8056	0.9810	0.9097	0.4777	
		7	52	1	1	1	1	1	1	1	
78		275466.1	23297.9	128068.3	128893.7	17785.1	106.6	296.6	147.8	170.0	0.9220
		0.0001	-	0.0001	0.0001	0.0001	0.6294	0.4196	0.5683	0.5405	
		7	42	1	1	1	1	1	1	1	
92		106268.1	44018.8	2845.5	94944.2	8237.5	72.5	152.3	9.7	6.3	0.7071
		0.0001	-	0.1069	0.0001	0.0076	0.7938	0.7049	0.9238	0.9385	
		7	42	1	1	1	1	1	1	1	
113		12411.0	37913.0	1890.4	9158.7	951.9	82.4	1.8	232.9	92.9	0.2466
		0.0001	-	0.1553	0.0037	0.3103	0.7641	0.9644	0.6141	0.7499	

[a]DAY is day after emergence, d.f. is degrees of freedom, S.S. are Type I sum of squares, P>F is the probability of a greater F-value.

However, studies on canopy light interception have shown that over 90 percent of the total incoming solar radiation is absorbed in the uppermost canopy regions, (53). A more efficient harvest of solar radiation on a field area basis probably occurred in the 13cm row-spacing due in part to the much higher number of plants per hectare, (Table 20).

Table 20. Plant populations in 1984.

rowspacing (cm)	$plants \cdot ha^{-1}$
13	594,000
25	393,000
38	268,000
51	209,000
76	145,000

Soil Carbon Dioxide Emissions

Soil CO_2 emissions were measured on a weekly basis from 21 June through 30 August. Other data collected included precipitation, average air temperature, plant height, and plant growth. A correlation analysis of the season's data is shown in Table 21. There was little correlation of CO_2 evolution with any of the other variables. The expected correlation with temperature was not evident, (r = 0.09).

Table 21. Correlation coefficients for 1984 soil CO_2 emissions

	DAY	HT	GRW	RS	RAIN	CO2RP	TEM
DAY	1.00						
HT	.91	1.00					
GRW	.96	.96	1.00				
RS	-.02	-.03	-.02	1.00			
RAIN	.08	.03	-.05	-.01	1.00		
CO2RP	.02	.14	.06	.14	.07	1.00	
TEM	.47	.74	.64	-.02	-.11	.09	1.00

[a]DAY is day after emergence, HT is plant height, GRW is growth, RS is rowspacing, RAIN is precipitation, CO2RP is CO_2 emission, and TEM is average air temperature.

This is because the soil chamber was in place over a 24 hour period. Release of CO_2 by the soil during high temperature extremes probably avoided detection due to readsorption by the soil, (because of pressure gradients), and adsorption in condensed water within the soil chamber, (greater amounts of condensed water were observed in the soil chambers following very hot days).

There was a lot of variation in soil CO_2 emissions when measured using the adsorption technique as observed on 12 July, where no significant difference was noticed between the bare soil and 25cm rowspacing, the mean difference between them being 186.7 $kg \cdot ha^{-1} \cdot day^{-1}$, (Table 22). However a few general trends are evident. The bare soil treatment, having little root activity, was always lower than the

Table 22. Soil CO_2 emissions for 1984.

rowspacing (cm)	CO_2 evolution ($kg \cdot ha^{-1} \cdot day^{-1}$)[a] date (mo/day)							
	6/21	6/26	7/12	7/20	8/3	8/9	8/17	8/30
bare soil	160.9ab	65.8b	60.8a	66.0b	126.7a	58.8c	54.3c	48.1b
13	175.9a	106.3a	244.0a	182.8ab	236.9a	175.5abc	152.1ab	101.1ab
25	193.5a	83.9ab	247.5a	193.7ab	208.1a	200.3ab	148.2ab	165.4a
38	-	95.3ab	195.0a	200.7ab	142.0a	238.6a	127.8ab	158.3ab
51	102.5c	66.7b	125.5a	203.3ab	149.4a	153.3abc	193.5a	151.1ab
76	120.6bc	100.6a	178.8a	247.9a	214.2a	101.5bc	164.9ab	101.5ab

[a]Column means followed by the same letter are not significantly different at the 0.05 level of probability according to Duncan's New Multiple Range test.

cropped treatments with the exception of the initial sampling of 21 June. Titration errors may have existed because the 21 June value of 160.9 $kg \cdot ha^{-1} \cdot day^{-1}$ was much higher than the subsequently measured values, which averaged around 60 $kg \cdot ha^{-1} \cdot day^{-1}$. On the 21 June sampling, the 13- and 25-cm rows had significantly higher soil evolution rates than the 51- or 76-cm rows. This may have been due to a more uniformly developed root system for the narrow rows at that time. The CO_2 emissions for the rest of the season varied among treatments and in most instances were similar.

Soil Temperatures

Initially, all the soil temperature data for the season was pooled and statistically analyzed in a preliminary investigation. An overall analysis of covariance, using hour of measurement over 24 hours as the covariate, revealed no significant differences among rowspacings or locations when analyzed over the whole seasons data, (Table 23). Daily analysis of covariance revealed similar trends, (not shown).

Soil temperatures for all rowspacings at 33, 75, and 114 days after emergence are shown on pages 137 through 139 in Appendix B, respectively. Most of the variation among treatments and location occurred between 1500 and 1900 hours. Prior to canopy closures, (occurring between 50 and 65 days), the temperature in the row middles were generally higher during this time period. Therefore, an analysis of covariance was used to test for differences between 1500 and 1900 hour. The overall analysis revealed no significant difference,

Table 23. Seasonal analysis of covariance for soil temperatures in all treatments in the row middle and drill. Type III sum of squares and least square means shown.

source[a]	d.f.	sum of squares	F-value	Prob>F
RS	3	0.0203	0.22	0.8790
L	1	0.0027	0.09	0.7645
RS*L	3	0.0120	0.13	0.9370
H	1	12.5295	414.36	0.0001
HR*RS	3	0.0352	0.39	0.7646
HR*L	1	0.0017	0.06	0.8105
HR*L*RS	3	0.0211	0.23	0.8734
error	1735	64.9341	-	-

LEAST SQUARES MEANS

rowspacing (cm)	location	temp. (C)
13cm	middle	23.7
13cm	drill	23.7
25cm	middle	23.6
25cm	drill	23.6
51cm	middle	24.1
51cm	drill	24.1
76cm	middle	24.0
76cm	drill	23.9

[a]RS is rowspacing, L is location, and HR is hour of day.

(Table 24). However, the analysis for individual days revealed significant treatment and location effects. These treatment effects were between 30 and 35 days when canopy closure was occurring in the 13- and 25-cm rows and were noticeable again after 100 days growth when plants were near physiological maturity. This is evident on days 33 and 114 in Table 25. The specific contrast tests for significance among rowspacings shown in Table 25 revealed that most of the variation on day 33 occurred between the 13- and 25-cm rows against the 75cm, (note the contribution of total sum of squares in addition to the probability of a greater F-value). This can be seen on page 140 of Appendix B, where temperatures for the 13- and 76-cm rows are contrasted at 33 and 75 days growth. Temperatures were 6 degrees higher between the rows in the 76cm than the 13cm rowspacing at the 1500 hour measurement on day 33. At no time were significant differences noted between row locations.

The measurements of soil temperature with depth in the 51- and 76-cm rows were statistically analyzed between 1500 and 1900 hour. There was no significant difference in soil temperatures between the row middles or drill and no interaction with depth and location was present, however temperatures varied significantly with depth (note the Prob>F for D on Table 26). The individual contrasts for depth in Table 26 reveal most of the variation with depth occurring between 3- and 10-cm as expected. There was a slight tendency for higher soil temperatures in the row middles at all depths for about 3 to 4 hours at midday early in the season, (pages 141 and 142 of

Table 24. Analysis of covariance for soil temperature between 1500 and 1900 hour pooled over all sampling dates.

source[a]	df	sum of squares[b]	F-value	Prob>F
RS	3	7.27	0.18	0.9062
L	1	0.076	0.01	0.9397
RS*L	3	2.49	0.06	0.9740
HR	1	130.66	9.84	0.0019
HR*RS	3	4.97	0.12	0.9412
HR*L	1	0.044	0.00	0.9541
HR*RS*L	3	2.044	0.05	0.9791
error	352	4673.78		

LEAST SQUARES MEANS

rowspacing (cm)	location	mean
13	drill	26.1
13	middle	26.6
25	drill	26.2
25	middle	26.2
51	drill	27.0
51	middle	27.1
76	drill	26.8
76	middle	26.8

[a]RS is rowspacing, L is location, and HR is sampling hour.

[b]Type III sum of squares.

Table 25. Analysis of covariance for soil temperatures between 1500 and 1900 hour for specific days after emergence.

source[a]	df	sum of squares[b]	F-value	Prob>F
		day 18		
RS	3	0.51	0.62	0.6070
L	1	0.09	0.31	0.5840
RS*L	3	0.29	0.35	0.7926
HR	1	85.08	308.21	0.0001
RS*HR	3	0.36	0.43	0.7306
(13vs76cm)	(1)	0.18	0.64	0.4314
(25vs76cm)	(1)	0.19	0.68	0.4165
(13vs51cm)	(1)	0.00	0.02	0.8976
L*HR	1	0.15	0.55	0.4636
HR*RS*L	3	0.17	0.22	0.8709
error	24	6.63		
		day 33		
RS	3	10.95	5.64	0.0045
L	1	0.014	0.02	0.8841
RS*L	3	2.63	1.37	0.2768
HR	1	49.61	77.32	0.0001
RS*HR	3	8.33	4.33	0.0142
(13vs76cm)	(1)	3.56	5.56	0.0269
(25vs76cm)	(1)	11.11	17.32	0.0004
(13vs51cm)	(1)	0.82	1.28	0.2693
HR*L	1	0.01	0.02	0.8902
HR*RS*L	3	2.14	1.11	0.3643
error	24	15.34		
		day 75		
RS	3	0.41	1.18	0.3382
L	1	0.15	1.28	0.2688
RS*L	3	0.06	0.18	0.9104
HR	1	2.91	24.11	0.0001
RS*HR	3	0.21	0.61	0.6168
(13vs76cm)	(1)	0.24	2.05	0.1653
(25vs76cm)	(1)	0.01	0.01	0.9198
(13vs51cm)	(1)	0.37	3.13	0.0894
HR*L	1	0.11	0.96	0.3359
RS*L*HR	3	0.06	0.18	0.9099
error	24	2.81		
		day 114		
RS	3	1.72	10.39	0.0001
L	1	0.02	0.39	0.5362
RS*L	3	0.09	0.55	0.6513
HR	1	0.08	1.42	0.2453
RS*HR	3	1.58	9.57	0.0002
(13vs76cm)	(1)	0.23	3.75	0.0645
(25vs76cm)	(1)	0.67	12.15	0.0019
(13vs51cm)	(1)	0.58	10.49	0.0035
HR*L	1	0.03	0.51	0.4823
RS*L*HR	3	0.08	0.51	0.6798
error	24	1.33		

[a]RS is rowspacing, L is location, and HR is sampling hour.

[b]Type III sum of squares.

Table 26. Analysis of variance for 51- and 76cm rowspacing, soil temperatures with depth and location between 1500 and 1900 hour.

source[a]	df	sum of squares[b]	F-value	Prob>F
RS	1	36.04	1.43	0.2316
D	2	189.65	3.78	0.0235
(3cm vs 10cm)	(1)	177.19	7.06	0.0081
(5cm vs 10cm)	(1)	94.33	3.76	0.0531
(3cm vs 5cm)	(1)	12.95	0.51	0.4729
L	1	7.06	0.28	0.5960
RS*D	2	7.40	0.15	0.8629
RS*L	1	1.24	0.05	0.8244
D*L	2	0.95	0.02	0.9812
error	566	14208.79		

[a] RS is rowspacing, D is depth, and L is location.

[b] Type III sum of squares.

Appendix B), but this was not observed after midseason, (compare with pages 143 and 144 of Appendix B). Note the high mid-row soil temperature in excess of 30C between 1500 and 1700 hours on pages 141 and 142 of Appendix B. Root activity is significantly reduced at these high temperatures, (131).

Leaf Area Index

The leaf area index are shown in Table 27. The highest values ranged from 3.6 to 4.0 on the 21 August sampling when the plants were at R5 growth, (late pod fill). The overall LAI was very similar among rowspacings throughout most of the 1984 growing season. There was considerable canopy variation among treatments and replications on the 25 June sampling as seen by the high coefficient of variation values of 78. This was due in part to a large water runoff area that caused poor plant survival during early season thunderstorms. It should be mentioned though, that this was a problem only in the field area used to measure LAI.

Plant Growth

An attempt was made to quantify the plant growth of the soybean communities in the different rowspacings. The individual plant data were used to calculate three growth analysis parameters; relative growth rate (RGR), net assimilation rate (NAR), and leaf area ratio (LAR). The growth parameters were calculated from the periodic measurements of the average plant leaf area, A, and dry weight, W. The plotted values for A and W may be seen in Figures 19 and 20.

Table 27. Leaf area index for 1984.

rowspacing (cm)	sampling date (mo/day)[a] 6/25	7/11	7/24	8/7	8/21	9/20
13	0.4a	2.5a	3.1a	3.2a	3.6a	1.9ab
25	0.4a	2.2ab	2.8a	2.9a	3.6a	1.9ab
38	0.5a	1.8cd	3.0a	3.1a	3.9a	1.8b
51	0.6a	1.7d	3.1a	2.8a	3.7a	2.7a
76	0.4a	2.1bc	2.9a	2.9a	4.0a	2.0ab
C.V.[b]	78	11	11	8	11	24
growth	V6	V7	R2	R5	R5	R7

[a]Column means followed by the same letter are not significantly different at the 0.05 level of probability according to Duncan's New Multiple Range test.

[b]Coefficient of variation.

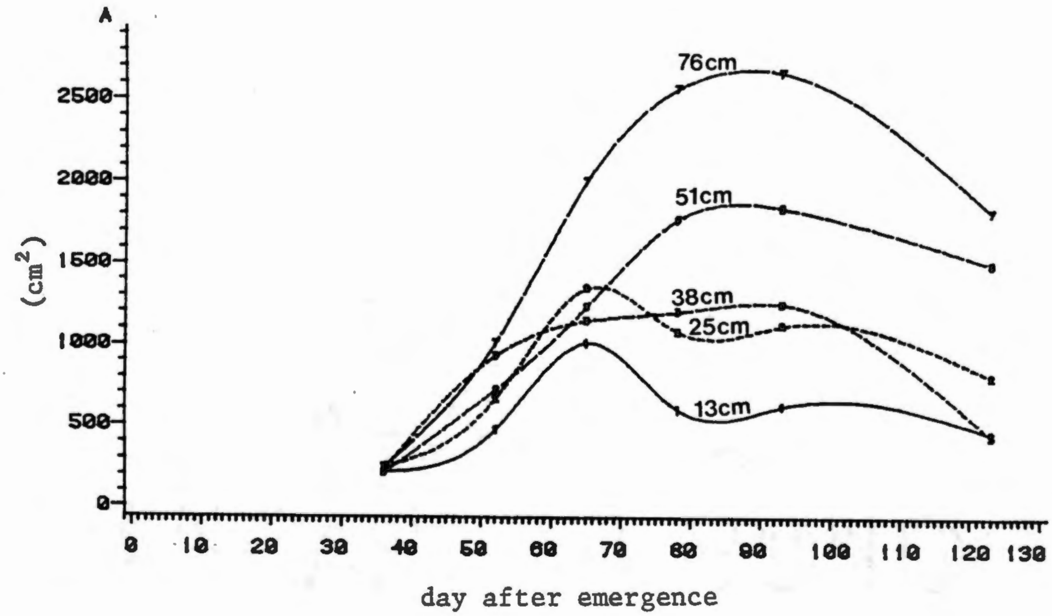


Figure 19. Total leaf area per plant over the 1984 growing season.

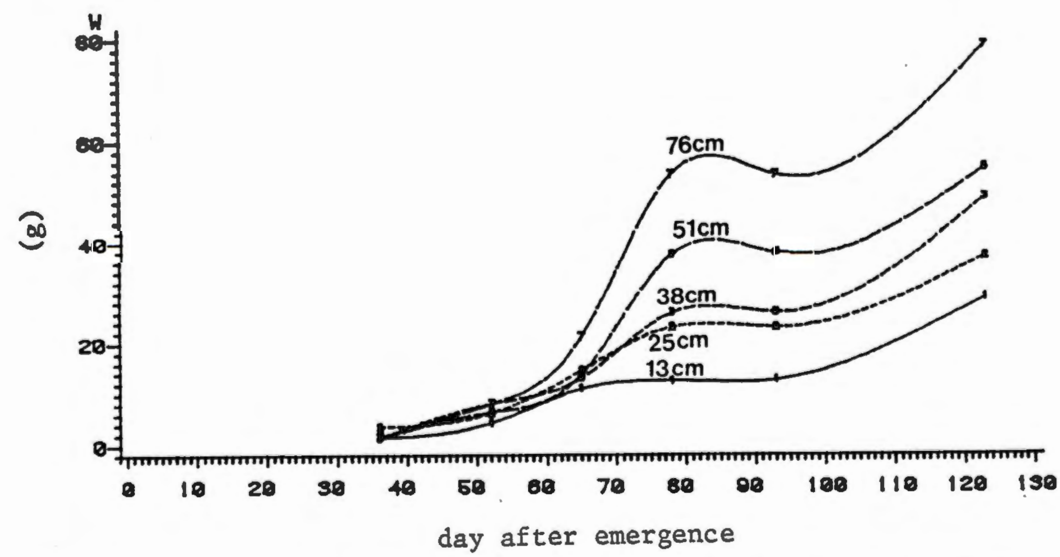


Figure 20. Total plant dry weight through the 1984 growing season.

Using least squares regression, (SAS general linear model), a polynomial curve was formulated to A and W for the determination of instantaneous values of RGR, NAR, and LAR based on the following equations, (107):

$$RGR = \frac{1}{W}\frac{dW}{dt} ,$$

$$NAR = \frac{1}{A}\frac{dW}{dt} ,$$

$$LAR = \frac{A}{W} .$$

The polynomial equations are shown in Table 28 and a good relationship was obtained as evidenced by the high coefficients of determination except for A in the 13- and 25-cm rowspacings. A log transformation was necessary for these curves resulting in the following equations:

$$A = e^{-0.733 + 0.263D - 0.003D^2 + 0.0000107D^3} \text{ and}$$

$$A = e^{-0.625 + 0.256D - 0.00272D^2 + 0.00000915D^3}$$

for the 13- and 25-cm rowspacings respectively. The variable, D, is day after emergence. These exponential equations were more accurate at predicting A than the original polynomials, having coefficient of determination values of 0.87 and 0.97 compared with the former values of 0.68 and 0.86 for the 13- and 25-cm rows respectively.

The RGR of a plant by definition is "the increase of plant material per unit of material present per unit of time," (107). In Figure 21A, note that RGR declines rapidly between 40 and 55 days,

Table 28. Regression equations used in plant growth models and corresponding coefficients of determination (R^2).

rowspacing (cm)	equation[a]	intercept	coefficients[b] D	D*D	D*D*D	R^2
13	W	-34.69	1.576	-0.0196	0.0000894	0.97
	dW/dt	1.576	-.0392	.000268	-	.97
	A	-2768.250	128.611	-1.489	0.00534	.68
25	W	-9.970	.306	.00146	.00000692	.97
	dW/dt	.306	.00292	.0000207	-	.97
	A	-3001.003	130.270	-1.285	.00388	.86
38	W	-24.525	.916	.00703	.0000359	.97
	dW/dt	.916	.0141	.000108	-	.97
	A	-2317.670	95.562	-.705	.000895	.99
51	W	25.746	-1.775	.0356	-.000157	.95
	dW/dt	-1.775	.0712	-.000471	-	.95
	A	-548.223	-.475	.764	-.00508	.99
76	W	29.327	-2.224	.0467	-.000207	.96
	dW/dt	-2.224	.0934	-.000621	-	.96
	A	-1519.546	24.856	.886	-.00706	.99

[a] Where W is total plant weight and A is total plant leaf area.

[b] Based on A or W = $\beta_o + \beta_1 D + \beta_2 D^2 + \beta_3 D^3$; β is the coefficient and D is day after emergence between 30 and 130 days.

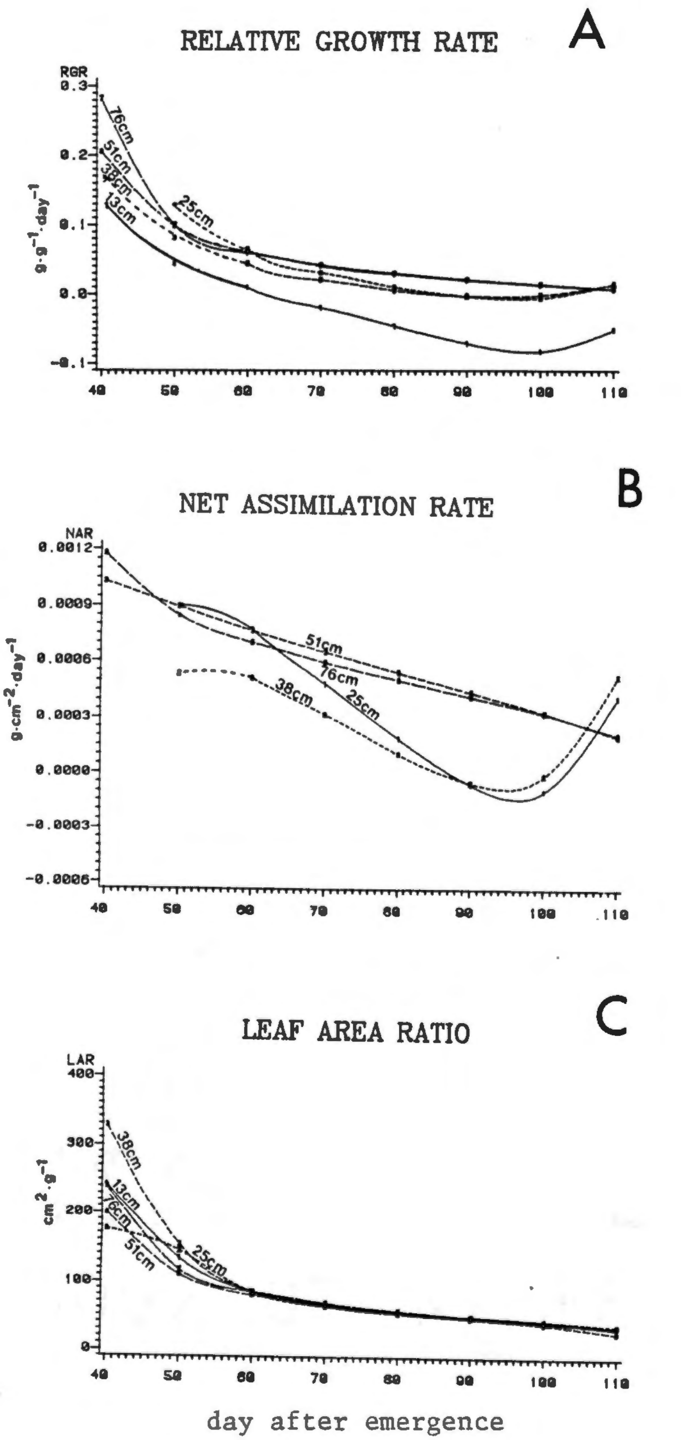


Figure 21. Growth characteristics; A), relative growth rate, B), net assimilation rate, C), leaf area ratio.

then shows a much slower decline from 60 to 120 days. This appears to be a two-phase system that is highly associated with the onset of reproductive growth, which occurred around 60 days. Phase I, the vegetative phase, is characterized by rapid vegetative weight gain and increased leaf area. Phase II, the reproductive phase, is characterized by a much slower weight gain as a greater proportion of assimilated carbon is utilized in the production of energy rich carbohydrates. The RGR of the 13cm rowspacing lags behind the other treatments. This is probably due to a comparative reduction in total leaf area around day 70, (Figure 19, page 94), which has been highly related to RGR and NAR in soybeans, (24).

Net assimilation rate is defined by Radford, (107), as "the increase of plant material per unit of assimilatory material per unit of time." The plotted curves for NAR are shown in Figure 21B. The NAR for the 76- and 51-cm rows were similar and distinctly higher than the curves for the 38- and 25-cm rows, particularly during reproductive growth. Buttery, (24), also noted slightly higher NAR values with increased rowspacing. The curve for the 13cm rowspacing is not shown due to a relatively poor empirical fit for A.

Radford, (107), defines LAR as "the ratio of the assimilatory material per unit of plant material present." During vegetative growth, the narrowest rows tended to have slightly higher LAR values, probably due to greater competition for light and formation of thinner main branches. However, the values of LAR were very similar for the rowspacings studied after onset of the reproductive growth period,

(Figure 21C). The weight gain per plant during reproductive growth is regulated by the amount of leaf area available to intercept maximum solar radiation. This available leaf area is affected by rowspacing, which influences canopy closure and lower leaf abscission. The lower leaf abscission can be observed by comparing Figure 21A with Figures 22B and 22C. During early reproductive growth, (days 50 to 60), greater leaf abscissions occur in the upper and lower middle zones of the narrower rows, (Figures 22B and 22C), lowered the LAR to be equivalent to the wider rowspacings. Less leaf abscission probably occurred due to decreased sunlight penetration.

There was no rowspacing effect on total node number, with most plants having 13. In terms of total seed production per node, the 51 and 76-cm rows produced significantly higher yields in the lower nodes, particularly nodes 2 through 5, than the other treatments, (Table 29 and Figure 23A). This was attributed to seed contributions from lateral branches, which were greater in number for the 51- and 76-cm rowspacings than the other treatments. Parks and Manning, (101), reported a significant decrease in the beans produced on the lateral branches with a decrease in rowspacing for Essex soybeans. Total seed production in the uppermost nodes was generally higher with increasing row widths, (Table 29).

The average seed weights per node were significantly lower in the 13- and 25-cm rows until about the fifth node, (Table 30). There was no significant difference among the treatment average seed weights in nodes 6 to 13, with an average value of 0.14 $g \cdot seed^{-1}$, (Table 30 and Figure 23B). The reduced seed weights in the lower nodal positions

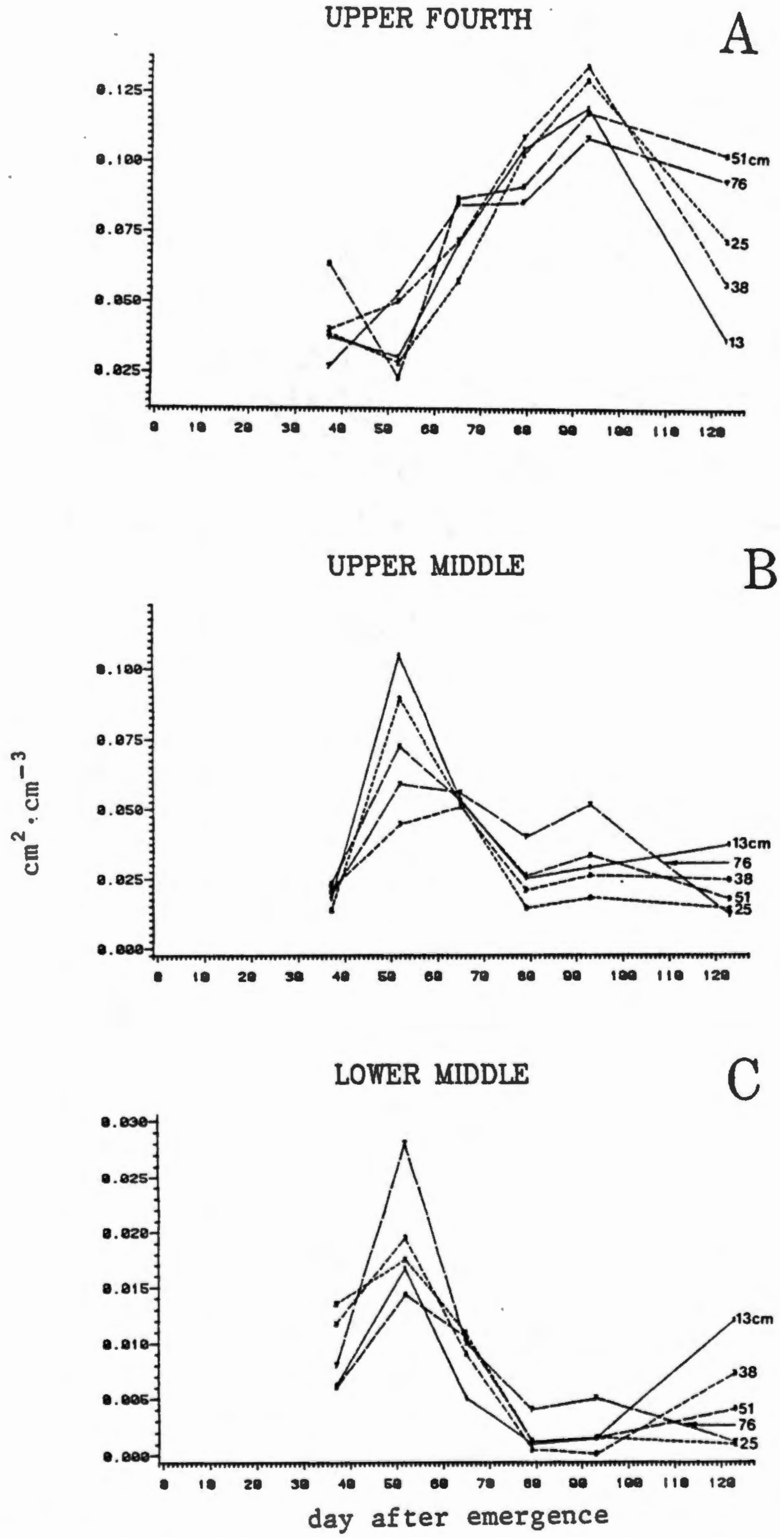


Figure 22. Leaf area density in A), the upper fourth, B), upper middle, and C), lower middle quarter of canopy.

Table 29. Total seed production, (g), per plant by node for 1984.

rows	node[a]												
(cm)	1	2	3	4	5	6	7	8	9	10	11	12	13
76	0a	4.19a	5.02a	7.64a	5.41a	2.11ab	3.00a	3.01a	2.48a	3.12a	3.14a	4.26a	4.11a
51	0a	1.36b	4.90a	6.47a	4.83ab	2.84a	1.70b	1.82b	2.47a	2.31a	2.48ab	1.84b	4.67a
38	0a	0.12b	2.00ab	2.66b	2.30bc	2.02ab	2.45ab	2.20b	2.28a	2.15a	2.64ab	2.78ab	4.61a
25	0a	0c	0.42b	1.61b	1.78c	1.38ab	1.65b	2.00b	2.02a	2.20a	1.94ab	2.31b	2.77b
13	0a	0c	0.14b	1.20b	1.20c	0.73b	1.66b	0.82c	1.08b	1.22b	1.10b	1.40b	2.42b

[a]Column values followed by the same letter are not significantly different at the 0.05 level of probability according to Duncan's New Multiple Range test.

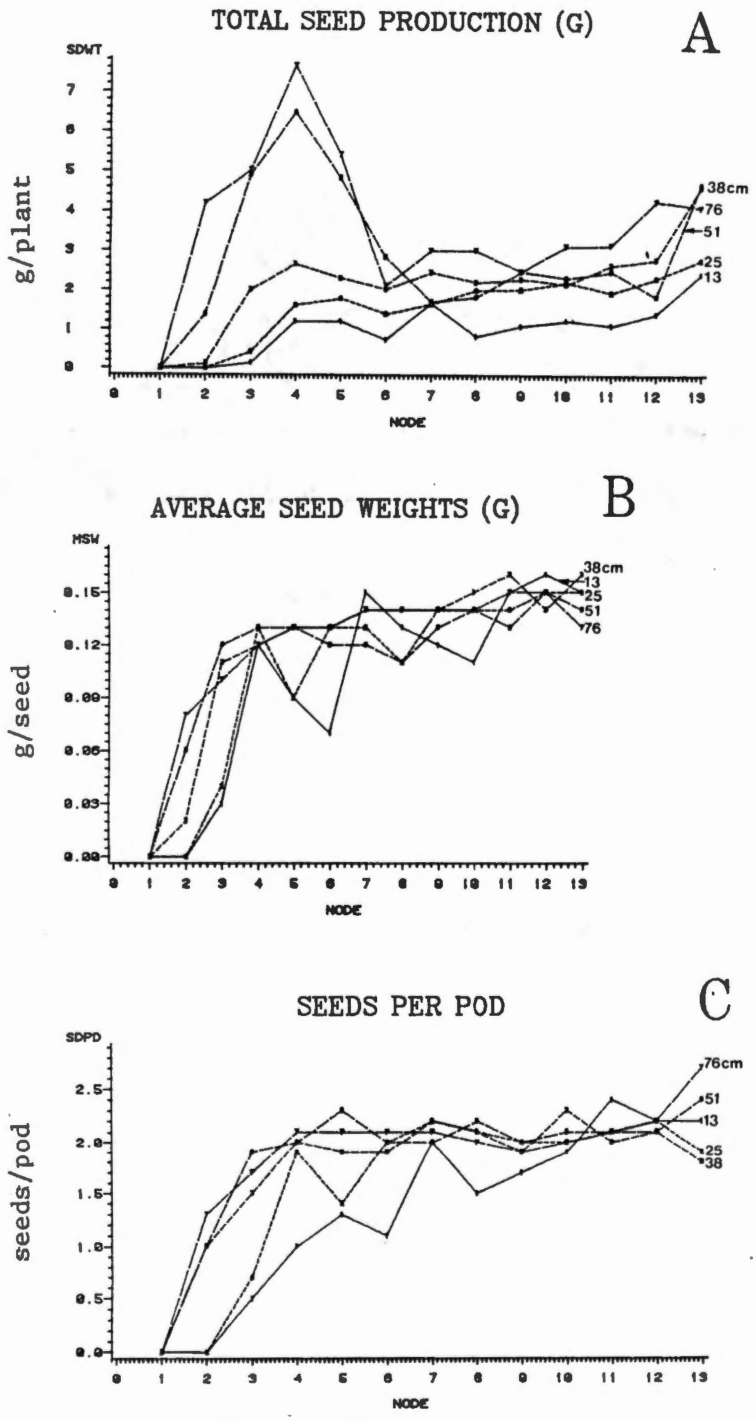


Figure 23. Fruiting characteristics in 1984; A) total seed production, B), average seed weights, and C), average number of seeds per pod for each node.

Table 30. Average seed weight, (g), by nodes for 1984.

rows	node[a]												
(cm)	1	2	3	4	5	6	7	8	9	10	11	12	13
76	0a	0.08a	0.10a	0.12a	0.13a	0.13a	0.14ab	0.14a	0.14a	0.14a	0.15ab	0.15a	0.13a
51	0a	0.06ab	0.12a	0.13a	0.13a	0.12a	0.12ab	0.11a	0.13a	0.14a	0.13b	0.15a	0.14a
38	0a	0.02b	0.11a	0.12a	0.13a	0.13a	0.14ab	0.14a	0.14a	0.15a	0.16a	0.14a	0.16a
25	0a	0c	0.04b	0.13a	0.09a	0.13a	0.13ab	0.11a	0.14a	0.14a	0.14ab	0.15a	0.15a
13	0a	0c	0.03b	0.12b	0.09a	0.07b	0.15a	0.13a	0.12a	0.11a	0.15ab	0.16a	0.15a

[a]Column values followed by the same letter are not significantly different at the 0.05 level of probability according to Duncan's New Multiple Range test.

is probably due to the lack of sufficient carbohydrate translocation from the uppermost leaves, which intercept most the solar radiation and produce most of the carbohydrates. Stephenson and Wilson, (130), showed that pods in the axils of assimilating leaves were always the major sink. The lower nodes for the narrower rows did have fewer lateral branches and leaves. The heaviest seeds for all rowspacings were in the upper 4 nodes, (nodes 9 to 13). The average number of seeds per pod was not affected by rowspacing, (Table 31), and was around two, (Figure 23C). The seeds per pod averaged less than two until the third node for the 38-, 51-, and 76-cm rows, and until the sixth node for the 25- and 13-cm rows. By observing Figures 23A and 23B, it can be seen that by decreasing row widths and increasing plant populations, a proportionally greater production of the largest seeds possible, (those above node 6), will be in the upper plant area, which should aid mechanical harvesting and increase yields.

A harvest index was calculated for the treatments from the single plant data in three different aspects; by dividing the final total seed weight per plant by the total maximum plant dry weight during the season and by the total leaf weight in the upper fourth and upper half of the plant at R5 growth, (late pod fill). A harvest index gives some information about the relative proportion of plant manufactured carbohydrates allocated to the fruiting bodies, with higher values indicating more efficient utilization of intercepted carbon. The leaf weights in the upper fourth and upper half of the plant at R5 growth were selected to observe what influence the

Table 31. Seeds per pod for individual plant by nodes for 1984.

rows	node[a]												
(cm)	1	2	3	4	5	6	7	8	9	10	11	12	13
76	0a	1.3a	1.7a	2.1a	2.1a	2.1a	2.1a	2.0a	1.9a	2.0a	2.1a	2.2a	2.7a
51	0a	1.0a	1.9a	2.0a	2.3a	2.0a	2.0a	2.2a	2.0a	2.1a	2.1a	2.1a	2.4a
38	0a	1.0a	1.5ab	2.0a	1.9a	1.9a	2.2a	2.1a	1.9a	2.3a	2.0a	2.1a	1.8a
25	0a	0b	0.7bc	1.9a	1.4a	2.0a	2.2a	2.1a	2.0a	2.0a	2.1a	2.2a	1.9a
13	0a	0b	0.5c	1.0b	1.3a	1.1b	2.0a	1.5a	1.7a	1.9a	2.4a	2.2a	2.2a

[a]Column means not followed by the same letter are significantly different at the 0.05 level according to Duncan's New Multiple Range test.

assimilating surfaces have on final seed yield. The upper layers were chosen because this is the zone where most of the incoming solar radiation energy is absorbed. Maximum plant weights for all rowspacings were recorded on the 20 September sampling.

There was a slight tendency for lower harvest index values with decreasing rowspacing when calculated using the maximum plant weights, although a Duncan's New Multiple Range test of the means showed no significant differences, (Table 32). This may indicate that the overall efficiency of seed interception of assimilated carbon increases with row width, (and subsequent decrease in plant density), which is probably related to the lower seed production in the bottom nodes with decreasing row width, (Figure 23, page 102). However, final harvest yields, on a field basis, are usually greater with narrower rows and higher populations due to significantly more plants per acre. There did not appear to be a consistent relationship in the harvest index when calculated using the leaf weights in the upper fourth and upper half of the canopy during pod fill, (Table 32).

Apparent Evapotranspiration

There were periods of heavy rainfall in 1984 that caused excessive surface runoff which, being unaccounted for in the method used, resulted in erroneous values for the calculated apparent evapotranspiration. Therefore, values obtained during these periods were not analyzed. This left five periods of reliable data to study. A Duncan's New Multiple Range test was used to compare the means at each period. The results are shown in Table 33.

Table 32. Single plant harvest index values.

row width (cm)	Harvest index as calculated by dividing final seed yield by[a]: MTPWt.[b]	TFP	THP
13	0.44a	4.93a	3.93a
25	0.48a	3.53a	3.13a
38	0.48a	4.30a	3.63a
51	0.68a	5.02a	3.94a
76	0.55a	4.70a	3.28a

[a]Column means not followed by same letter are significantly different at the 0.05 level of probability according to Duncan's New Multiple Range test.

[b]MTPWt. is mean total plant weight, and TFP and THP are maximum leaf dry weights in the upper fourth and upper half of canopy respectively.

Table 33. Apparent evapotranspiration for selected periods in 1984.

	AET ($cm \cdot H_2O \cdot day^{-1}$)				
	7/6-7/20	7/20-7/27	8/3-8/10	8/16-8/24	8/31-9/7
	growth				
	V7-R1	R1-R2	R4-R5	R5	R5-R6
	days after emergence				
rowspacing (cm)	47-61	61-68	76-83	90-96	103-110
76	0.59a	0.82a	0.27a	0.61a	0.32a
51	0.71a	0.53bc	0.50a	0.58a	0.17a
38	0.47a	0.77ab	0.41a	0.56a	0.22a
25	0.57a	0.71abc	0.57a	0.56a	0.23a
13	0.56a	0.48c	0.52a	0.48a	0.33a

[a]Column means not followed by the same letter are significantly different at the 0.05 level of probability according to Duncan's New Multiple Range test.

As in 1983, there were no significant differences in water use except during early pod set, where the 13cm rowspacing tended to use less water than the others. Canopy closure had occurred in the 13-, 25-, and 38-cm rowspacings at 30, 37, and 50 days after emergence respectively. This did not seem to affect water use during the first period from 6-20 July. The 51cm rowspacing had canopy closure at 66 days, toward the end of the second measuring period. This did tend to reduce moisture use from 0.71 to 0.53cm $H_2O \cdot day^{-1}$, as was the case in the 13cm rows also, from 0.56 to 0.48cm $H_2O \cdot day^{-1}$. However, moisture use increased by as much as 0.20cm $H_2O \cdot day^{-1}$ in the remaining treatments. The moisture use among rowspacings was similar for the remainder of the season, with highest rates of around 0.70 cm $H_2O \cdot day^{-1}$ at early pod set and decreased to around 0.22 cm $H_2O \cdot day^{-1}$ in early September at R6 growth.

Some relationship between leaf area index and moisture use may have been present in the 20-27 July measurement period. A leaf area index measurement on 24 July showed the highest values of 3.1 for the 13- and 51-cm rowspacings, (Table 27, page 93), which also had the lowest apparent evapotranspiration of 0.48 and 0.53cm $H_2O \cdot day^{-1}$ respectively. It could be that the thicker canopies reduced evaporation from the soil surface as in 1983, however this is pure speculation because there was no statistical difference in LAI among treatments on 24 July, which ranged closely among treatments between 2.8 and 3.1. Canopy closure probably influences moisture use in the early growing periods rather than LAI. Overall, moisture use for

1984 varied considerably among treatments and sampling periods. The apparent evapotranspiration was similar among treatments except for one period from 61 to 68 days after emergence, when plants were in early pod set.

Yields

Yields were obtained from a randomized complete block design experiment adjacent to the study site. There were 10 replications for each rowspacing and they were combine harvested on 8 November. A Duncan's New Multiple Range test was used to compare the treatment means. The narrowest rowspacing, 13cm, outyielded all the others, (Table 34). Yields for the remaining rowspacings ranged from 2982 to 4072 $kg \cdot ha^{-1}$ and were not significantly different. However, the general trend was decreasing yields with increasing rowspacing, (and subsequent decrease in plant population).

Table 34. Final seed yields for 1984.

rowspacing (cm)	yield ($kg \cdot ha^{-1}$)[a]
13	5434.4a
25	4072.1b
38	3703.9b
51	2982.3b
76	3468.3b

[a]Means not followed by the same letter are significantly different at the 0.05 level of probability according to Duncan's New Multiple Range test.

CHAPTER V

SUMMARY

Microclimate investigations have been used to observe crop canopy fluxes of various components such as CO_2 and water vapor. In these studies, microclimate techniques were used to observe the effects of rowspacing on the canopy carbon dioxide concentrations rather than fluxes for "Essex" soybeans in various rowspacings ranging from 13- to 76-cm. As rowspacing decreased, plant population increased. In 1983, a wheatstraw mulch treatment was applied to observe what contributions, if any, a decaying wheatstraw mulch has on the observed CO_2 concentrations. The results showed that mulching had no significant effect on the canopy CO_2 concentrations. In 1984, the mulch treatment was omitted and the CO_2 concentration was observed vertically and horizontally between the row drill and middles. Other data collected included water use, soil temperatures, plant growth, and soil CO_2 emissions.

Alterations of the observed vertical CO_2 concentration among rowspacing treatments were evident only in the upper canopy strata. Horizontal differences were noticed in the wider rowspacing only, presumably due to variations in sunlight penetration downward in the canopy. The CO_2 concentration in the upper half of the canopy during periods of high irradiance was observed to be 10 to 20 $\mu L \cdot L^{-1}$ lower in the narrower rows than the wider rows. At dusk, and for a short period thereafter, the trend reversed, with higher concentrations

observed in the upper canopy strata for the narrower rows. During periods of high irradiance, the CO_2 concentration was 5 to 15 $\mu L \cdot L^{-1}$ lower in the row middles than the drills in the wider rowspacings, but near equal across the row in the narrower rowspacings.

These differences in observed CO_2 concentrations in the canopy were attributed to the interaction of light intensity and leaf density. A higher leaf density was present in the upper strata of the narrower rows which provided a greater area for CO_2 assimilation by the plant at high irradiances, resulting in greater depletion of CO_2. At dusk, when plant respiration of CO_2 exceeded assimilation, greater amounts of CO_2 were released in the upper strata of the narrow rows. In wider rows, more light was thought to be infiltrating between rows during periods of high irradiance which resulted in increased photoassimilation of CO_2. Higher and more uniform leaf densities in the upper strata during the critical early reproductive stages of growth in narrow rows undoubtedly favors higher seed yields on an area basis.

Soil emmision of CO_2 was found to be similar among the rowspacing and mulch treatments. Early in the growing season there were indications of higher rates of emission with lower rowspacings. A weak, positive correlation was observed between soil CO_2 emmission and temperature, ($p = 0.55$), when measured over short time intervals of 10 minutes. This relationship was not observed over longer time intervals of 24 hours.

Apparent evaporation was reduced with the onset of canopy closure in the narrow rows due to reductions in water evaporation from the soil surface. This occurred in both years of study at critical early reproductive growth stages. At all other times, there was no obvious difference in water use among treatments.

Soil temperatures in the row middles at 3cm depth were extremely high for short periods at midday prior to canopy closures. Temperatures often exceeded 30C for periods up to 3 to 4 hours. Variations in soil temperatures among rowspacings, across row location, and depth were only noticeable between 1500 and 1900 hour up until mid-pod fill growth. Overall, lower temperatures were associated with narrower rowspacings.

Temperatures under the row drill were generally lower than in the row middles. Temperatures at 10cm depth were fairly constant across all treatments and locations, ranging from 22 to 26C.

Average seed weight and the number of seeds per pod were unaffected by rowspacing for "Essex" soybeans. The leaf area ratio was similar among rowspacings but due to competition for light, net assimilation rate and relative growth rate decreased slightly with decreasing rowspacing when measured on a single plant basis. Plants from wider rowspacings were stouter, shorter, and produced more lateral branches and seeds.

Rowspacing studies in Tennessee have shown consistently higher yields for narrower rows. The microclimate and growth data collected in this study reveal that optimum yields are favored in closer row-spacing primarily due to the development of a dense, uniform canopy during early reproductive growth. The conditions of the early reproductive growth stages have been highly related to crop yields by other researchers. A dense, uniform canopy reduces water loss from the soil surface and provides for maximum light interception and photoassimilation. Total seed production per plant is reduced in narrow rows, but this is offset in terms of yield due to the much higher plant populations present per unit land area.

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LITERATURE CITED

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APPENDIX

APPENDIX A

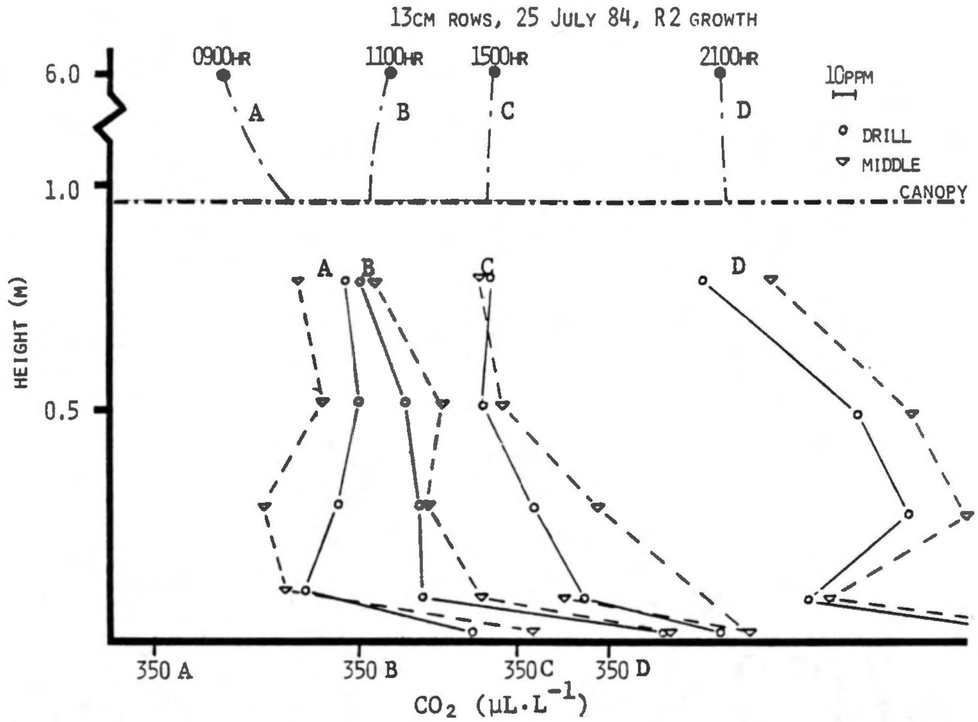

Figure A.1. Canopy CO_2 concentrations for 13cm rowspacing on 25 July.

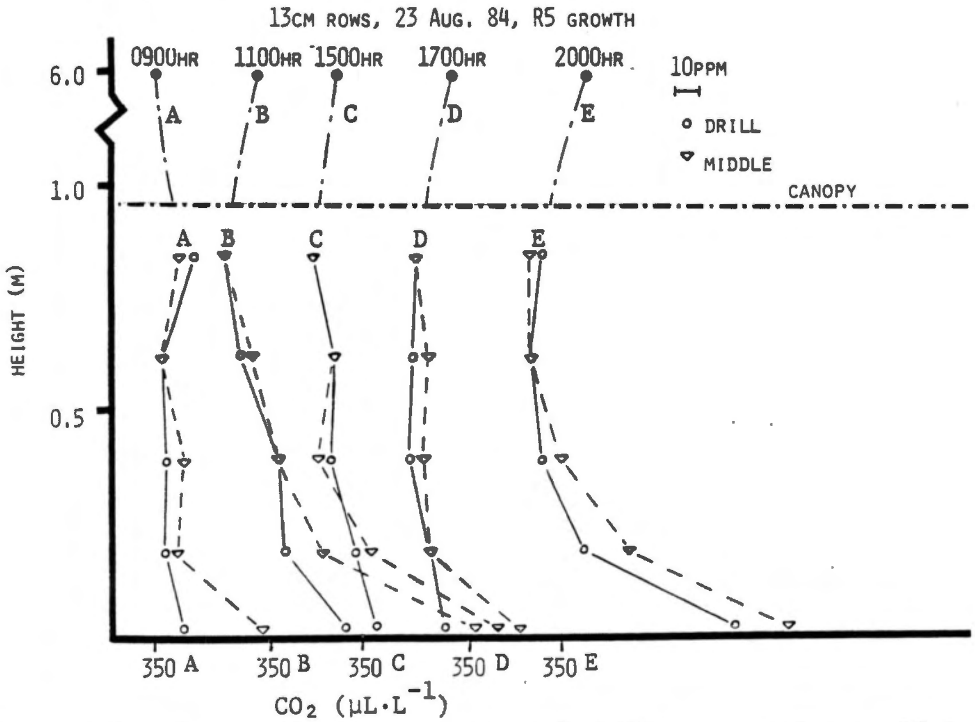

Figure A.2. Canopy CO_2 concentrations for 13cm rowspacing on 23 August.

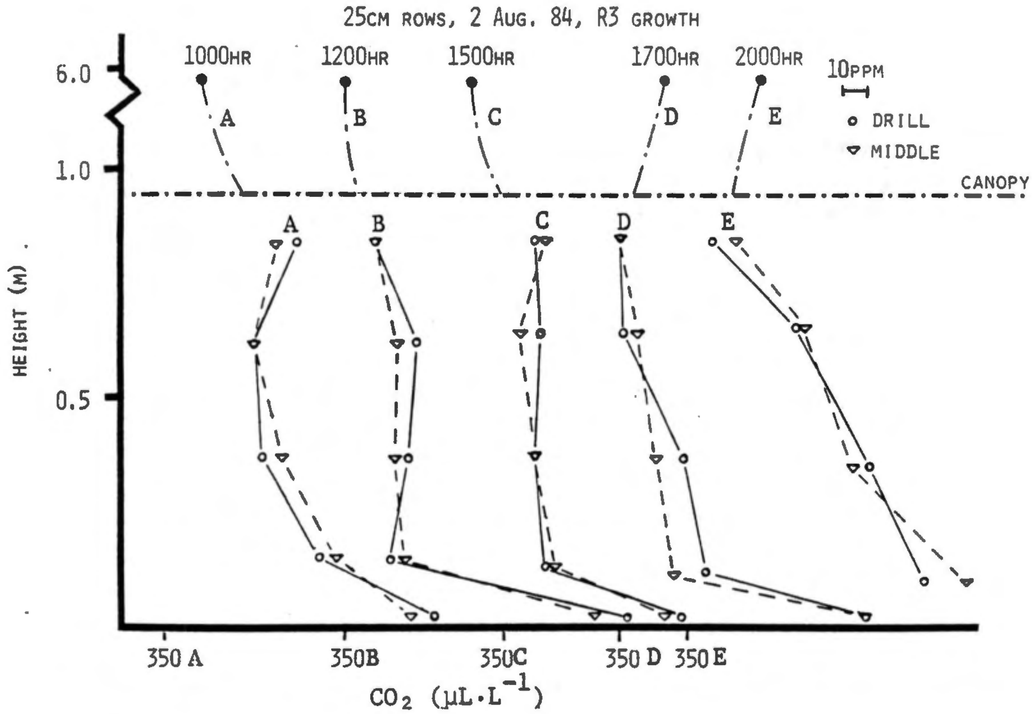

Figure A.3. Canopy CO_2 concentrations for 25cm rowspacing on 2 August.

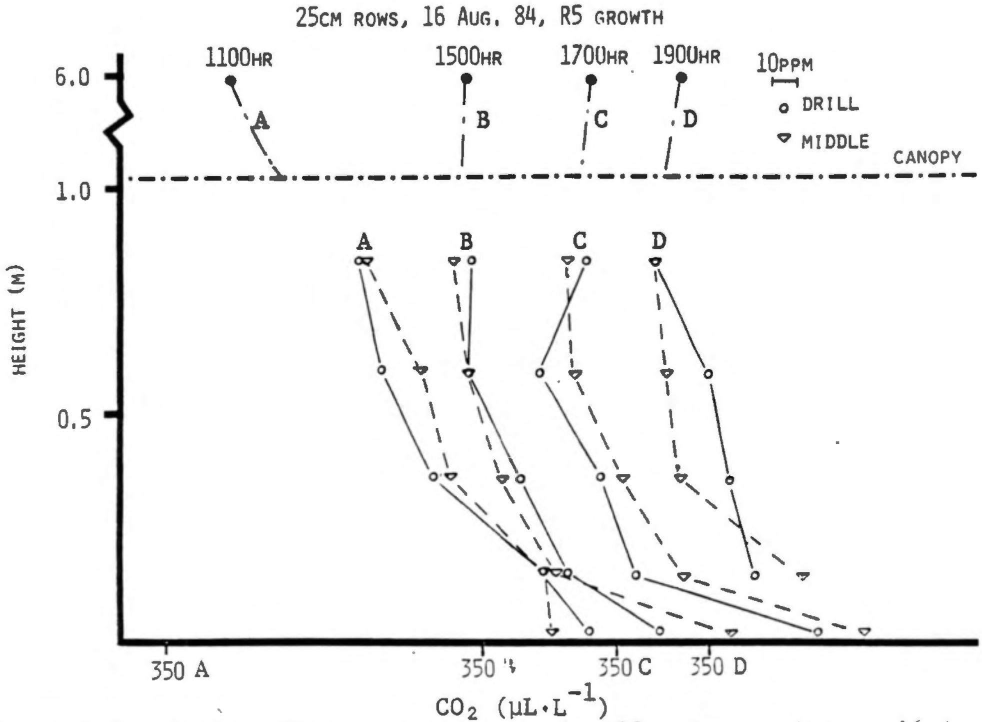

Figure A.4. Canopy CO_2 concentrations for 25cm rowspacing on 16 August.

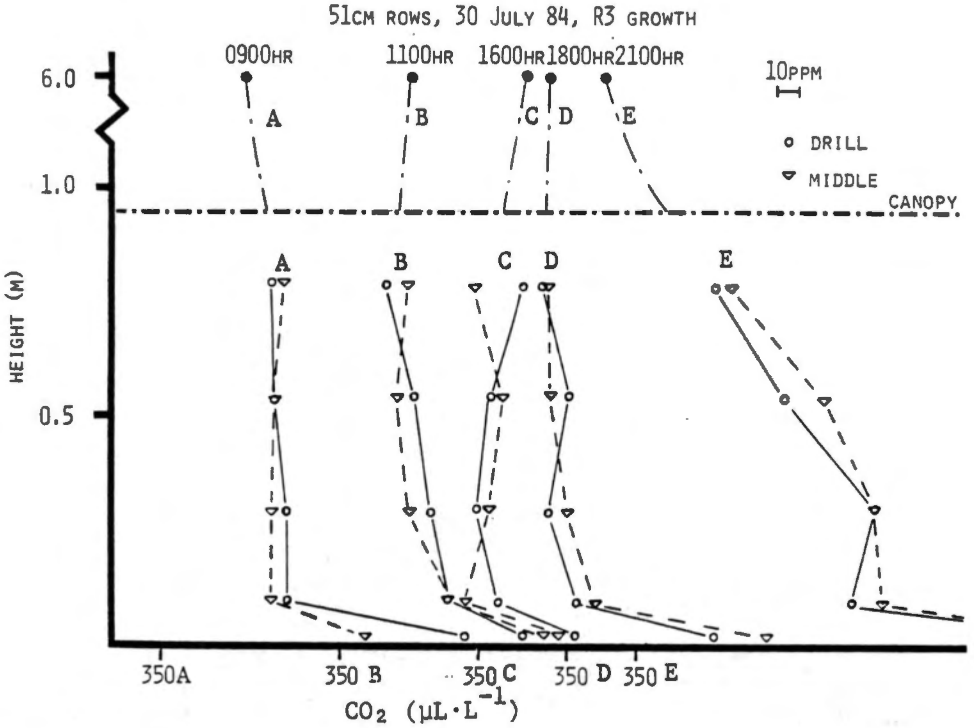

Figure A.5. Canopy CO_2 concentrations for 51cm rowspacing on 30 July.

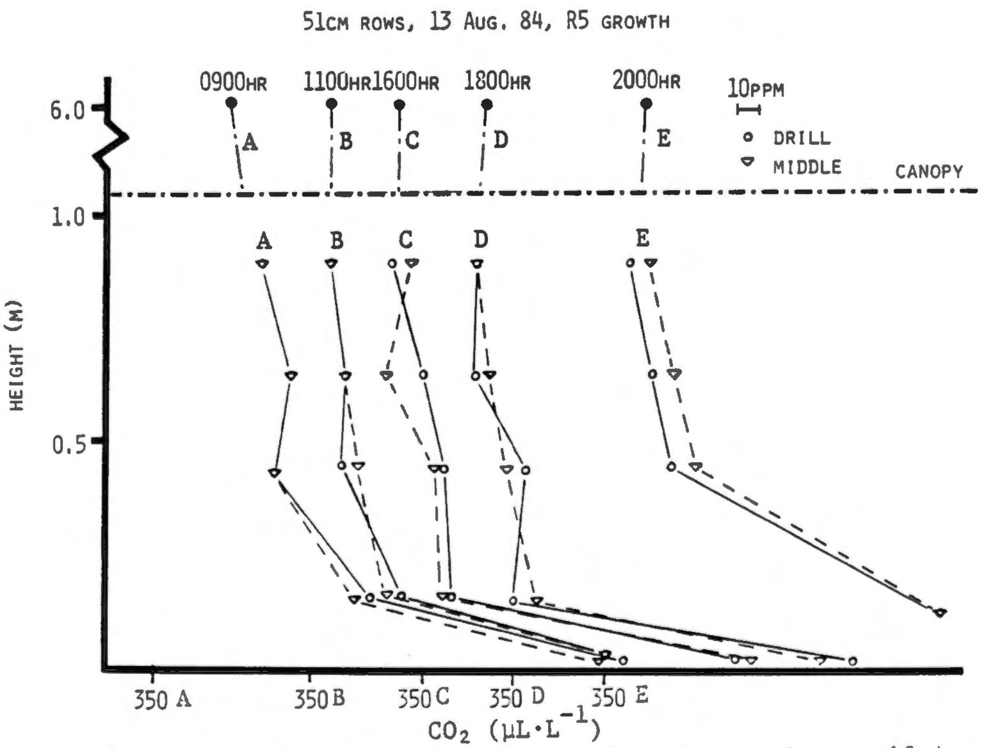

Figure A.6. Canopy CO_2 concentrations for 51cm rowspacing on 13 August.

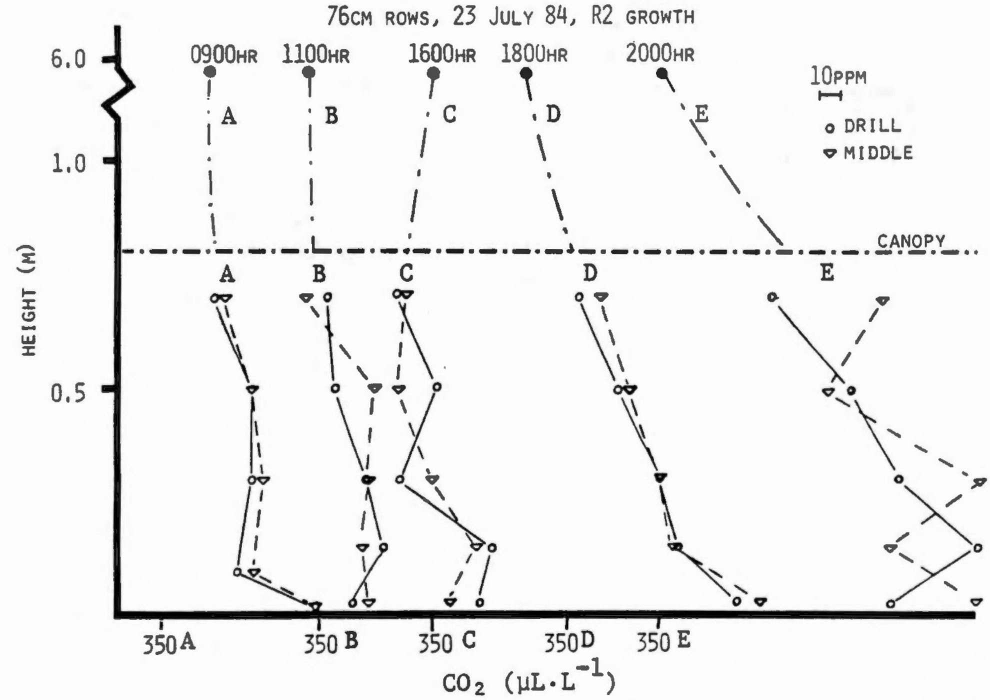

Figure A.7. Canopy CO_2 concentrations for 76cm rowspacings on 23 July.

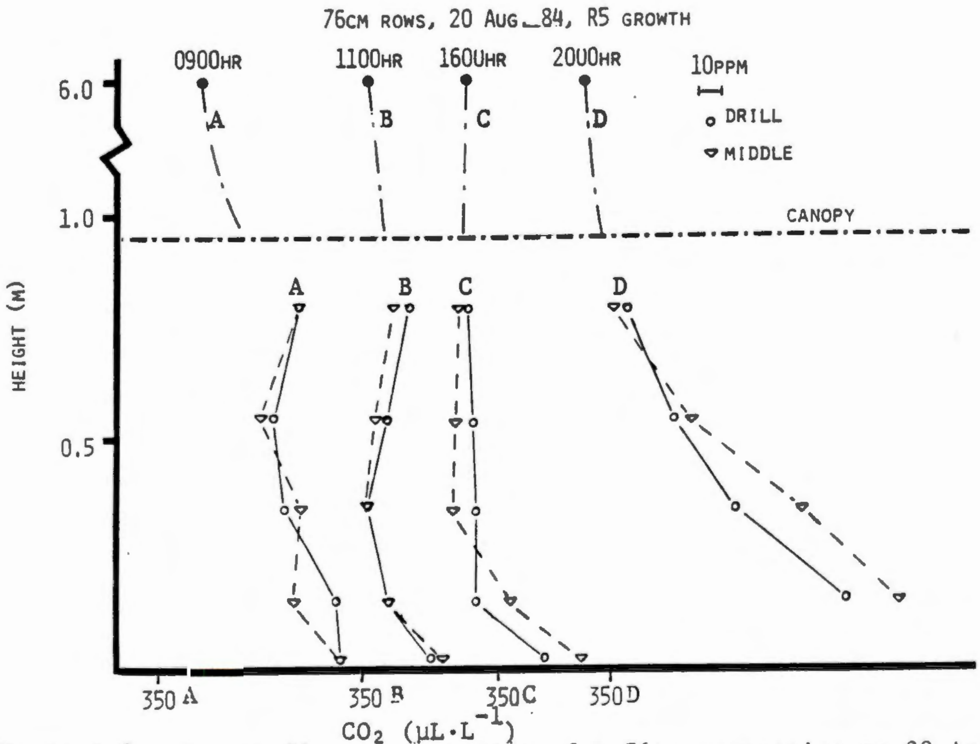

Figure A.8. Canopy CO_2 concentrations for 76cm rowspacing on 20 August.

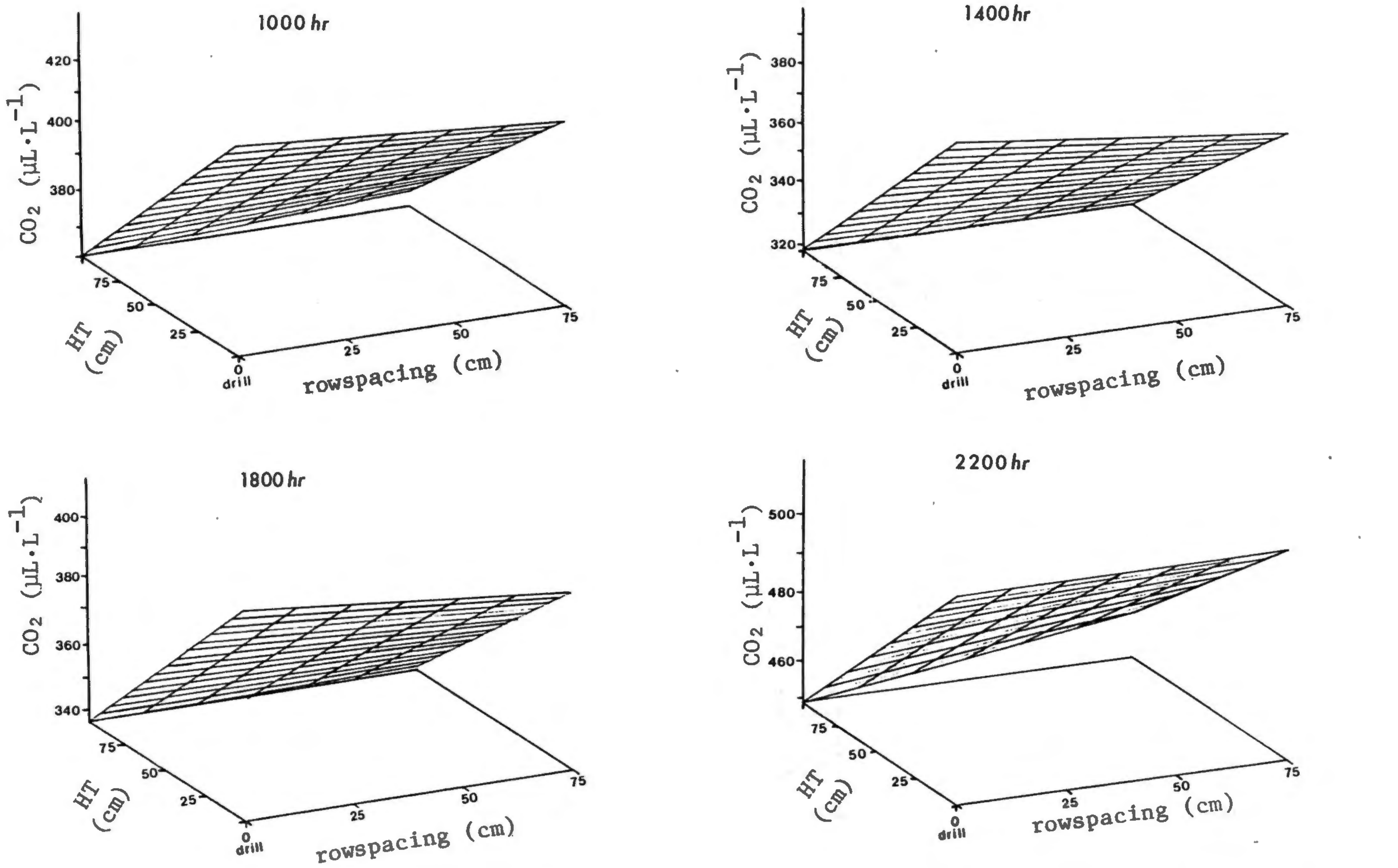

Figure A.9. Computor simulation of CO_2 concentration in the row middle with canopy height for various hours, (EDST), based on data from R1 to R5 growth.

APPENDIX B

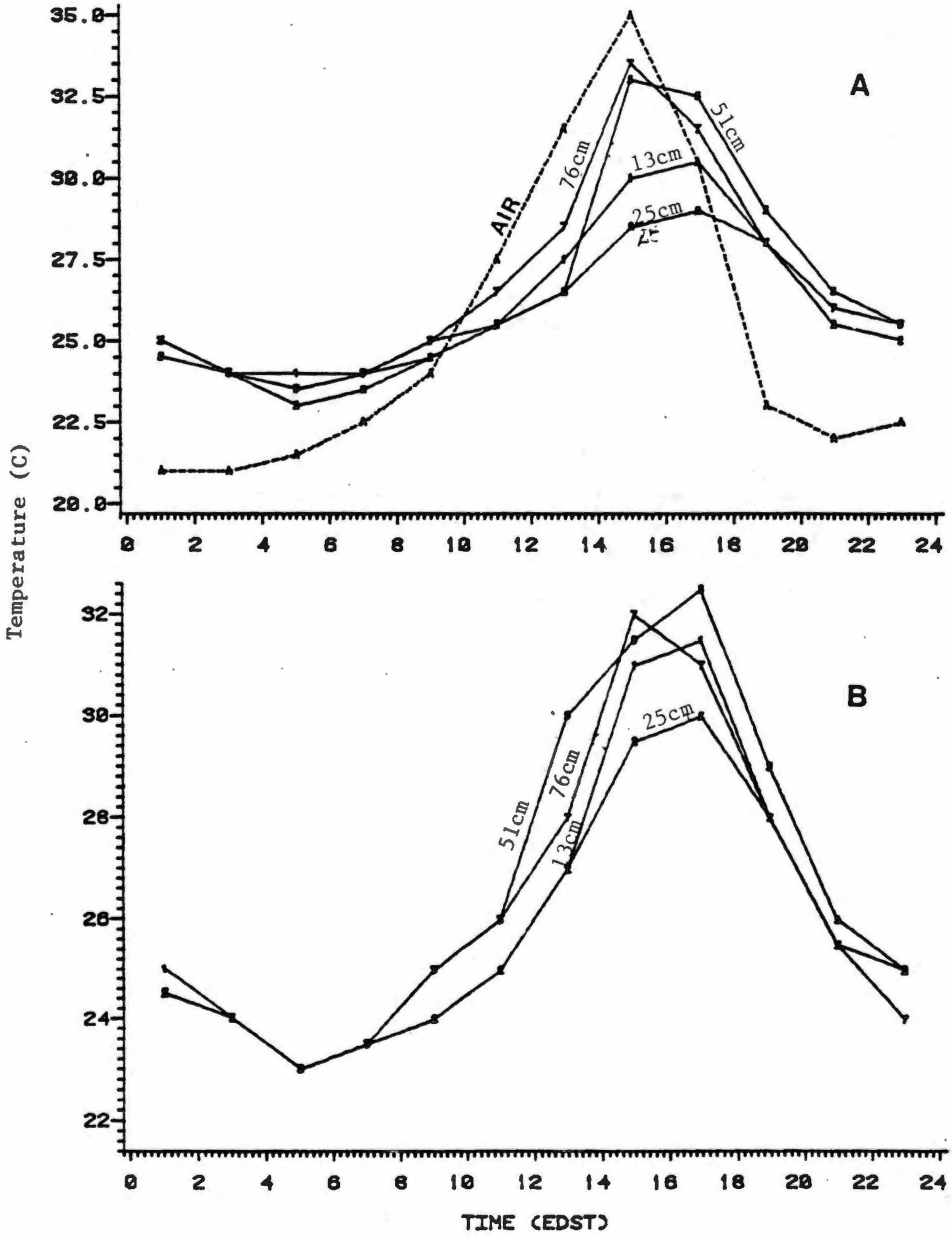

Figure B.1. Soil temperatures, 33 days after emergence, 3cm depth, A) under the row, B) between rows. Note expanded scale on B).

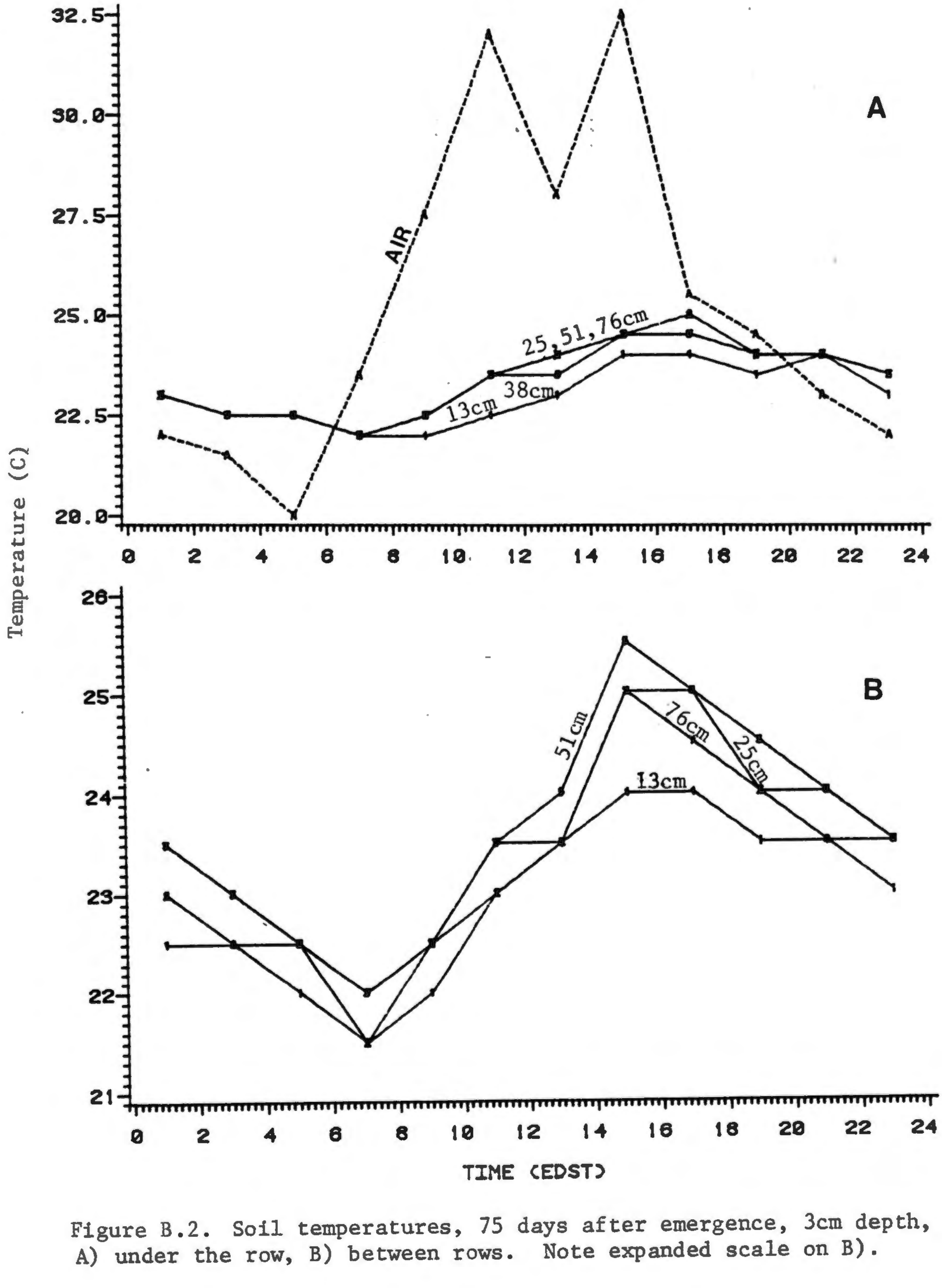

Figure B.2. Soil temperatures, 75 days after emergence, 3cm depth, A) under the row, B) between rows. Note expanded scale on B).

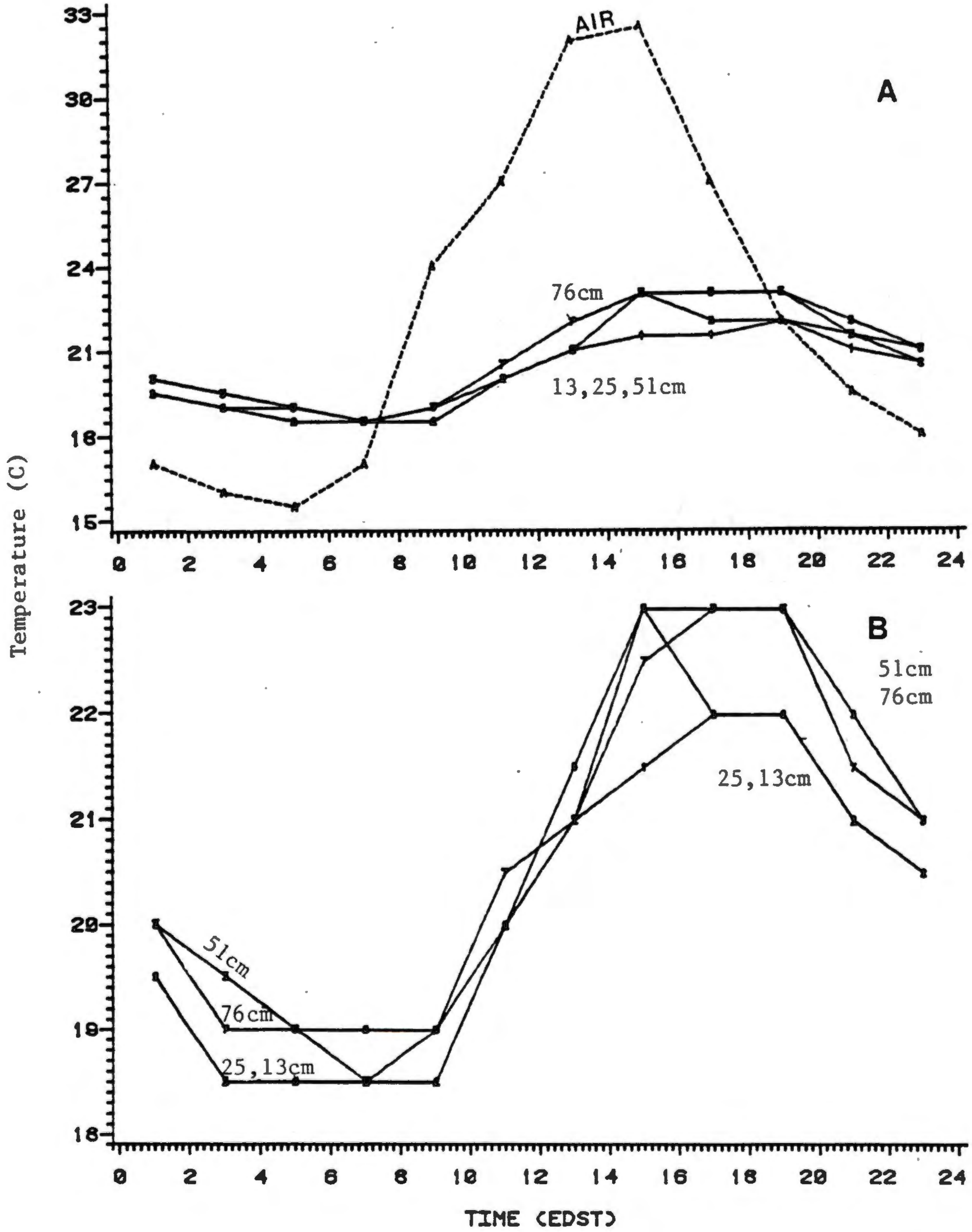

Figure B.3. Soil temperatures, 114 days after emergence, 3cm depth, A) under the row, B) between the rows. Note expanded scale on B).

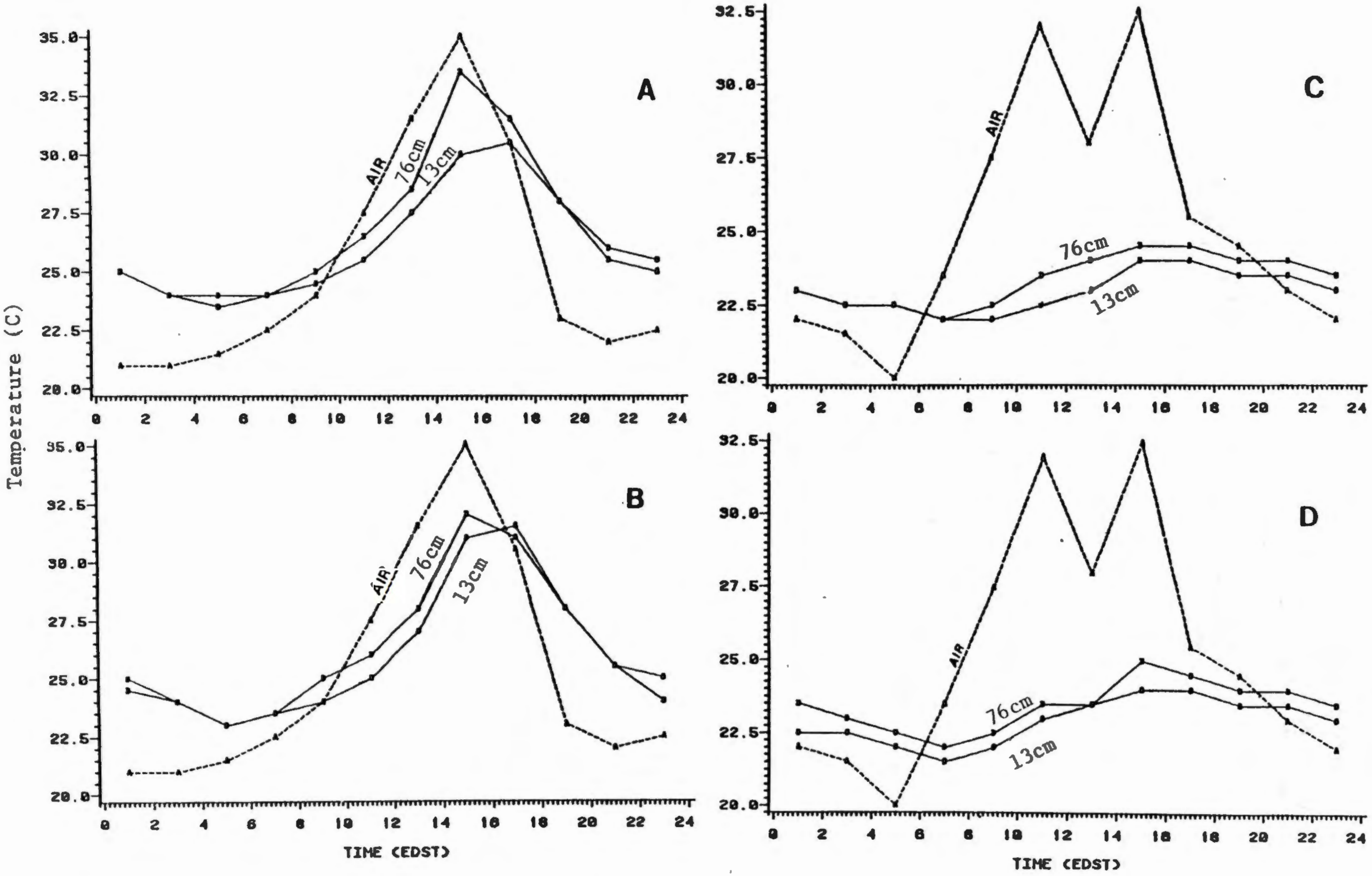

Figure B.4. Soil temperatures: A) between rows, day 33, B) under row, day 33, C) between rows, day 75, D) under row, day 75, (75 days after emergence).

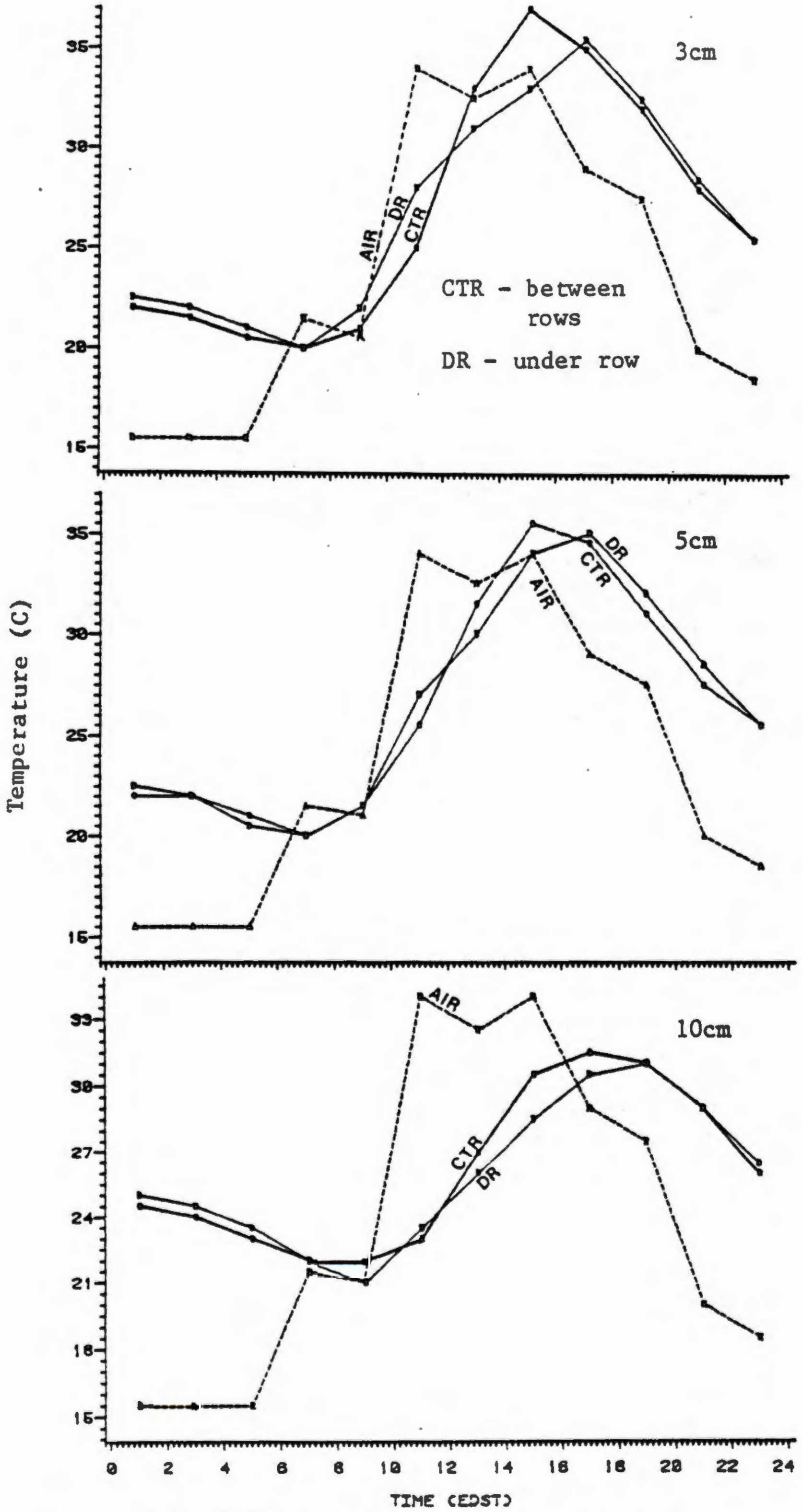

Figure B.5. Soil temperature with depth for 51cm rowspacing, 37 days after emergence.

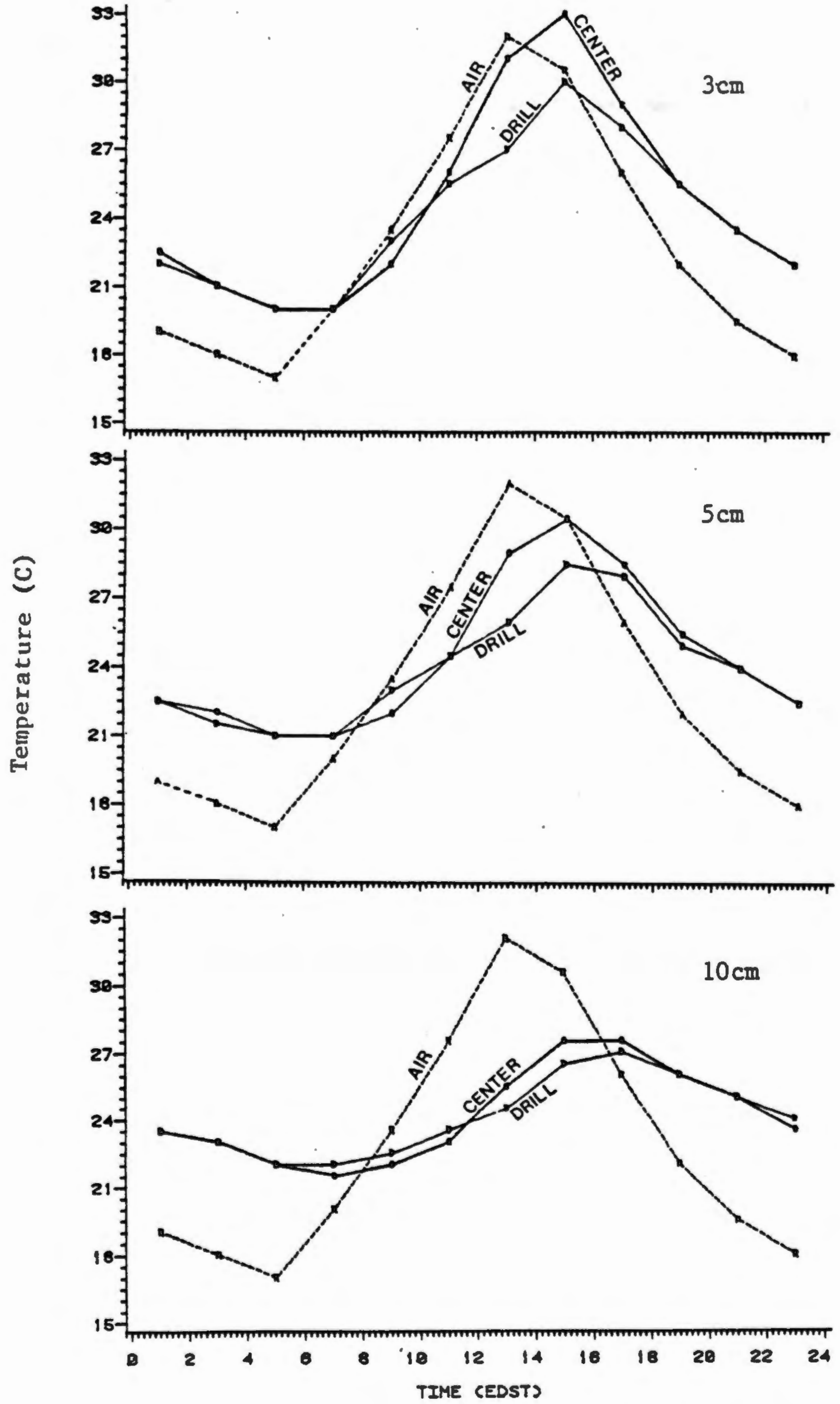

Figure B.6. Soil temperature with depth for 76cm rowspacing, 26 days after emergence.

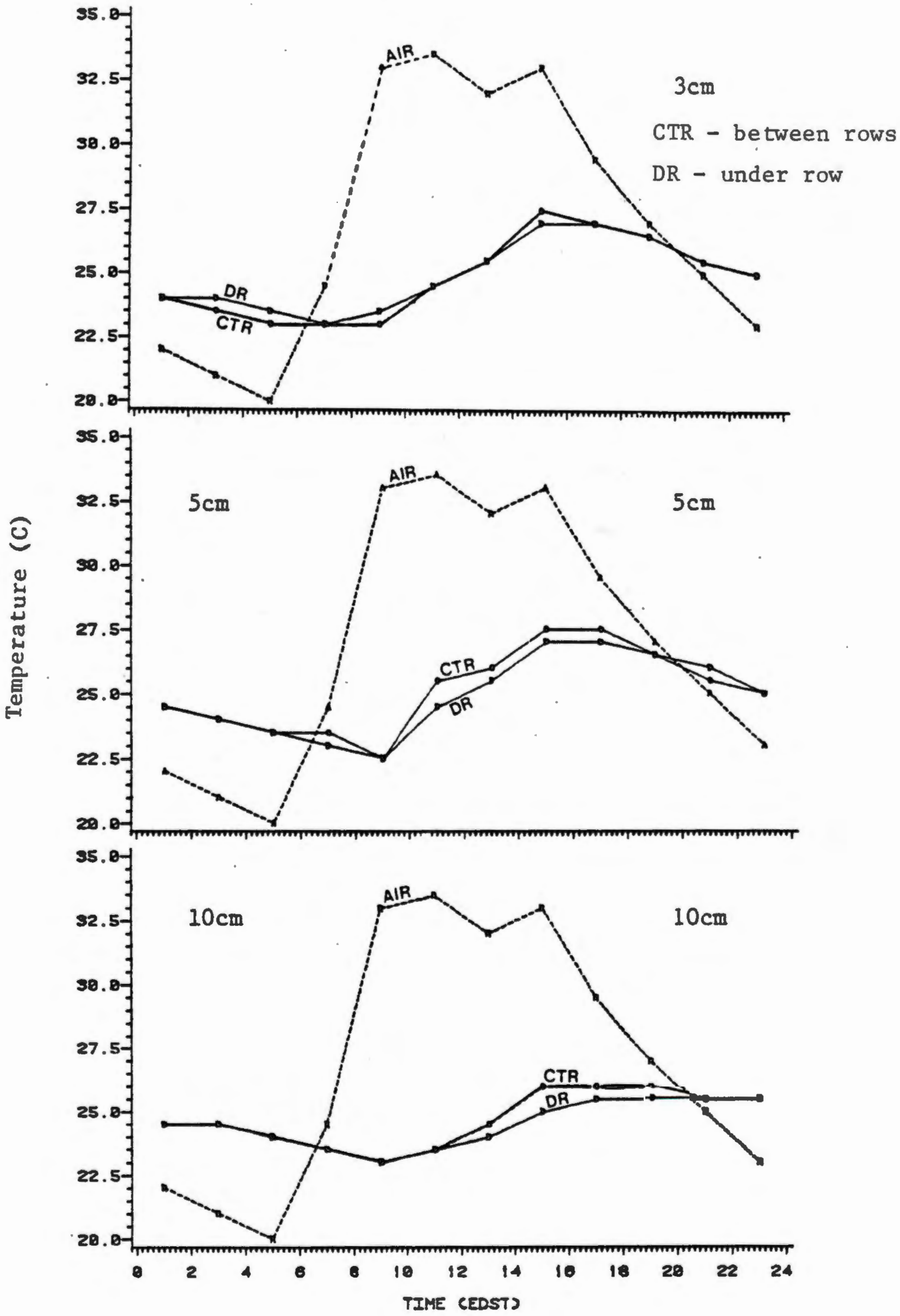

Figure B.7. Soil temperature with depth for 51cm rowspacing, 78 days after emergence.

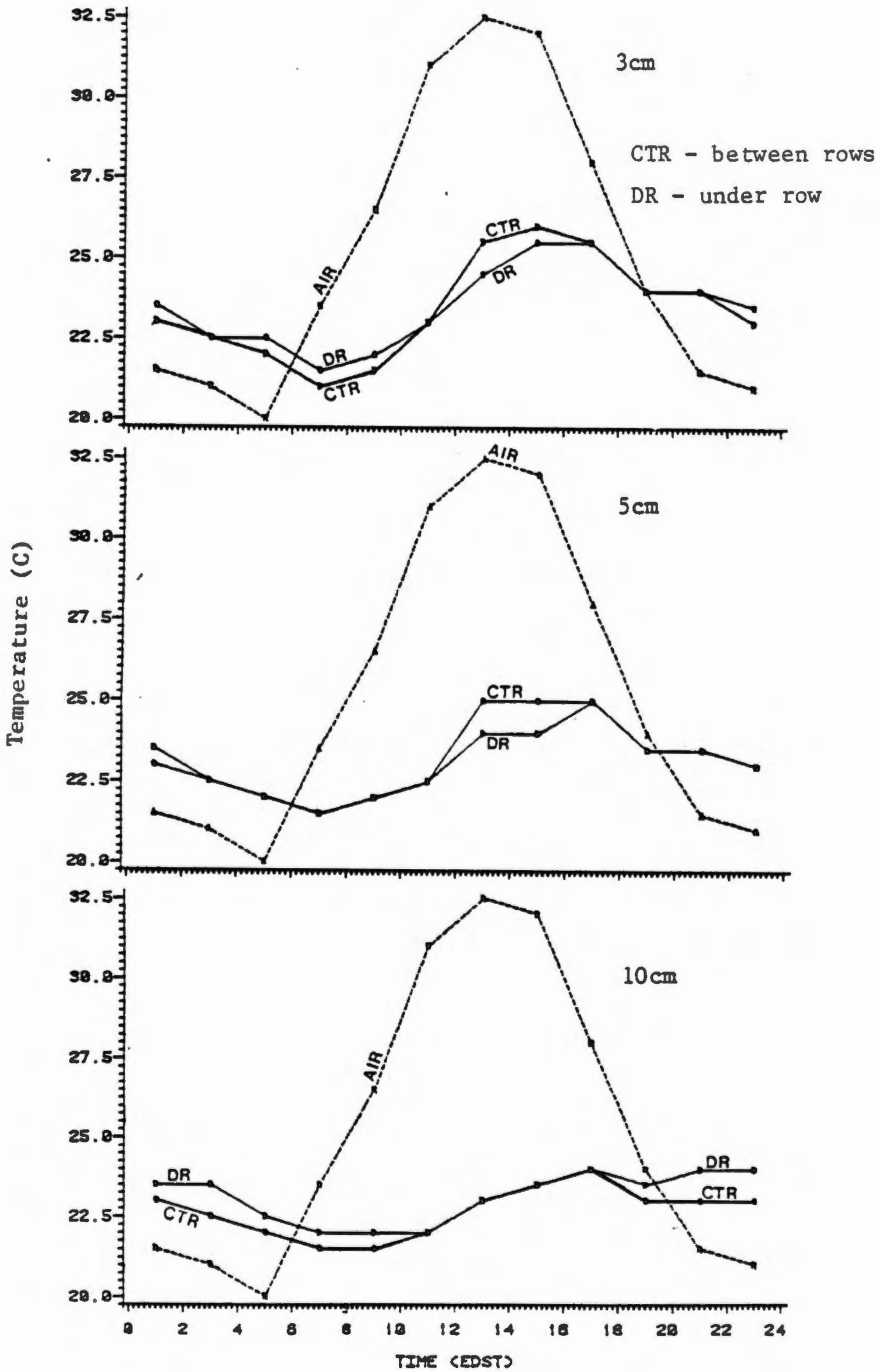

Figure B.8. Soil temperature with depth for 76cm rowspacing, 76 days after emergence.

VITA

Paul B. Francis was born to James and Sue Francis on May 17, 1957 in Memphis, Tennessee. He lived there for 12 years after which his family moved to Bettendorf, Iowa, where his father continued work as a product engineer with International Harvestor in East Moline, Illinois. While growing up in an area predominant in agriculture, Paul worked at various jobs as a farm laborer throughout his high school days and developed a desire to pursue a career in soil science.

He entered the University of Tennessee at Martin in 1975 and obtained a B.S. degree in Natural Resources Management--Soil and Water Conservation in 1979. He then entered Iowa State University in 1979 as a teaching assistant, receiving a M.S. degree in Soil Management in 1981. He continued his education at The University of Tennessee, Knoxville and received a Ph.D. in Plant and Soil Science in August, 1985.

He married the former Donna L. Brennan of Knoxville, Tennessee on September 1, 1984.