STOMATAL BEHAVIOR INFLUENCED BY ROW SPACING IN IRRIGATED GRAIN SORGHUM

By

JOAQUIN SANABRIA-RODRIGUEZ

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Thesis Approved:

John F. Stone
Thesis Adviser

David L. Weeks

Don S. Murray

William Raun

[illegible]

Thomas C. Collins
Dean of the Graduate College

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure		Page

Figure Page

Figure Page

NOMENCLATURE

AOV	Analysis of variance
AST	Apparent solar time
CDT	Central daylight time
C.V.	Coefficient of variation
d.f.	Degrees of freedom
IADV	Integrated advective energy
ISA	Intermediate narrow-row stomatal action
LWP	Leaf water potential
M.S.	Mean square
MSR	Daily mean of stomatal resistance
NRSA	Narrow-row stomatal action
NSA	No narrow-row stomatal action
S. of V.	Source of variation
WM	Wind movement

CHAPTER I

INTRODUCTION

The principal factors participating in the evapotranspiration process are energy supply, a transport mechanism, and the presence of water in the soil-plant system. The energy is required to convert liquid water into vapor and the transport mechanism (mainly wind) conveys the vapor away from the evaporation site. The site where evapotranspiration takes place can be taken as a box containing the plant canopy and the soil surface. The primary source of energy that enters in the box is solar radiation. Some of this energy leaves the box by reflection or reradiation. The net amount of energy remaining in the box is called net radiation. This is energy available to heat the soil, evaporate water, heat the air, and operate the photosynthetic process. If a wind blows across the box, the wind leaving the area may be warmer or cooler than the input air. The following is the energy budget equation at the box:

$$\mathbf{Rin} - \mathbf{Rout} = \mathbf{Rn} = \mathbf{H} + \mathbf{S} + \mathbf{L(ET)} + \mathbf{P}$$

Where **Rin** is principally solar radiation, **Rout** is upward radiation, **Rn** is net radiation, **H** is sensible heat exchanged with the air, **S** is heat conducted into the soil,

L is the latent heat of vaporization of water, **ET** is evapotranspiration, and **P** is photosynthesis and other energy absorbers. Multiplying **ET** by **L** expresses ET as the amount of energy to cause its evaporation, so all the terms of the equation have the same energy units. If the air coming out of the evapotranspiration area is cooler than the input air, advection of energy takes place and the **H** term in the equation becomes negative. In this case both **Rn** and **H** are sources of energy (Stone, 1977).

After water is vaporized, a diffusion flow of water vapor from the water surface to the turbulent air takes place, and then the turbulent air above the canopy takes over to convey the water vapor to the atmosphere. The turbulent transport can be described by the following equation.

$$ET = k \frac{\text{Grad } P}{Rv}$$

Where Grad P is the gradient in water vapor pressure in the turbulent air above the canopy, Rv is the turbulent transport resistance. The constant k imparts proper dimensions to the variables. The v subscript in Rv indicates that this resistance varies with wind velocity, in general the higher the wind velocity the more turbulence and the lower Rv becomes. Several plant factors influence evapotranspiration. Plant stomates exert a major control over transpiration. Closed stomata are a resistive restraint to the diffusion process from the leaf surfaces to the turbulent air. The turbulence in the air above the canopy is determined in part by plant morphological factors. Amount of water transpired by the plant also depends on the ability of the roots to absorb water from the soil (Stone, 1977).

Reduction of evapotranspiration is a realistic alteration of the hydrologic cycle to increase available water for irrigation or for direct human consumption. Evapotranspiration reduction may be achieved through manipulation of the planting geometry factors (row orientation and row spacing) that have been shown to affect stomatal behavior.

The literature contains reports of the effects of planting geometry variation on stomatal behavior. Peanut (Arachis hypogea L.) grown in narrow, 30 cm spaced, north-south oriented rows lost less water by evapotranspiration than those grown in wide, 90 cm spaced, north-south oriented rows or than east-west oriented rows of both spacings. Reductions as great as 40% were reported (Chin Choy et. al., 1977).

McCauley et al.(1978) showed in further work with peanut that in high evaporative demand days (daily maximum temperature greater than 32 ^{o}C, clear skies, and moderate to high wind velocity), narrow, north-south rows tend to conserve water. Net radiation in narrow rows was lesser, and the aerodynamic roughness length to a south wind seemed to be greater in the north-south rows. The evapotranspiration was not proportional to net radiation probably because of stomatal closure. Stomatal closure in the narrow north-south rows was more pronounced, and the excess energy was advected away by the increased wind turbulence.

Stone et al.(1985), in a study designed to characterize stomatal closure behavior in wide and narrow row planting of peanut, found that the stomatal resistance of plants grown in narrow rows became higher than the stomatal resistance of plants grown in wide rows during the afternoon of high evaporative demand days. Paired determinations of stomatal resistance and leaf water potential indicated that in high evaporative demand days, both variables presented higher values than in low or moderate evaporative demand days. The prevalent situation in days of high evaporative demand was that in narrow rows the stomatal resistance presented a dramatic increase as the leaf water potential levels decreased in response to increased evaporative demand in the afternoon.

Simultaneously, in the wide rows the leaf water potential reached even lower values than in the narrow rows but stomatal resistance did not increase. The data suggested that stomatal resistance was the result of a complex interaction of leaf water potential and evaporative demand, and was highly influenced by row spacing. The authors concluded that stomatal closure is operative in peanut and that the narrow row stomatal closure appears to be a compensatory mechanism in response to environmental stress.

Erickson et al. (1986) based on the findings of the previous reference studied peanuts to measure the evaporative demand that causes the stomates to start closing early in the afternoon. Potential evapotranspiration calculated every 15 minutes with the Van Bavel equation (Van Bavel, 1966) was used to estimate evaporative demand. The Van Bavel equation contains a radiant energy term and an advective energy term. The estimated evaporative demand and the advective component were observed through the daylight hours and were also accumulated from 730 to 1330 h Apparent Solar Time (AST). The same manipulation was done with the horizontal wind velocity and with the vapor pressure deficit. Neither the peak rate of evaporative demand nor the accumulated evaporative demand appeared to establish a threshold level that triggered the stomatal action in narrow rows. There were no evidences of a threshold in either vapor pressure deficit or horizontal wind velocity. Rather, it seemed that vapor pressure deficit and wind velocity participate together in the cumulated advected energy to trigger the narrow row stomatal closure effect. The data suggested that the threshold level of cumulative advective energy to trigger the narrow row stomatal closure is 8.5 MJ/m^2 occurring between 730 and 1330 h AST.

Steiner (1986) reported that grain sorghum (<u>Sorghum bicolor</u>, (L.) Moench) in narrow rows compared to wide rows, and in north-south rows compared to east-west rows showed less evapotranspiration for a given amount of light interception. Furthermore, it appeared that narrow row spacing increased dry matter production and production of dry matter per unit of evapotranspiration, and increased light interception per unit of evapotranspiration, indicating increased partitioning of evapotranspiration into the transpiration component. Furthermore, Steiner (1987) reported that grain sorghum stomatal resistance was not affected by differences in net radiation due to row spacing or row direction.

Stomatal behavior of grain sorghum and the particularities of the water loss control of sorghum seem more complex than peanut. Garrity et al. (1982) in a study of the stomatal behavior across growth stages of grain sorghum found that stomatal resistance was sensitive to small reductions in leaf water potential during the vegetative period. During the reproductive stage the stomates became nearly insensitive to leaf water potential in plants irrigated weekly.

Ackerson and Krieg (1977) studied stomatal and nonstomatal water regulation in sorghum, corn (Zea mays L.), and cotton and found that stomates of sorghum responded to changes in leaf water potential during the vegetative growth phase. During the reproductive growth, leaf resistance was no longer sensi- tive to bulk water stress. Under nonlimiting water soil conditions, sorghum leaf water potentials approach steady-state values of approximately -15 bars, even as transpira- tion increased. Under nonlimiting soil water conditions, sorghum exhibited an efficient water transport system capable of maintaining leaf water potential at about -15 bars.

Ackerson and Krieg (1979) also observed that stomatal response to increasing water stress was altered after flowering in some sorghum hybrids. They suggested that sorghum regulates water loss by reducing evapotranspiration through increases of stomatal resistance during early periods of growth, and that it has the ability to adapt physiologically to water stress through osmotic adjustment during latter stages.

Hatfield et al. (1988) suggested that factors other than incident radiation influence stomatal resistance in several species, under conditions of adequate water availability. They found that wheat (Triticum aestivum L.) and cotton (Gossypium hirsutum L.) show a high canopy resistance, higher than the expected for a given energy balance, when foliage temperatures were 20 °C or lower in wheat and 27.5 or lower in cotton. Their data suggest a strong relationship between the biological aspects of the stomatal resistance in the plant and the physical conditions of the environment. This relationship seems to be mediated by the thermal dependency of glyoxilate reductase which has a thermal kinetic window. Foliage temperatures below the thermal kinetic window are suboptimal for enzymatic function, and the ability of stomates to open is reduced.

Pasternak and Wilson (1976) reported that sorghum heads are responsible for 12% of the total transpiration of well watered plants during the reproductive stage of the crop.

Because the work of Chin Choy et al. (1977) suggested that evapotranspiration responses in grain sorghum might be similar to peanut, it appeared desirable to determine whether a mechanism similar to that described for peanut (McCauley et al., 1978) was involved.

The objectives of this study are two; the first is to establish if stomatal action is operative in narrow rows in a larger extent than in wide rows of grain sorghum, and the second is to characterize the micrometeorological conditions that propitiate the narrow row stomatal action in grain sorghum.

CHAPTER II

MATERIALS AND METHODS

The study was conducted during the six growing seasons from 1986 to 1991 at the Agronomy Research Station, Perkins, Oklahoma. At this location 1200 h AST corresponds to 1330 h Central Daylight Time (CDT). The experimental site was on Teller loam soil (fine-loamy, mixed, Thermic Udic Argiusto-ll) with 0 to 1% slope (Ford et al., 1976). The study crop was grain sorghum (Sorghum bicolor (L.) Moench). Ammonium nitrate was applied in the six growing seasons at the rate of 153 Kg N / Ha in 1986, 168 Kg N / Ha in 1987, and 112 Kg N / Ha from 1988 to 1991. Triple superphosphate at a rate of 34 Kg $P_{2O}5$ / Ha was applied in 1988. Also 1.12 Ton / Ha of lime was used in 1990. Weed control was done with 1.12 Kg / Ha of Propazine and 2.24 Kg / Ha of Alachlor in 1986, 0.84 Kg / Ha of Atrazine and 2.24 Kg / Ha of Alachlor in 1987, and 1.12 Kg / Ha of Propazine from 1988 to 1991. Weeds not controlled by the herbicides were controlled by hoeing. Treatment configurations were 0.4 and 1.22 m row spacing of north-south orientation. Plots measured 15 by 24 m and had borders at least 5 m wide. Each year one plot was planted entirely to the narrow spacing and one to the wide.

Locations in the experimental area were randomly assigned each year.

The requirements for water maintenance was met by irrigating at a weekly interval (Friday). A solid-set irrigation system was used with impact-type sprinklers. Three laterals spaced on 12.2 m centers crossed the plots and the borders. Water was applied in full-circle overlapping patterns. The average amount of water applied per irrigation was 55 mm. The distribution and amount of water applied in the plots was checked with rain gauges. Irrigation water application was no more variable than the rains. This was the same system for water maintenance as employed by Erickson et al., (1986) on the same plot of ground.

Soil water content was monitored by the neutron scattering method (Troxler model 3223 depth gauge, Troxler Electronics Inc., Research Triangle Park, NC). Two access tubes were placed in each of the plots. Readings were taken weekly just prior to irrigation. Measurements were made at 15 cm depth increments through the soil profile from 0.15 m to 1.2 m. Readings for depths greater than 0.30 m were from a single calibration curve and the 0.15 m readings were from a separate calibration for that depth.

Stomatal resistance readings were made on randomly selected leaves with an LI-1600 Steady State Porometer (Licor Inc., Lincoln, NE). Leaf water potential measurements were made on randomly selected leaves (not necessarily the ones selected for resistance measurements) using the same criteria as for resistance. Readings were made with a Wescor LI-51 in-situ leaf hygrometer read out on a Wescor HR-33T Dew Point Microvoltimeter from 1986 to 1990 and read out on a Wescor HP-115 in 1991 (Wescor, Inc., Logan, UT). Leaf water potential readings were made on plants in the same general area as those selected for resistance measurement. Leaf measurements were made on the youngest fully expanded leaf which had full exposure to the sun.

Stomatal diffusive resistance and leaf water potential readings were made in each plot at hourly intervals in 1986 and 1988 and at thirty minute intervals in 1987 and from 1989 to 1991. Readings started every day after disappearance of morning dew (approximately at 930 h CDT) and continued until 1600 h CDT from Monday to Thursday. The measurement site within each plot was centrally located near the northern edge of the plot. This gave about 30 m fetch to the prevailing southerly winds.

The following procedure was repeated for leaf measurements. The first reading device was randomly selected to measure either resistance or leaf water potential. The starting plot was randomly selected also. Three plants in each plot were selected and measurements were made on one leaf on each plant. When there was only one operator, once the first device was selected, readings were made in both plots before measurements were started with the other instrument. When there were two operators the two types of leaf readings were made simultaneously in the same plot. Thus, at each measurement period the operator(s) gathered three readings in each plot with each instrument on total of twelve leaves. Total elapsed time to complete all the measurements with both devices was about 10 minutes. One operator made all the measurements in the 1986 season, two operators made them in the rest of the years, the operators alternated instruments from day to day. Measurements were carried out Monday through Thursday, weather, personnel and instruments permitting. Irrigation was on Friday. Plots were free of activity on Saturday and Sunday.

The days of readings were classed as to evaporative demand in accordance with the procedure of Erickson et al. (1986): Evaporative demand was assumed to be represented by the potential evapotranspiration of Van Bavel (1966). This included measurements of wind velocity at 2 m height, wet and dry bulb temperatures, solar radiation, and net radiation in each plot. These readings were made at the north end of the plots, and were gathered by a data acquisition system that scanned the weather instruments every minute and stored the averages every 15 minutes. In addition, daily measurements of barometric pressure and weekly measurements of plant height were required. Prevailing wind in the summer at the site are generally south-southeast.

The descriptive statistical methods included plots of stomatal resistance and leaf water potential versus time, soil water content versus depth, and stomatal resistance versus leaf water potential. All the plots were made for each day of data collection. Means, maximums, minimums, and standard deviations were calculated for all the variables in each data collection period. The 65 days of data were separated in three groups according with the behavior of stomatal resistance in the stomatal resistance versus time plots.

The inference statistical methods employed were as follows. Analysis of variance to compare the two row spacings in the following variables: Stomatal resistance, micrometeorological conditions in the three group of days, evaporative demand, and soil water content. In the stomatal resistance analysis a model constituted by the interaction reading-time by treatment was used (Appendix C), the treatments consisted in the two row spacings. Using contrasts the difference between the two treatments were tested at each time. In the micrometeorological comparisons, the model used was a completely randomized with the three groups of days as treatments. For evaporative demand, a randomized complete block model was used with the evaluation times through the day as blocks and the two row spacings as treatments. In the soil water content analysis the model was a randomized complete block with the dates within years as blocks and the row spacings as treatments.

A paired-comparison test was used for the comparison of yields from the two row spacings across the six seasons of the study. Pearson correlation coefficients were used to establish the degree of association between stomatal resistance and leaf water potential in each day of data collection

Cluster analysis (Everitt, 1980; and SAS Institute Inc., 1986) was employed to separate the 65 days of data in two disjoint clusters based in wind velocity and integrated advective energy.

CHAPTER III

RESULTS AND DISCUSSION

The 65 days of data collection were classified into three groups according to the behavior of the stomatal resistance through time in each day. Stomatal resistance during the afternoon hours (high evaporative demand) was the determinant factor for this classification.

The first group of days, Fig. 1 to Fig. 14, contains 14 days that presented a well defined separation of narrow row and wide row stomatal resistances. In these days stomatal resistance becomes higher in the narrow rows at some time during the afternoon and remains higher than the stomatal resistance in the wide rows until the end of data collection in the day. Narrow-row stomatal resistance is significantly higher than wide-row stomatal resistance at one or more times during the afternoon after the two row stomatal resistances become separated. On 26 JUL 1990 (Fig. 9), narrow-row stomatal resistance becomes lower than wide-row stomatal resistance at 1530 h but the two significantly higher values of narrow-row stomatal resistance at 1400 h nd 1430 h and then at 1600 h are enough evidence to include this day in the first group. These are called days with narrow row stomatal action (NRSA).

The second group of days, Fig. 15 to Fig. 25, is composed of 11 days that did not show a well defined separation of narrow-row and wide-row stomatal resistance in the afternoon. Narrow-row stomatal resistance becomes higher than wide-row stomatal resistance at some time during the afternoon but either the superior narrow-row stomatal resistance does not reamain consistently higher until the last reading of the day or the stomatal resistance in the narrow rows is consistent through the afternoon, but it is not significantly higher than in the wide rows at any time during the afternoon. This group is called days with indeterminate stomatal action (ISA).

The third group included 40 days. Days in this group have either a higher wide-row stomatal resistance than narrow-row stomatal resistance during the afternoon or higher narrow-row and wide-row stomatal resistance alternate randomnly during the afternoon hours. Fig. 26 shows the only day in this group from 1986. Figs. 27 to 36 represent typical cases of higher wide-row stomatal resistance and random pattern of stomatal resistance in both row spacings in each year. This group is called days with no stomatal action (NSA).

Fourteen days (Group 1) out of sixty five (22%) show evidence of the stomatal closure operation in sorghum as an evapotranspiration control mechanism in well-watered conditions, and also show evidence of the row spacing effect over stomatal closure in grain sorghum. Stone et al., (1985) reported the occurrence of stomatal action in peanut in 26% of the data collection days.

Leaf water potential (LWP) can be a principal factor in stomatal closure. In the days with NRSA, LWP does not describe an increasing trend through the day (Fig 37 to Fig 48). Of six days with significant LWP differences between row spacings, three have LWP averages higher in the wide rows than in the narrow rows, and three have LWP higher in the narrow rows. Comparing the stomatal resistance figures in NRSA days (Figs. 1 to 14) with Figs. 37 to 48 it can be noted that some of the days with periods of high LWP in the wide rorws show greater stomatal resistance in the narrow rows or vice versa. LWP and stomatal resistance correlation coefficients are shown in Appendix D. They are not significant in most of the data collection days. Only five days had significant correlation coefficients, but none of these days showed a well defined relationship between the two variables. Figs. 49, 50, and 51 are examples of the poor defined LWP-stomatal resistance relationships obtained in this study. According with the same type of relationship reported by Stone et al.,(1985) for the identification of stomatal action days in peanut, a LWP-stomatal resistance relationship in a NRSA day should basically present increasing tendency of stomatal resistance as LWP decreases in both row spacings. It should also show a clear separation between the two row spacing lines as result of higher stomatal resistance values in the narrow rows than in the wide rows for a given level of LWP. Note that Fig. 51 indicates some degree of separation between the two row spacings but it does not establish a causal effect of LWP on stomatal resistance. Several values of stomatal resistance are associated with only one value of LWP.

There is little evidence that increase in stomatal resistance in action days is mitigated by leaf water potential differences between narrow and wide rows. In Fig. 49 the narrow rows show lesser LWP but show the same range of stomatal resistance as the wide rows. In Fig. 51 the wide rows show lesser LWP but narrow rows show greater stomatal resistance. In the study of LWP vs. stomatal resistance in peanut by Stone et al.,(1985), LWP in wide rows was less than in narrow, but stomatal resistance was higher in narrow than wide. On NSA days in peanut, Stone et al. (1985) found stomatal resistance in both narrow and wide rows to be nearly equal and to increase through the day. NSA days in the peanut study were of low evaporative demand. In the present study NSA days, while showing no preference of narrow or wide rows, suggested that stomatal resistance decreased through the day. These days were generally of low evaporative demand but the stomatal resistance relationship to LWP is not so classical as for the peanut.

However, there is evidence that the mechanics of heat dissipation in grain sorghum is more complex than for peanut. Several physiological mechanisms appear to be active in grain sorghum that evidently have lesser importance in peanut or are not existent. This makes relationships between LWP and stomatal resistance more poorly defined in grain sorghum.

Stomatal action of peanut planted in narrow rows was a reaction to conditions of high evaporative demand days (Stone et al., 1985). Patterns of stomatal resistance change over time in the NRSA days generally show an abrupt increase starting between 1200 and 1400 h CDT, this suggests a threshold that may be a response of stomates closing to reduce loss of water. In a study of stomatal action in peanut, Erickson et al. (1986) suggested that a threshold of accumulated advective energy triggered the stomatal action in narrow rows. The principal micrometeorological factors that lead to increases in stomatal resistance in peanuts were the wind velocity and the vapor pressure deficit. These two factors interacted in the advective component of energy transfer, which was seen to cause the narrow row stomatal action (Erickson et al.,1986).

To see if grain sorghum responds similarly to micrometeorological conditions, air temperature, wind movement (WM), accumulated solar radiation, and accumulated net radiation, were compared, Tables 1 to 4. The wind movement accumulated during the last six hours of the days presented differences at 0.05 significance level, the means were 65.98 Km/6h, 61.60 Km/6h, and 56.70 Km/6h for the groups 1, 2, and 3 respectively. The percentages of days with WM equal or above 70 Km/6h were 35%, 27%, and 5% for the group 1, 2, and 3 respectively. The data suggest a close association between high wind velocities and days that show some degree of stomatal action. Association of NRSA or ISA days and the other weather variables analyzed was not obvious.

Motivated by the association of high WM and the stomatal action days, a cluster analysis based in WM, and advected energy integrated from 730 to 1330 AST (IADV) was performed trying to separate the total number of days into two populations, one containing days of low WM associated with low values of IADV, and the second population containing days with high WM associated with high values of IADV. Another purpose of the cluster analysis was to obtain values of WM and IADV for the characterization of days with high evaporative demand suitable for the stomatal closure operation in grain sorghum.

Results of the cluster analysis are shown in Fig. 52 and Tables 5 and 6. Cluster 2 is formed by 31 days, it contains 11 of the 14 NRSA days, and 5 of the 11 ISA days, a total of 16 days contained in this cluster had some evidence of stomatal closure. Averages for MSR, WM, and IADV in the two clusters are presented in Table 7. The three variables had higher averages in the Cluster 2. Fig. 52 shows a clear separation of the two clusters specially with respect to wind movement. The figure also shows a higher frequency of days from Cluster 2 in the area of high advective energy (above 10 MJ/m^2). Fig. 52 suggests the participation of wind velocity and advected energy as important factors for the occurrence of stomatal action.

The 95% confidence intervals for Cluster 2 suggest that the micrometeorological conditions associated with a NRSA day are a WM between 67 Km/6h and 73 Km/6h, and an IADV between 7.2 MJ/m^2 and 11 MJ/m^2.

It is important to observe that the 8.5 MJ/m^2 suggested by Erickson et al.,(1986) as the break-point of days with NRSA and days without NRSA in peanut is within the IADV confidence interval for the Cluster 2.

Fig. 53 from Cluster 1 and Fig. 54 from Cluster 2 indicate a more pronounced effect of WM and IADV over stomatal resistance in Cluster 2. From the general data, combining the two clusters (Fig. 55) it can be observed that WM has an increasing tendency for effect over stomatal resistance especially at levels of advected energy below 10 MJ/m^2. This may indicate that wind velocity affects the stomatal behavior independently of the advection of energy. The same idea is suggested by Fig. 52 since the higher concentration of days from Cluster 2 is at low to intermediate advective energy and intermediate to high wind movement. Fig 55 also suggests that most of the influence of IADV over stomatal resistance takes place at a specific range of WM approximately between 40 Km/6h and 80 Km/6h. It is apparent that at WM below 40 Km/6h there is not enough advected energy for the evaporation process and the closing reaction of stomates. Furthermore, WM above 80 Km/6h are excessive for an adequate supply of advected energy, perhaps because at such high velocity the foliage is not able to absorb enough energy because of a low temperature differential between leaves and air.

WM above 70 Km/6h under low advection conditions (top left corner of Figures 54 and 55) may have a cooling effect causing the foliage temperature to drop below suboptimal temperatures for enzymes participating in sorghum stomatal control. Hatfield, et al. (1988) reported that foliage temperatures of 20 ^{o}C or lower in wheat and 27.5 ^{o}C or lower in cotton inhibits enzymes that control the stomatal aperture. They suggested that this phenomenon may take place in other species.

Evaporative demand (ED) as calculated by the Van Bavel equation was used by Erickson et al. (1986) in the study of stomatal closure effect in peanut. To see the possible involvement of the ED in sorghum, ED was calculated and compared in the two row spacings in all the days using analysis of variance. The narrow rows presented significantly lower ED 83% of the time, 54 days out of 65 days, it was lower in the narrow rows in 12 days out of 15 NRSA days (Appendix E). The results are indication of a resemblance between peanuts and sorghum with respect to the participation of the ED in the narrow row stomatal closure effect.

There were differences in plant morphology between the two row spacings. The more evident differences are that the narrow row plants are few centimeters taller, their stems are slimmer, their leaves are narrower, and the panicles are smaller than the wide row plants. It may be that the morphological characteristics of the taller narrow-row plants and the closed canopy of the narrow-row plot are associated with a higher aerodynamic roughness coefficient than with the wide row plants. The same suggestion was reported for peanut by Stone et al.(1985).

Table 8 presents grain yields for the six growing seasons. A paired comparison analysis shows a significant difference of yield, favoring the higher grain yield of the narrow rows, Table 9. Heads in the narrow rows are smaller, but a larger number of heads per unit area results in higher yields from the narrow-row plots.

Stomatal action as a reaction to soil water depletion was investigated. Soil water determinations were made the day prior to irrigation to validate the permanent well-watered conditions. Fig. 56 to Fig. 67 show that volumetric soil water contents were at 0.20 (approximately -100 KPa) or higher in 9 weeks for the complete soil profile of 120 cm, and between 0.11 and 0.13 (approx. -550 KPa) for the top 20 cm and 0.20 or higher for the rest of the profile in three weeks. The analysis of variance for soil water content between 0 and 60 cm depth (Table 10) indicates that there is not significant difference between the two row spacings. The difference between the two row spacings was 0.0049 by volume fraction. This non significant difference may be taken as indication of higher water use efficiency of sorghum plants grown in the narrow (0.40 m) spaced rows since the population at this row spacing is 3 times the plant population in the wide (1.22 m) spaced rows. Stone et al. (1985) suggested that the reason for the lower consumption of water by plants growing in narrow rows seems to be the ability of these plants to close their stomates with higher frequency than plants growing in wide rows in days that present conditions of high evaporative demand.

From the 65 days of data, 10 days that presented meteorological conditions sufficient for NRSA did not show evidences of stomatal closure, this situation may be due to the participation of other unknown factors in the operation of the stomates and may be because the existence of other mechanisms of evapotranspiration control different to stomatal closure. Ackerson and Krieg (1980) reported that appreciable osmotic adjustment occurs to maintain positive turgor because sorghum stomates become insensitive to stress conditions after flowering. All the 10 days mentioned above were after flowering.

CHAPTER IV

SUMMARY AND CONCLUSIONS

Previous studies of well-watered peanut showed that the stomates in narrow row planting close earlier in the day than in wide rows. This peculiar stomatal action has been suggested as a factor that causes differences in water use between peanut planted in narrow and wide rows. The present study was designed to investigate whether the narrow row stomatal closure effect takes place in well-watered grain sorghum. The grain sorghum crop was planted in two plots, one plot with narrow (0.40 m) spaced rows and the other plot with wide (1.22 m) spaced rows, at the Agronomy Research Station at Perkins, Oklahoma during six growing seasons from 1986 to 1991. Manual measurements of leaf water potential and stomatal resistance were made daily at half hour intervals. Determinations of wind velocity, dry and wet bulb temperature, solar radiation and net radiation were gathered by a data acquisition system every 15 minutes. The micrometeorological data were used to calculate evaporative demand and its advective component by the Van Bavel equation (Van Bavel, 1966). Soil water content was monitored weekly by neutron scattering probe on the day prior to the irrigation day.

The 65 days of data were separated into three groups based in graphs of stomatal resistance vs. day time. Group 1 was composed of 14 days that showed a consistent separation of narrow-row and wide-row stomatal resistance during the afternoon, these days also had stomatal resistance significantly higher in the narrow rows than in the wide rows at one or more times during the afternoon after the two row stomatal resistances became separated. These were called narrow row stomatal action (NRSA) days. Group 2 was formed by 11 days that showed no well defined separation of stomatal resistance for the two row spacings during the afternoon. These days presented either inconsistent higher narrow-row stomatal resistance during the afternoon or the narrow-row stomatal resistance was consistently higher than wide-row stomatal resistance but the difference was not significant at any time during the afternoon. These were called indeterminate stomatal action (ISA) days. Group 3 included 40 days that showed higher wide-row stomatal resistance during the afternoon or presented a random alternation of higher narrow-row and wide-row stomatal resistance during the afternoon. These were called no stomatal action (NSA) days.

A two dimensional cluster analysis based in wind velocity accumulated in 6 hours, and advective energy accumulated in 6 hours, separated the 65 days into two disjoint clusters. Cluster 1 contained the days with lower values of wind velocity and lower values of advective energy. Cluster 2 grouped the days of higher wind velocity and high advective energy. Confidence intervals for Cluster 2 permitted estimation of the levels of wind movement and advective energy that seem to be associated with a NRSA day for grain sorghum.

Conclusions are as follows. NRSA is a factor in sorghum as a mechanism of evapotranspiration control as was found for peanut in earlier studies. In contrast with the stomatal resistance-LWP relationship observed in peanut, it is apparent that LWP does not control stomatal resistance in as large extent as in peanut, but there is enough evidence of the effect of row spacing over the stomatal resistance on days with stressful conditions. In 22% of the days the narrow rows had consistent higher stomatal resistance during the afternoon, which seems to agree with the 26% of NRSA days obtained by Stone et al. (1985) in their study with peanut. The narrow rows had higher yields in the six growing seasons and showed evidences of higher water use efficiency. The main physical environmental factors shown to influence the stomatal behavior are the wind velocity and the advected energy. If a particular day has an accumulated wind movement between 67 Km/6h and 73 Km/6h, and an integrated advected energy between 7.2 MJ/m^2 and 11 MJ/m^2 it is likely that stomatal closure took place to reduce evapotranspiration. The lower limit of the confidence interval for the mean of the integrated advected energy in an stomatal action day appeared to be very close to the 8.5 MJ/m^2 suggested by Erickson et al.(1986) as the critical advected energy level for the separation of action and non-action days in peanut.

The data suggest that wind velocity participates in the stomatal control through the advection of energy, and also participates independently of the advection of energy. It is apparent that the effect of advected energy on stomatal resistance is better expressed at intermediate wind movement from 40 Km/6h to 80 Km/6h.

The high values of stomatal resistance associated with wind movements of 80 Km/6h or above at low levels of integrated advected energy have a cooling effect over the foliage, possibly owing to the phenomenon reported by Hatfield et al.,(1988). They found that when foliage temperatures of wheat and cotton drop below the optimal conditions for the action of an enzyme, this enzyme is impaired and the stomates remain closed. A similar acting enzyme may operate in grain sorghum.

The non-action days meeting the conditions of high evaporative demand may be indication of the presence of other factors affecting stomatal behavior and/or the existence of other water saving mechanisms different to stomatal operation. Ackerson and Krieg (1980) reported that sorghum stomates become insensitive to stressing conditions after flowering. They suggest that osmotic adjustment is the main water loosing control method after flowering.

LITERATURE CITED

Ackerson,R.C. and D.R. Krieg. 1977. Stomatal and nonstomatal regulation of water use in cotton, corn, and sorghum. Plant Physiol. 60:850-853.

Ackerson, R.C., D.R. Krieg and F.J. M. Sung. 1979. Leaf conductance and osmoregulation of field-grown sorghum genotypes. Crop Science 20:10-14.

Chin Choy, E.W., J.F. Stone, and J.E. Garton. 1977. Row spacing and direction effects on water uptake characteristics of peanuts. Soil Sci. Soc. Am. J. 41:428-432.

Erickson, P.I., J.F. Stone, and J.E. Garton. 1986. Critical evaporative demands for differential stomatal action in peanut grown in narrow and wide row spacing. Agron. J. 78:254-256.

Everitt, B.S. 1980. Cluster Analysis. Pages 23-40. 2nd. ed. Heineman Educational Books Ltd. London.

Ford, J., E. Nance, and F. Gray. 1976. Modern detailed soil survey: Perkins Research Station. Oklahoma State University. Research report p-744. Pages 24-25.

Garrity, D.P., C.Y. Sullivan, and D.G. Watts. 1982. Changes in grain sorghum stomatal and photosynthetic response to moisture stress across growth stages. Crop Science 24:441-446.

Hatfield, J.L., J.J. Burke, J.R. Mahan, and D.F. Wanjura. 1988. Foliage temperature measurements: A link between the biological and physical environment. Agron. J. 80: 553.

McCauley, G.N., J.F. Stone, and E.W. Chin Choy. 1978. Evapotranspiration reduction by field geometry effects in peanuts and grain sorghum. Agric. Meteorol. 19:295-304.

Pasternak, D., and G.L. Wilson. 1976. Photosynthesis and transpiration in the heads of droughted grain sorghum. Australian J. of Exptal. Agriculture and Animal Husbandry. 16:272-275.

SAS Institute. 1986. Statistical Analysis System User's Guide: Statistics. Pages 433-447. 1986 ed. SAS Institute Inc., Cary, NC.

Steiner, J.L. 1986. Dryland grain sorghum water use, light interception, and growth responses to planting geometry. Agron. J. 78:720-726.

Steiner, J.L. 1987. Radiation balance of dryland grain sorghum as affected by planting geometry. Agron. J. 79:259-265.

Stone, J.F. 1977. Symposium New Developments in Soil and Crop Science: Evapotranspiration control in Agricultural lands. Soil and Crop Science Society of Florida Procedings vol 37, 1978.

Stone, J.F., P.I. Erickson, and A.S.Abdul-Jabbar. 1985. Stomatal closure behavior induced by row spacing and evaporative demand in irrigated peanuts. Agron. J. 77:197-202.

Van Bavel, C.H.M. 1966. Potential evapotranspiration: the combination concept and its experimental verification. Water Resour. Res. 2:455-467.

APPENDIX A

TABLES

TABLE 1

GROUP1, DAYS THAT PRESENTED WELL DEFINED STOMATAL ACTION.

		Air Temperature (oC)		Wind	Radiation (MJ/m2)	
Year	Date	Maximum	Mean	(km/6h)	Solar	Net
1986	JUL23	36.1	33.8	69.3	14.2	13.6
1986	JUL24	40.1	37.1	82.3	18.0	13.9
1986	AUG20	31.0	29.9	82.5	16.2	13.8
1987	AUG05	32.4	32.4	42.8	18.1	12.2
1988	AUG02	34.3	32.1	85.0	14.4	9.1
1988	AUG03	33.5	32.1	74.0	18.1	13.5
1988	AUG04	35.6	33.7	63.7	17.5	12.9
1990	JUL16	30.7	28.2	62.4	17.1	12.0
1990	JUL26	33.2	30.6	64.3	12.7	10.9
1990	AUG02	32.4	30.5	56.6	12.1	7.6
1990	AUG08	25.3	29.2	56.1	17.3	12.0
1990	AUG22	36.5	36.5	41.3	17.9	13.9
1991	AUG08	39.0	37.3	80.6	16.1	10.3
1991	AUG22	35.1	32.6	52.8	17.5	13.5

TABLE 2

GROUP 2, DAYS THAT PRESENTED INDETERMINATE STOMATAL ACTION

Year	Date	Air Temperature (oC) Maximum	Air Temperature (oC) Mean	Wind movement (Km/6h)	Radiation (Mj/m2) Solar	Radiation (Mj/m2) Net
1986	AUG26	31.0	29.9	82.5	16.2	13.8
1987	JUL16	30.3	28.4	74.2	17.5	11.5
1987	JUL21	31.0	30.1	51.9	16.7	13.0
1987	AUG12	37.1	35.1	57.1	16.7	11.1
1987	AUG19	35.2	30.6	66.3	16.5	11.9
1988	JUL14	38.1	34.4	72.6	15.6	11.7
1988	JUL21	29.7	28.6	42.9	18.6	14.5
1988	AUG09	36.1	33.5	56.0	14.0	9.8
1988	AUG18	32.4	30.8	45.5	12.8	9.6
1989	AUG10	23.9	23.4	57.6	9.9	6.3
1991	AUG06	36.5	34.5	71.0	17.3	11.8

TABLE 3

GROUP 3, DAYS THAT PRESENTED NO STOMATAL ACTION

		Air Temperature (oC)		Wind movement	Radiation (Mj/m2)	
Year	Date	Maximum	Mean	(km/6h)	Solar	Net
1986	AUG12	31.0	29.7	83.2	17.0	13.6
1987	JUL14	31.4	30.1	51.4	17.7	14.4
1987	JUL20	30.7	29.9	63.1	18.9	15.1
1987	JUL22	31.7	30.3	50.2	17.6	13.5
1987	JUL23	32.8	32.8	58.6	11.8	3.2
1987	JUL27	33.6	32.7	52.7	18.7	14.4
1987	JUL29	35.6	33.8	52.3	16.8	12.6
1987	JUL30	36.6	35.3	59.2	18.3	13.3
1987	AUG06	37.5	34.6	45.3	17.3	14.2
1987	AUG11	35.6	33.3	42.3	17.4	13.9
1988	JUL25	37.1	33.3	52.2	17.6	14.2
1988	AUG08	39.1	35.6	62.9	16.8	12.9
1988	AUG10	34.4	31.6	44.2	17.0	13.3
1988	AUG11	32.4	30.7	56.8	17.3	12.9
1988	AUG15	37.1	33.7	76.9	16.4	13.1
1988	AUG16	38.6	36.1	61.9	16.7	13.6
1988	AUG17	37.1	33.6	42.8	17.2	11.7
1989	AUG01	34.1	32.6	44.1	18.2	13.3
1989	AUG02	28.8	27.8	58.6	7.2	8.6
1989	AUG08	25.6	24.4	43.6	18.1	13.0
1989	AUG09	25.9	25.4	53.1	17.9	13.2
1989	AUG17	29.2	27.9	48.0	15.4	9.4
1989	AUG18	29.9	29.2	50.1	9.9	7.6
1989	AUG21	31.9	31.0	63.7	14.6	12.6
1989	AUG28	37.9	36.7	60.3	17.9	13.8
1990	JUL17	30.3	27.9	63.3	10.9	9.6
1990	JUL19	33.2	31.2	63.4	17.8	13.3
1990	JUL24	29.9	29.4	63.4	17.7	8.9
1990	JUL25	31.1	27.4	54.4	9.5	5.7
1990	AUG01	31.5	29.3	46.2	18.9	10.9
1990	AUG21	39.5	39.2	38.6	17.4	13.4
1991	JUL30	35.5	35.3	53.5	18.3	13.7

TABLE 3 (continued)

1991	JUL31	39.0	36.7	68.9	18.4	13.9
1991	AUG01	39.5	37.1	67.7	18.6	14.0
1991	AUG05	37.5	35.2	68.9	16.9	12.8
1991	AUG07	36.9	34.4	67.6	17.1	13.5
1991	AUG12	30.7	29.3	53.6	12.1	8.9
1991	AUG15	29.9	27.7	63.8	16.6	13.3
1991	AUG19	32.8	29.9	67.2	17.1	13.2
1991	AUG21	31.1	28.6	49.8	16.7	12.5

TABLE 4

ANALYSIS OF VARIANCE AND MEANS OF MICROMETEOROLOGICAL VARIABLES FROM THE THREE GROUPS OF DAYS.

		Mean Squares				
S.of V.	d.f.	Air Temperature Maximum	Air Temperature Mean	Radiation Solar	Radiation Net	Wind Movement
Group	2	3.860	5.396	2.273	5.767	475.40*
Error	62	14.537	10.932	6.854	3.320	120.55
C.V. (%)		11.36	10.44	16.16	19.91	18.44

* Significant difference at alpha=0.05

	Means		
Variable	Group 1	Group 2	Group 3
Maximum Temperature	33.94	32.84	33.60
Mean Temperature	31.15	30.85	31.72
Solar Radiation	16.23	15.62	16.34
Net Radiation	12.09	11.36	12.24
Wind Movement	65.98	61.60	56.70

TABLE 5

CLUSTER 1, DAYS OF LOW INTEGRATED ADVECTED ENERGY ASSOCIATED WITH LOW VALUES OF WIND MOVEMENT.

Year	Date	Stomatal Resistance (sc/cm)	Wind Movement (km/6h)	Integrated advected energy (Mj/m2)
1987	JUL14	2.01	51.4	2.3
1987	JUL20	1.22	63.1	11.1
1987	JUL21 +	1.15	51.8	2.2
1987	JUL22	1.24	50.2	1.8
1987	JUL23	1.35	58.6	1.1
1987	JUL27	1.32	52.7	2.8
1987	JUL29	1.18	52.3	2.7
1987	JUL30	1.43	59.2	4.1
1987	AUG05 *	1.28	42.8	2.1
1987	AUG11	1.05	42.3	2.3
1987	AUG12 +	1.08	57.7	6.6
1988	JUL21 +	1.51	42.9	1.9
1988	JUL25	1.44	52.2	3.0
1988	AUG09 +	0.91	56.0	12.6
1988	AUG10	0.65	44.3	6.5
1988	AUG11	0.88	56.8	7.8
1988	AUG15	1.69	76.9	23.4
1988	AUG17	1.52	42.8	8.9
1988	AUG18 +	1.53	45.5	8.5
1989	AUG08	1.17	43.6	3.3
1989	AUG09	1.03	53.1	5.1
1989	AUG10 +	.	57.6	4.5
1989	AUG17	1.20	48.0	5.5
1990	JUL25	1.16	54.4	3.6
1990	AUG02 *	1.37	56.6	6.5
1990	AUG21	1.17	38.6	8.0
1991	JUL30	1.02	53.5	10.1
1991	AUG01	1.24	67.7	17.2
1991	AUG05	1.06	68.9	13.5
1991	AUG12	1.32	53.6	7.6
1991	AUG15	1.34	63.8	7.8
1991	AUG19	1.39	67.2	10.5
1991	AUG21	1.31	49.8	5.4
1991	AUG22 *	1.23	52.8	7.3

* Stomatal Action Day + Indeterminate Action Day

TABLE 6

CLUSTER 2, DAYS WITH HIGH VALUES OF ADVECTED ENERGY ASSOCIATED WITH HIGH VALUES OF WIND MOVEMENT

Year	Date	Stomatal Resistance (sc/cm)	Wind Movement (Km/6h)	Integrated advected energy (Mj/m2)
1986	JUL23 *	2.01	69.3	10.9
1986	JUL24 *	1.18	82.3	17.6
1986	AUG12	1.09	83.2	9.7
1986	AUG20 *	1.00	82.5	6.8
1986	AUG26 +	1.55	82.5	9.8
1987	JUL16 +	2.00	74.2	2.0
1987	AUG06	1.11	45.3	3.1
1987	AUG19 +	1.35	66.3	2.9
1988	JUL14 +	2.00	72.6	5.1
1988	AUG02 *	1.63	85.0	3.4
1988	AUG03 *	1.07	74.0	9.7
1988	AUG04 *	1.18	63.7	11.5
1988	AUG08	1.25	62.8	16.3
1988	AUG16	1.58	61.8	13.8
1989	AUG01	0.89	44.2	5.2
1989	AUG02	1.60	58.6	4.9
1989	AUG18	1.55	50.2	7.8
1989	AUG21	1.76	63.7	8.1
1989	AUG28	1.18	60.3	14.2
1990	JUL16 *	1.20	62.4	6.6
1990	JUL17	1.59	63.3	4.9
1990	JUL19	0.99	63.4	6.8
1990	JUL24	0.94	63.4	4.0
1990	JUL26 *	1.38	64.3	7.1
1990	AUG01	0.80	46.2	5.4
1990	AUG08 *	1.16	56.1	6.5
1990	AUG22 *	0.80	41.3	7.9
1991	JUL31	0.94	68.9	17.2
1991	AUG06 +	1.36	70.9	14.3
1991	AUG07	0.88	67.6	13.5
1991	AUG08 *	1.28	80.6	19.4

* Stomatal Action Days

\+ Indeterminate Stomatal Action Days

TABLE 7

DESCRIPTIVE STATISTICS FOR THE TWO CLUSTERS

CLUSTER 1

N	Variable	Minimum	Maximum	Mean
35	Stomatal Resistance	0.65	2.01	1.22
	Wind Movement	38.59	59.17	50.74
	Integrated Advected Energy	1.18	12.62	6.00

CLUSTER 2

N	Variable	Minimum	Maximum	Mean
30	Stomatal Resistance	0.88	2.01	1.35
	Wind movement	60.38	85.04	70.00
	Integrated Advected Energy	2.04	23.37	9.16

TABLE 8

GRAIN YIELD FROM THE GROWING SEASONS
OF 1986 TO 1991

Year	Row Spacing	Yield (kg/Ha)	Difference narrow - wide
1986	Narrow	5582.07	
	Wide	5115.06	467.01
1987	Narrow	5746.63	
	Wide	5281.95	464.68
1988	Narrow	5669.60	
	Wide	5042.89	526.71
1989	Narrow	4240.31	
	Wide	3872.33	367.98
1990	Narrow	8256.07	
	Wide	4722.61	3533.46
1991	Narrow	6280.16	
	Wide	5336.86	943.30

TABLE 9

PAIRED COMPAPISON TEST FOP THE GRAIN
YIELD OF THE NAPPOW AND
WIDE PLOTS

N	Mean	Standard Error	T	Prob > T
6	1067.19	500.13	2.13	0.086

TABLE 10

ANALYSIS OF VAPIANCE AND MEANS FOP SOIL WATEP CONTENT.
TREATMENTS ARE THE TWO ROW DISTANCES. WATEP
CONTENT IN VOLUME.

S.of V.	d.f.	Mean Square	Pr > F
Date(year)	41	0.00171	0.0001
Treatment	1	0.00051	0.2161
Error	41	0.00032	

Narrow Row Mean: 0.231
Wide Row Mean: 0.236

APPENDIX B

FIGURES

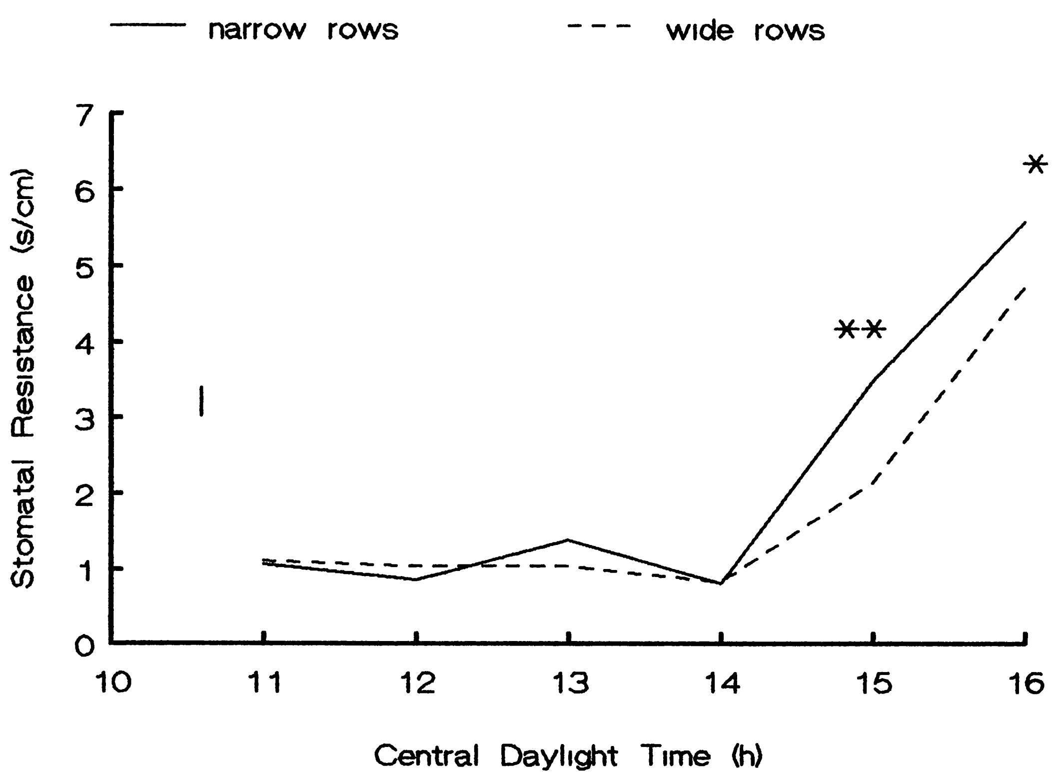

Fig 1. Stomatal resistance on July 23,1986. Vertical line represents standard error. *: Significant difference between row spacing at alpha=0.10. **: Significant difference at alpha=0.05.

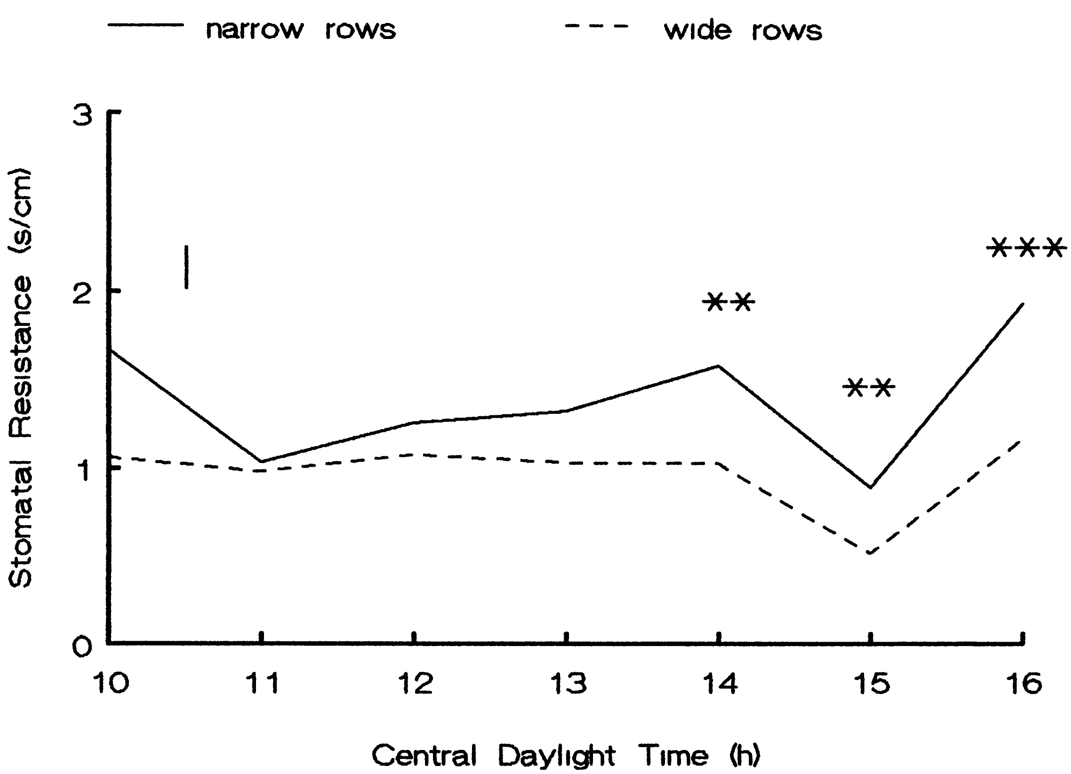

Fig 2. Stomatal resistance on July 24,1986.
Vertical line represents standard error.
***:Significant difference at alpha<=0.01
**:Significat difference at alpha=0.05.

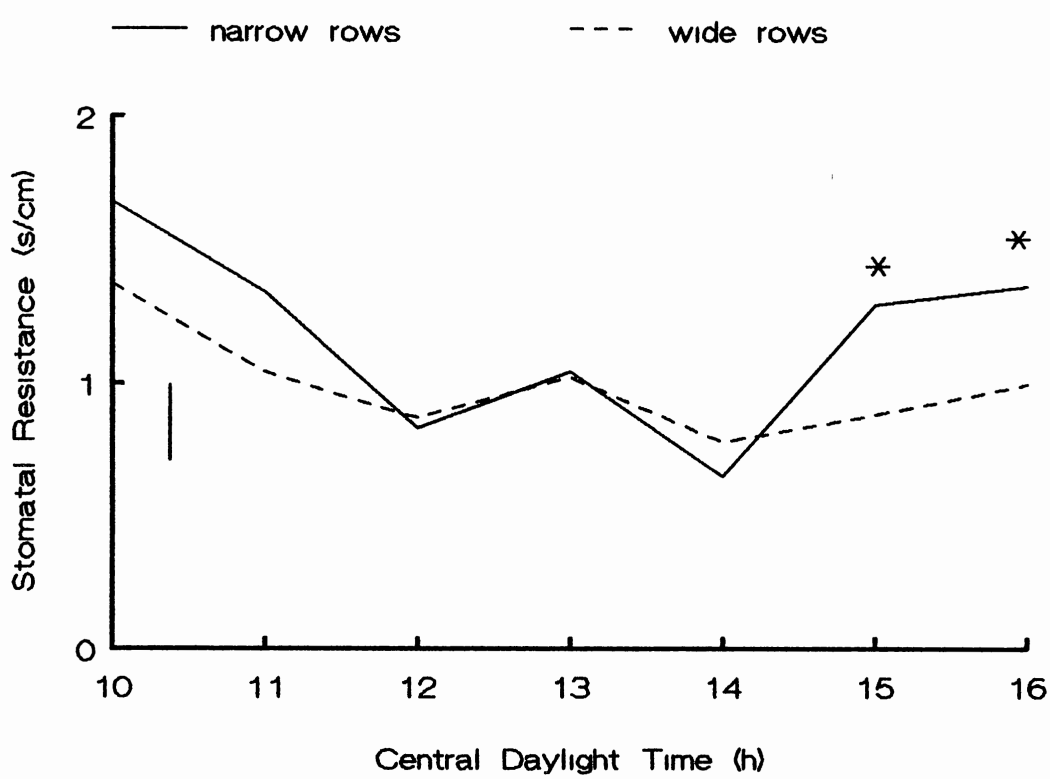

Fig 3. Stomatal resistance on August 20,1986.
Vertical line represents standard error.
* :Sificant difference at alpha=0.15

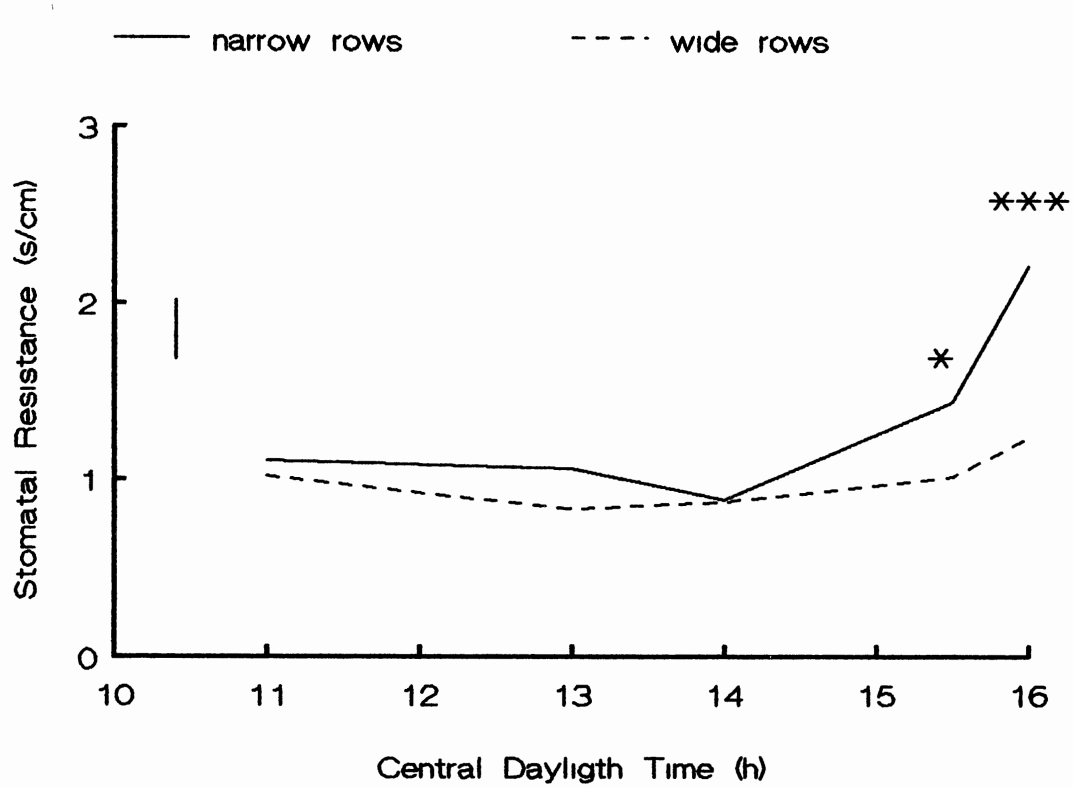

Fıg 4. Stomatal resıstance on August 5,1987.
Vertıcal lıne represents standard error.
***: Sıgnıfıcant dıfference at alpha<=0.01
*: Sıgnıfıcant dıfference at alpha=0.10

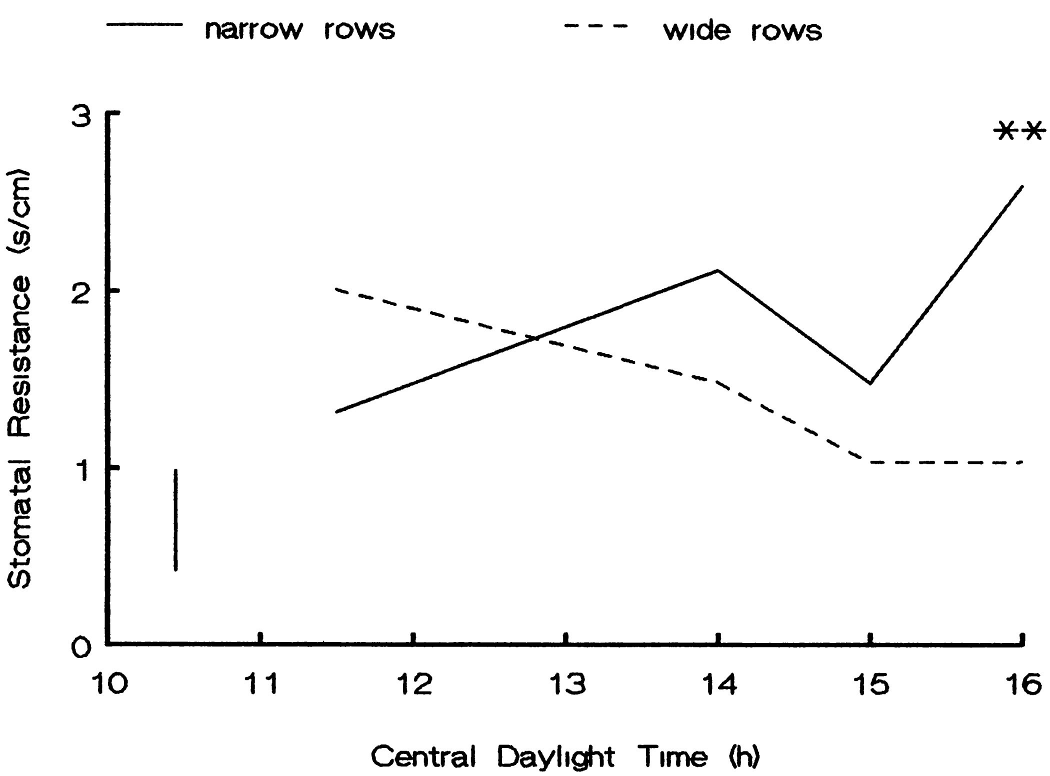

Fig 5. Stomatal resistance on August 2, 1988.
Vertical line represents standard error.
** : Significant difference at alpha=0.05.

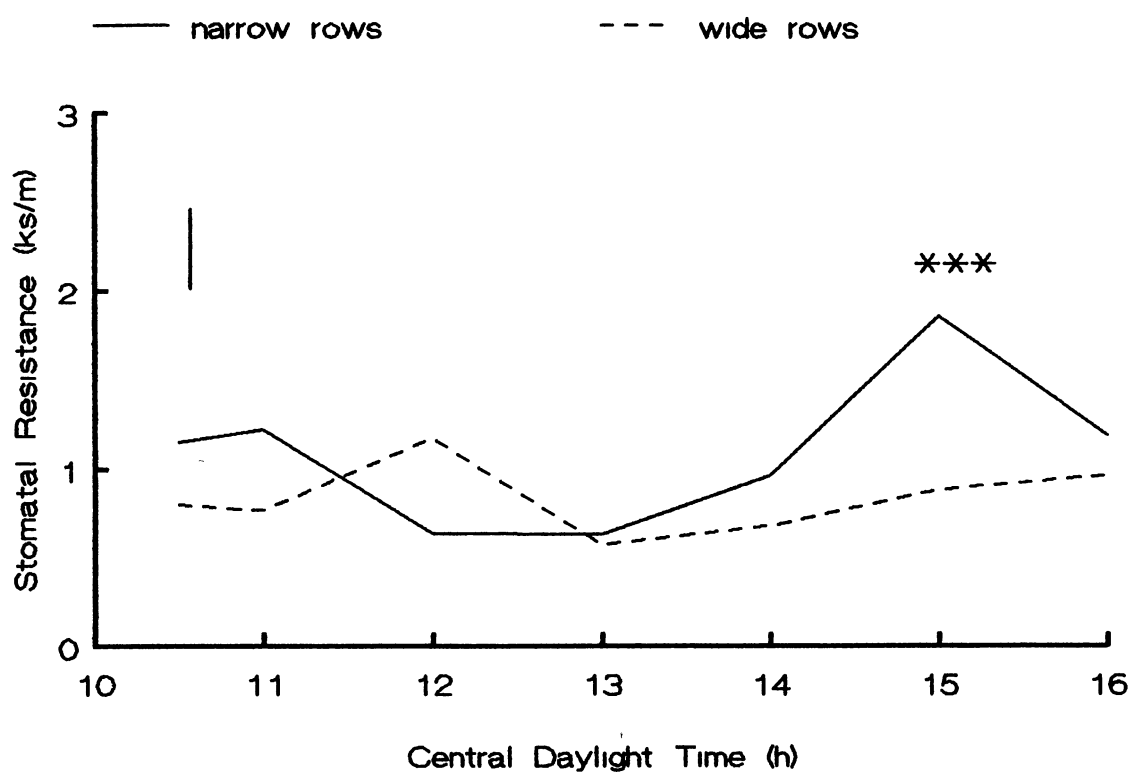

Fig 6. Stomatal resistance on August 3,1988.
Vertical line represents standard error.
***: Significant difference at alpha<=0.01

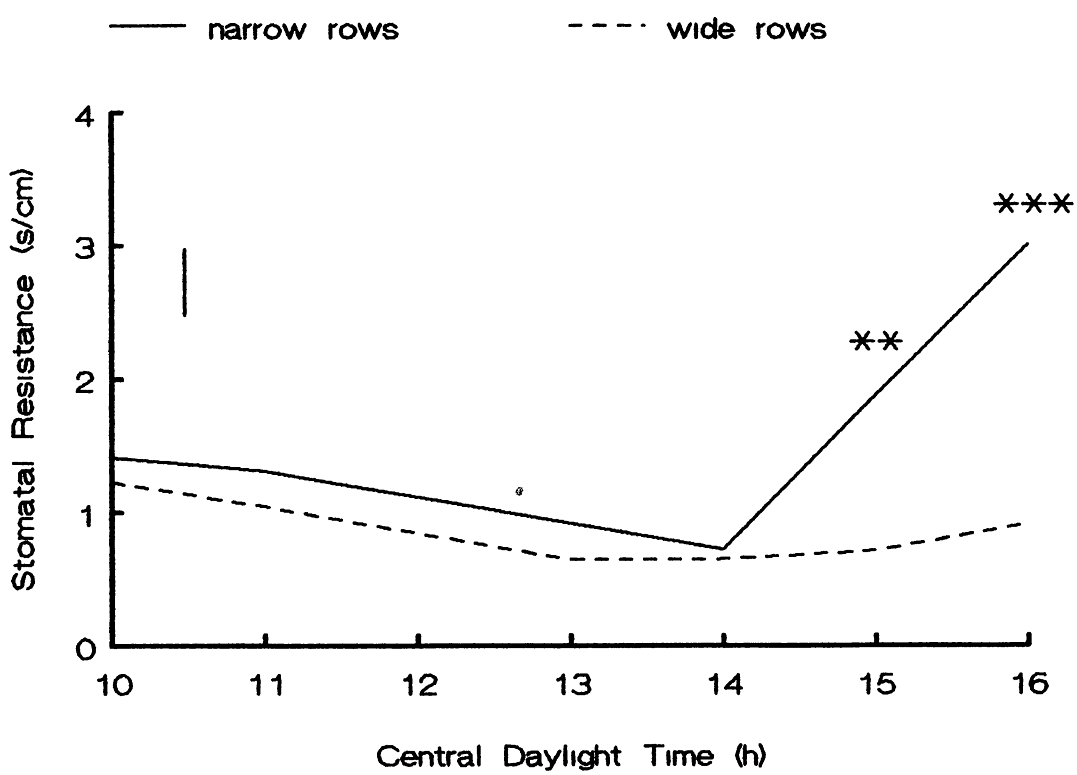

Fig 7. Stomatal resistance in August 4,1988.
Vertical line represents standard error.
***: Significant difference at alpha=0.01.
**: Significant difference at alpha=0.05.

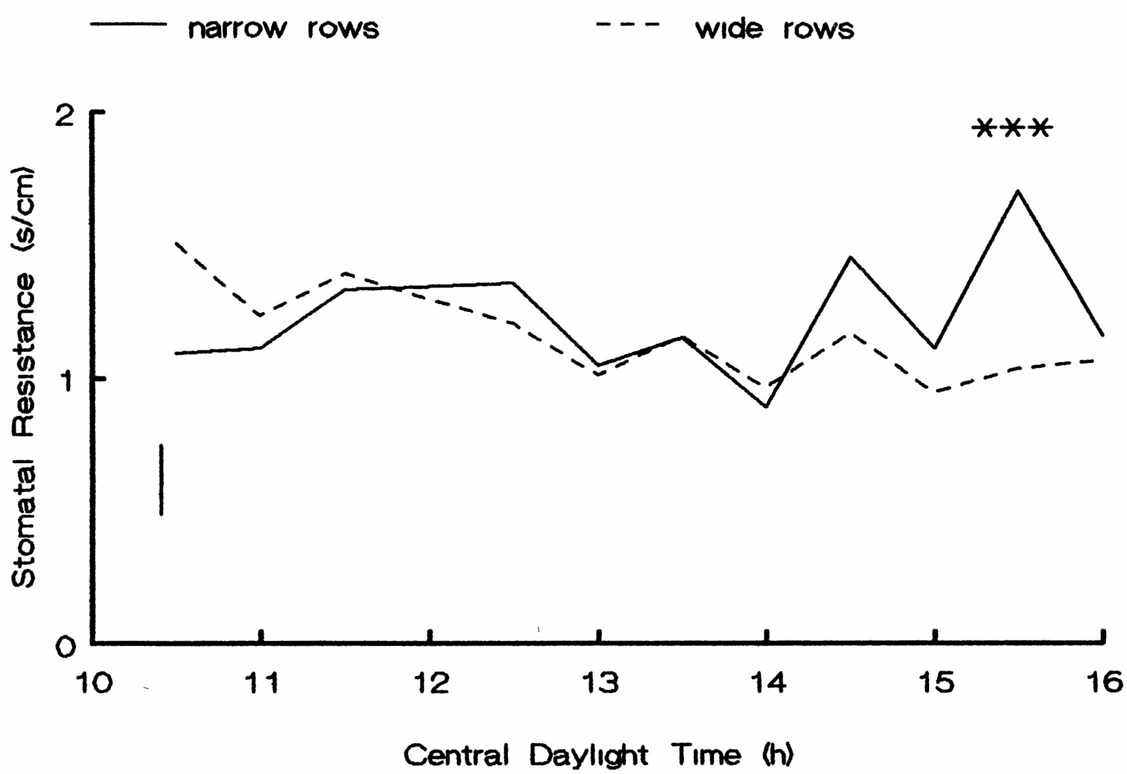

Fig 8. Stomatal resistance in July 16,1990.
Vertical line represents standard error.
***: Significant difference at alpha<=0.01

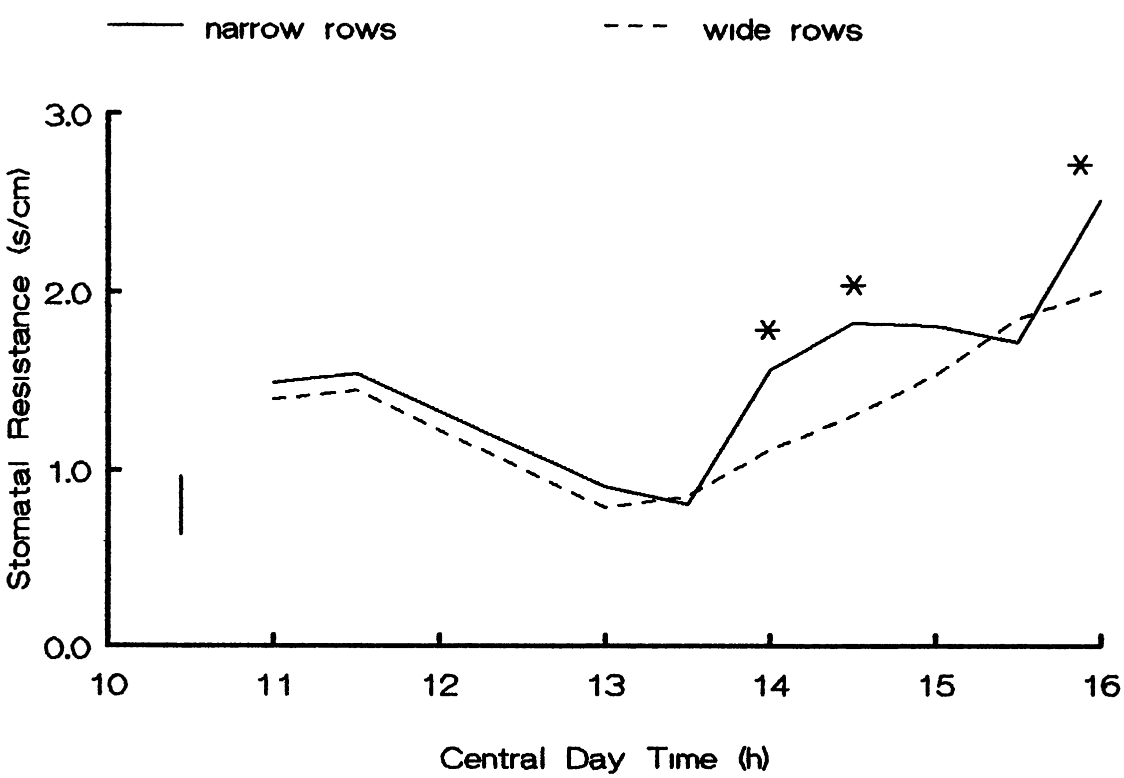

Fig 9. Stomatal resistance in July 26,1990.
Vertical line represents standard error.
*: Significant difference at alpha=0.10.

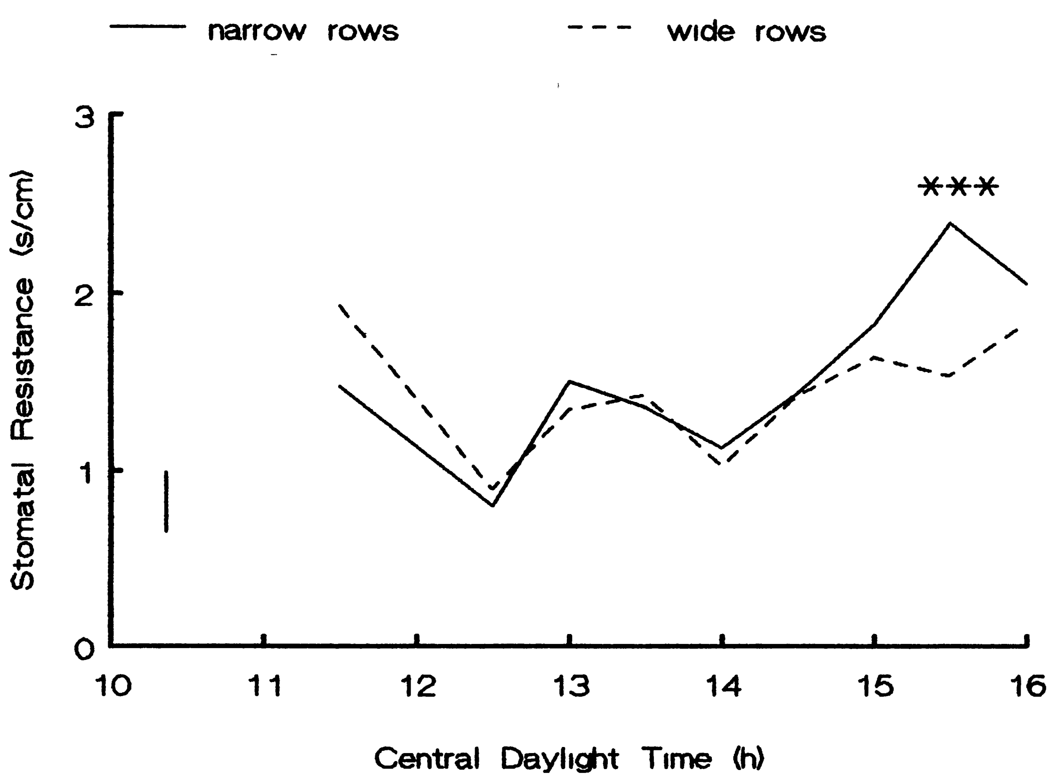

Fig 10. Stomatal resistance in August 2,1990.
Vertical line represents standard error.
***:Significant difference at alpha<=0.01

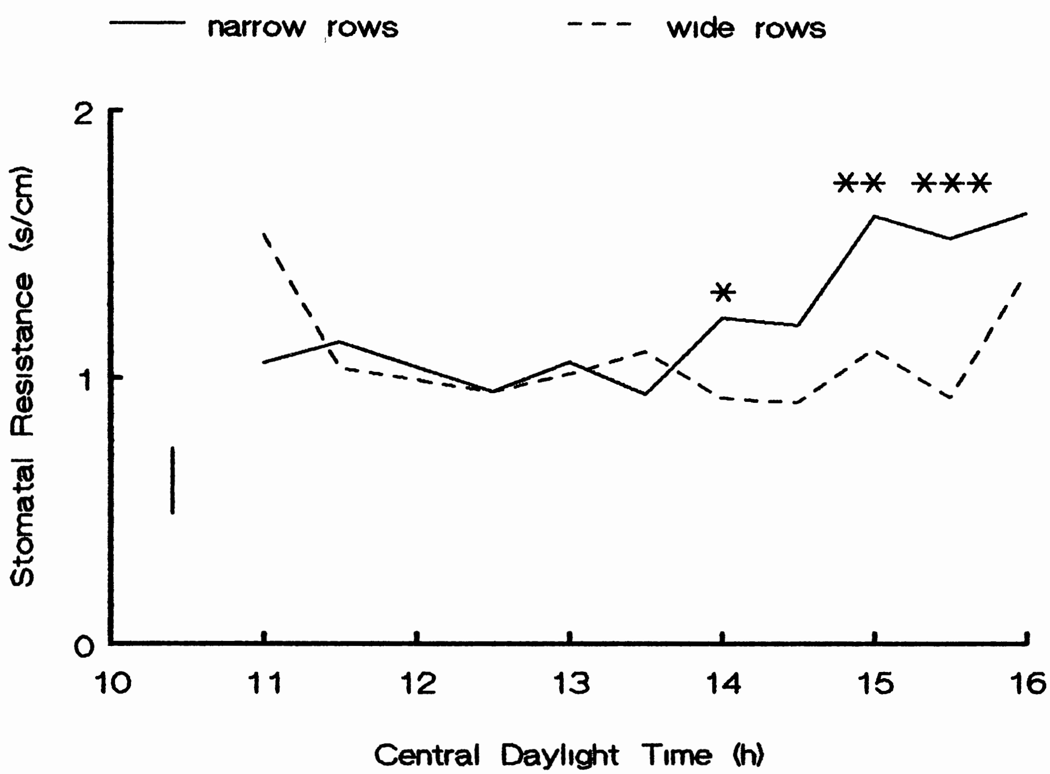

Fig 11. Stomatal resistance in August 8, 1990.
Vertical line represents standard error.
***:Significant difference at alpha<=0.01.
**: Significant difference at alpha=0.05.
*: Significant difference at alpha=0.15

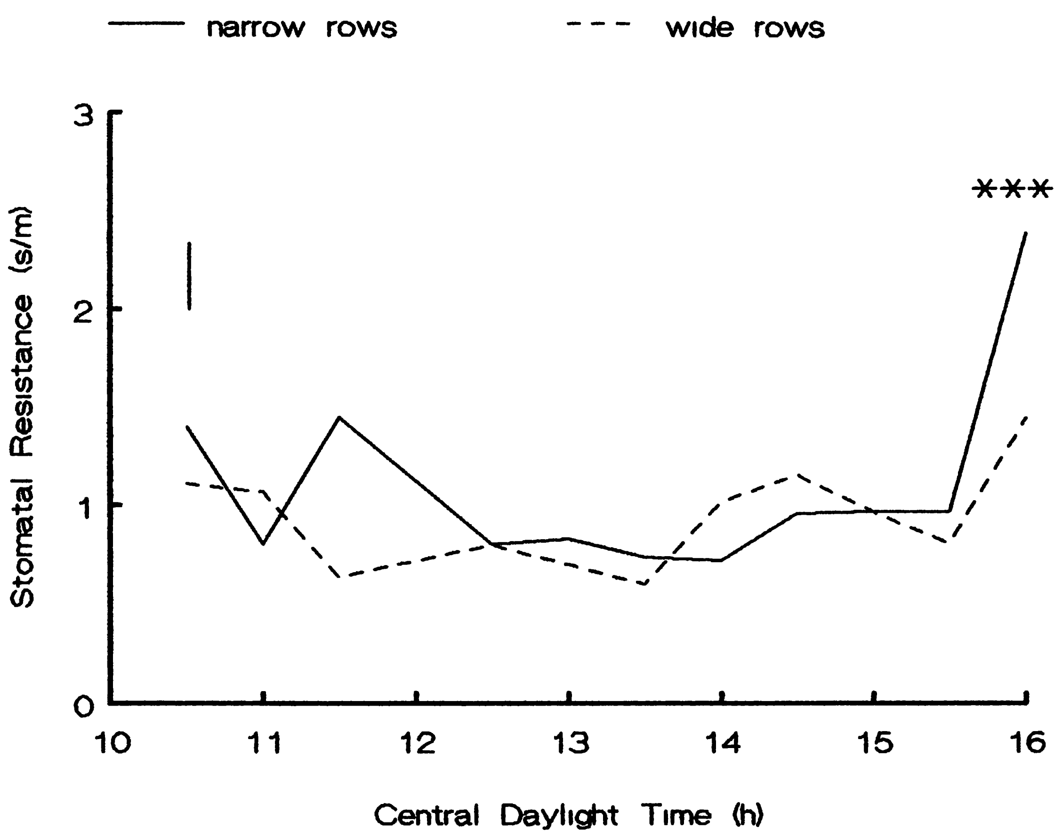

Fig 12. Stomatal resistance on August 22,1990.
Vertical line represents standard error.
***: Significant difference at alpha<=0.01

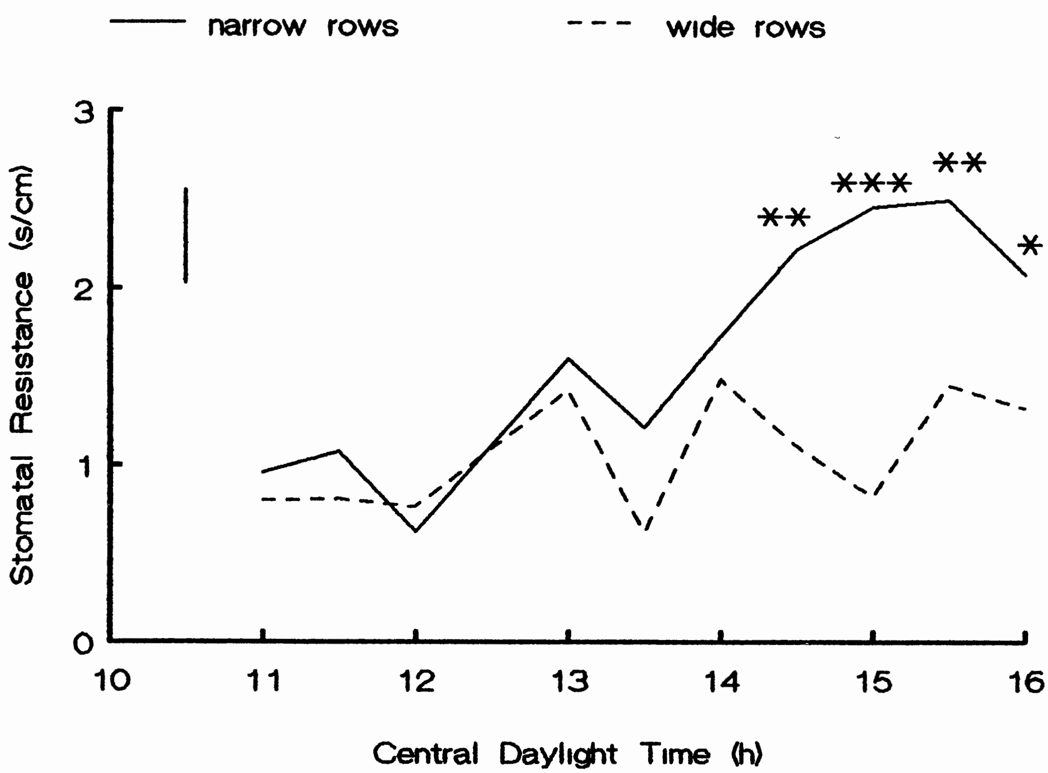

Fig 13. Stomatal resistance on August 8,1991.
Vertical line represents standard error.
***: Significant difference at alpha<=0.01.
**: Significant difference at alpha=0.05.

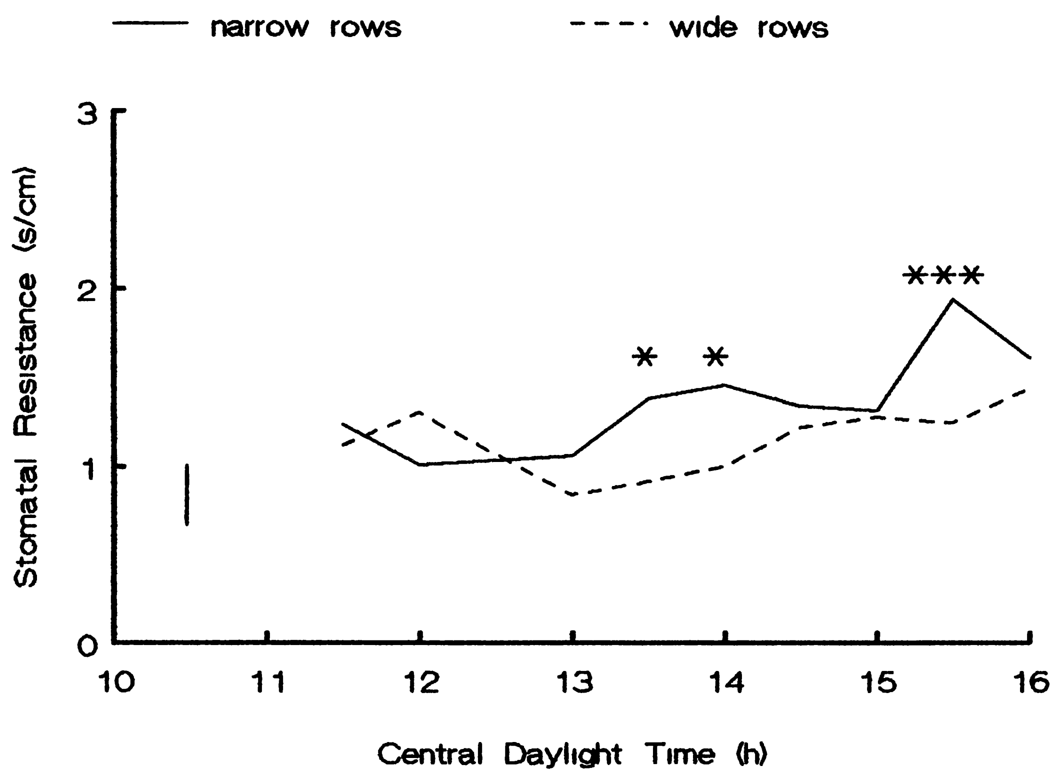

Fig 14. Stomatal resistance in August 22,1991.
Vertical line represents standard error.
***: Significant difference at alpha<=0.01
*: Significant difference at alpha=0.10.

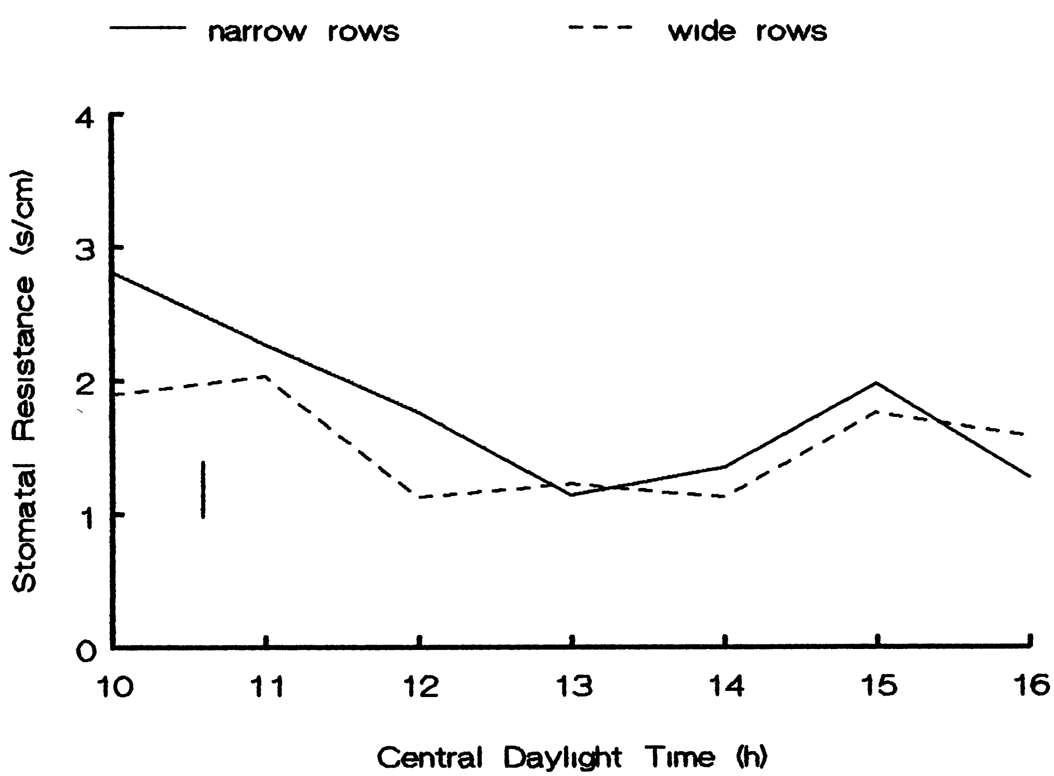

Fig 15. Stomatal resistance on August 26,1986.
Vertical line represents standard error.

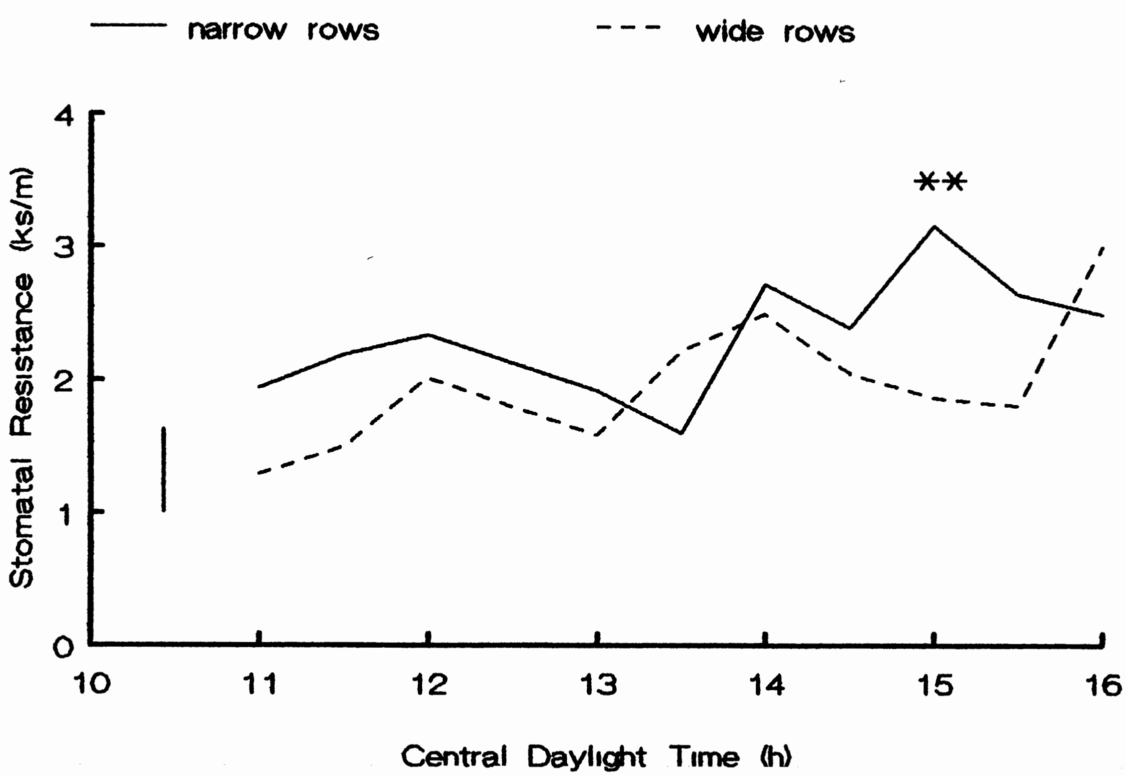

Fig 16. Stomatal resistance on July 16,1987.
Vertical line represents standard error.
**: Significance at alpha=0.05.

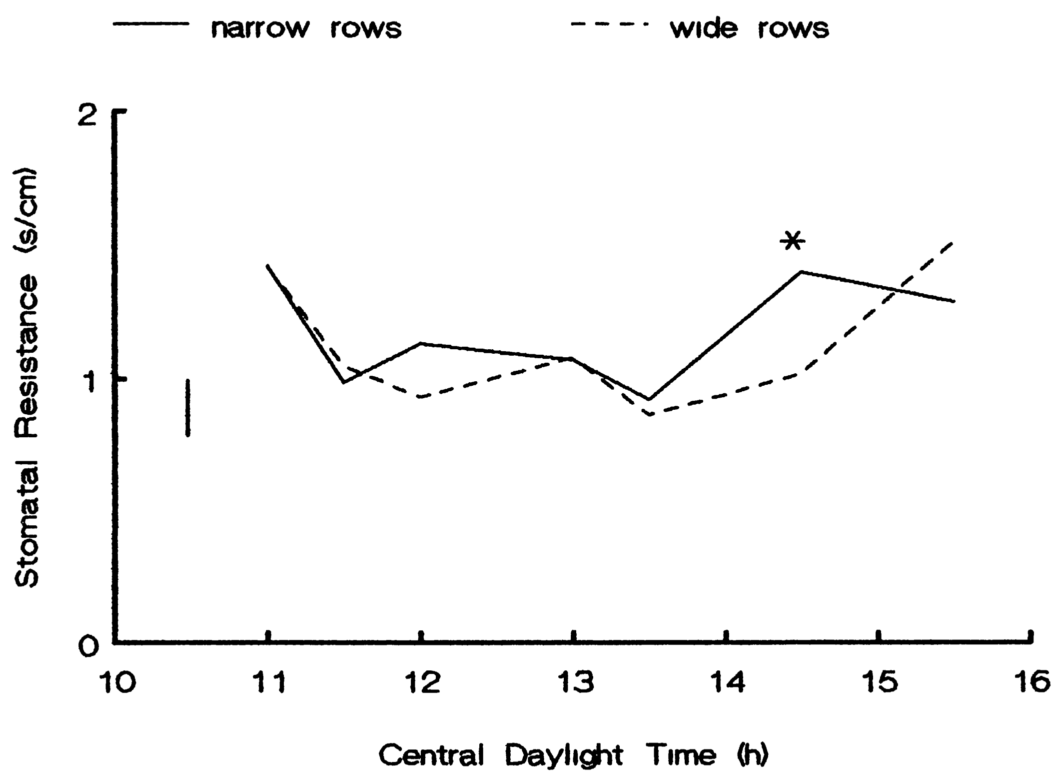

Fig 17. Stomatal resistance on July 21,1987.
Vertical line represents standard error.
*: Significance at alpha=0.10.

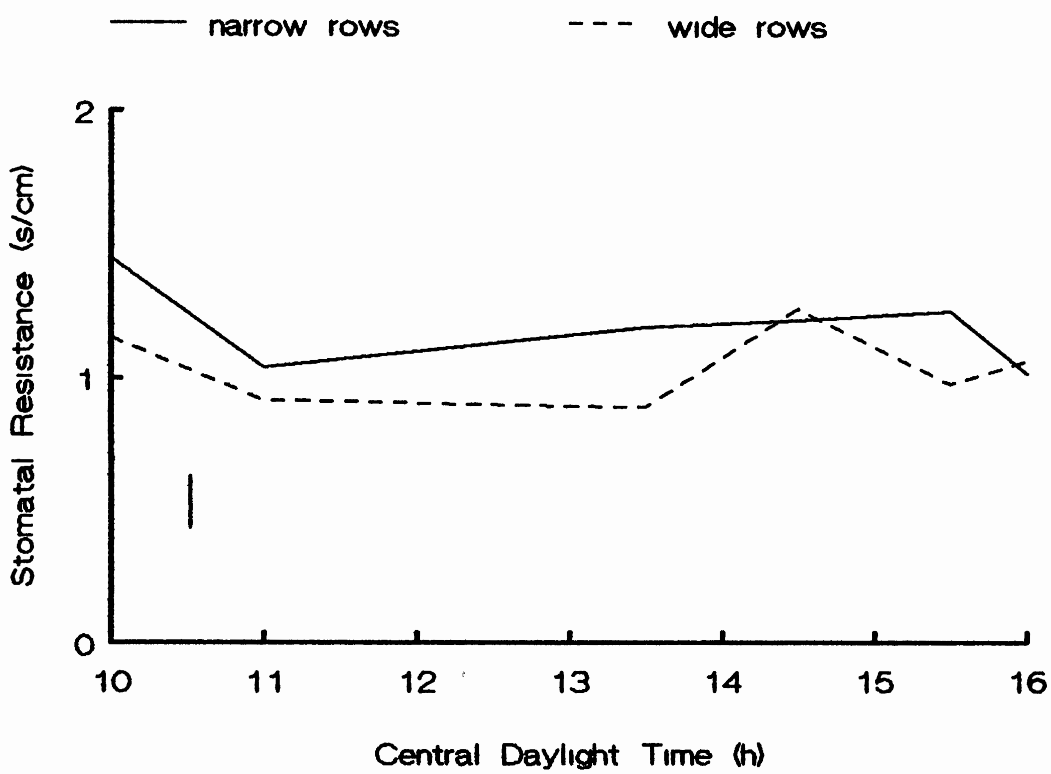

Fig 18. Stomatal resistance on August 12,1987. Vertical line represents standard error.

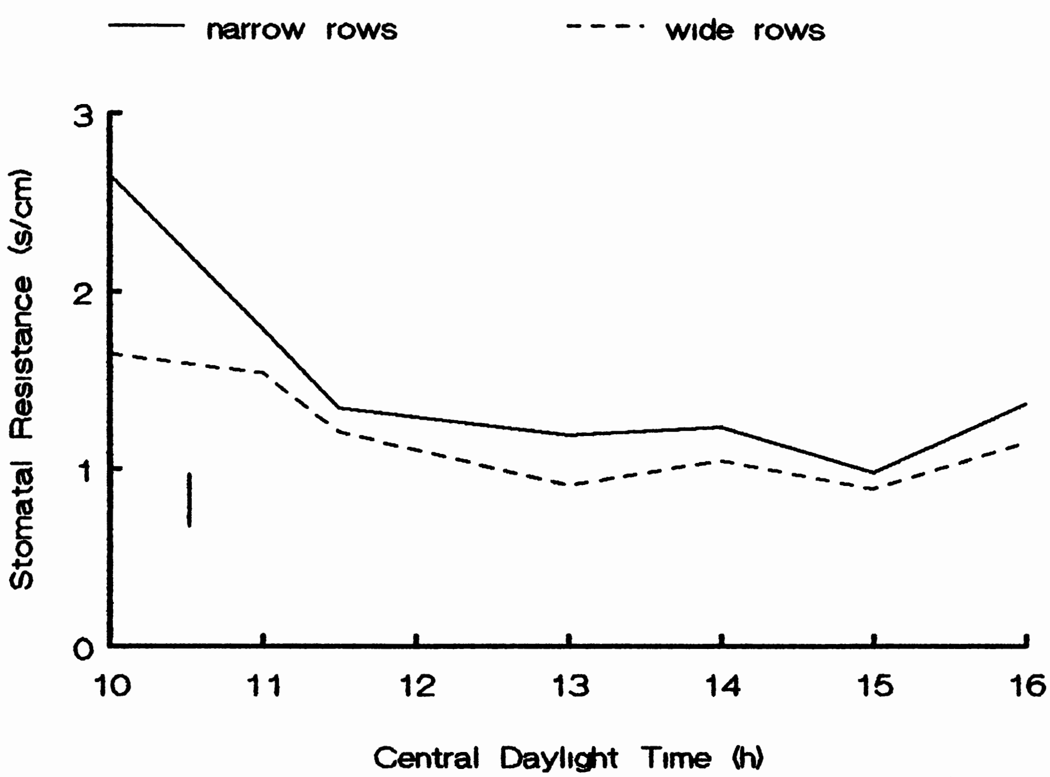

Fig 19. Stomatal resistance on August 19,1987. Vertical line represents standard error.

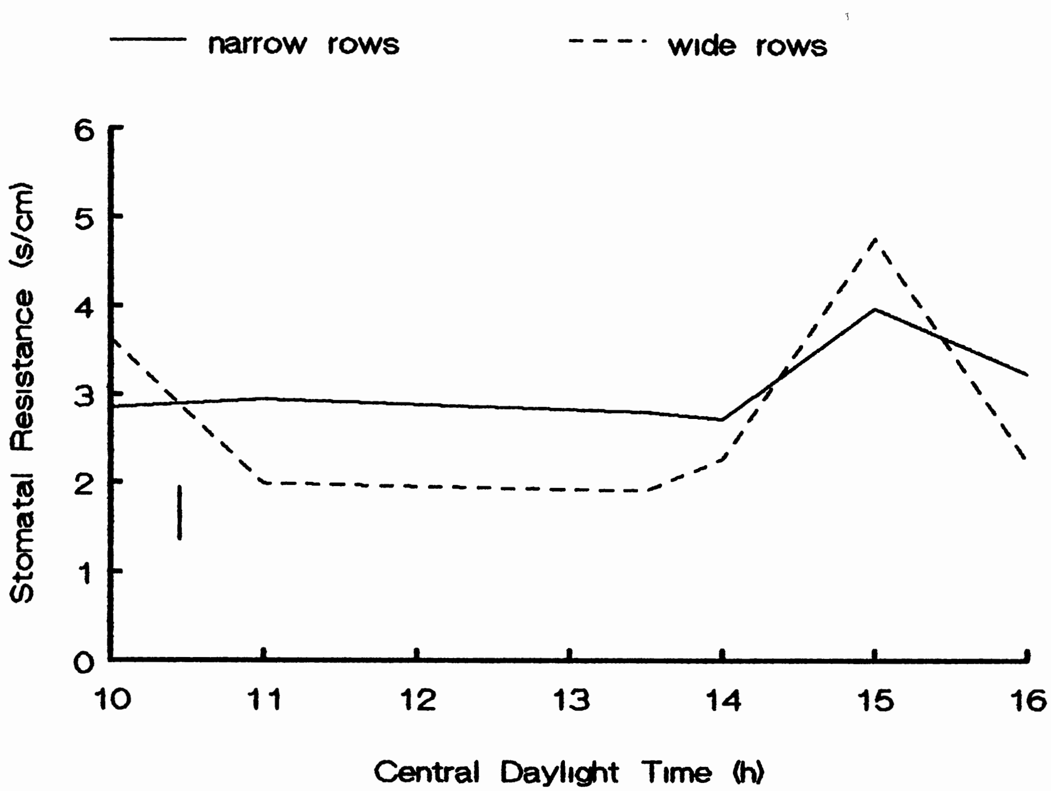

Fig 20. Stomatal resistance on July 14, 1988. Vertical line represents standard error.

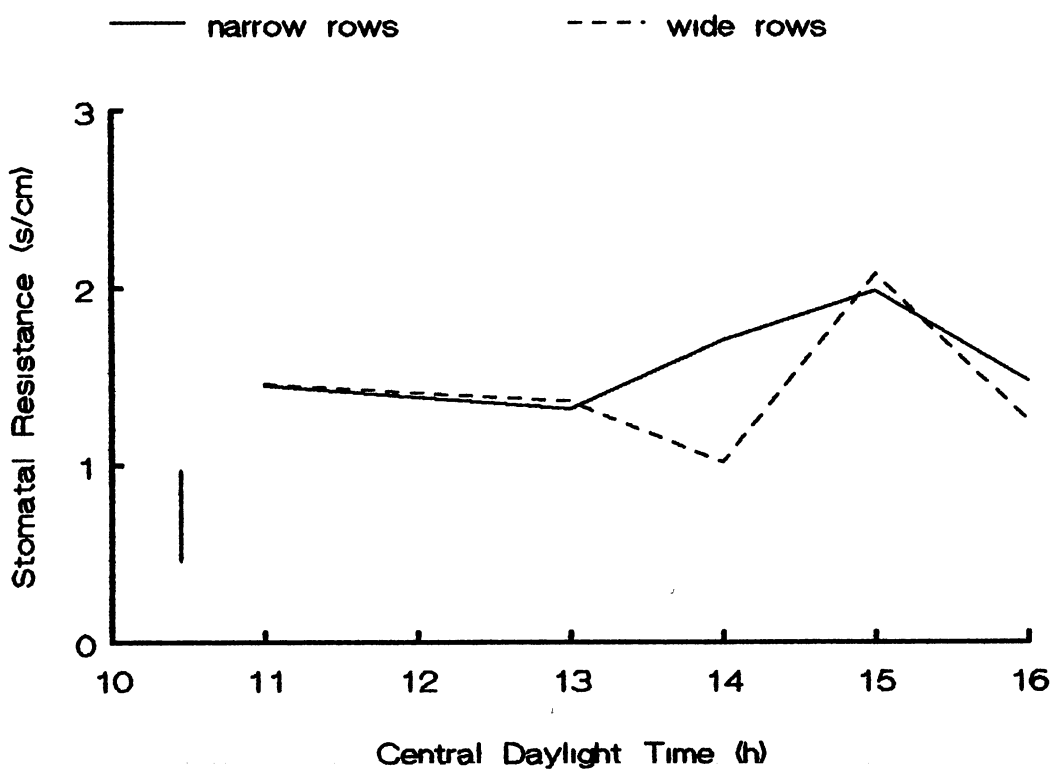

Fig 21. Stomatal resistance on July 21,1988. Vertical line represents standard error.

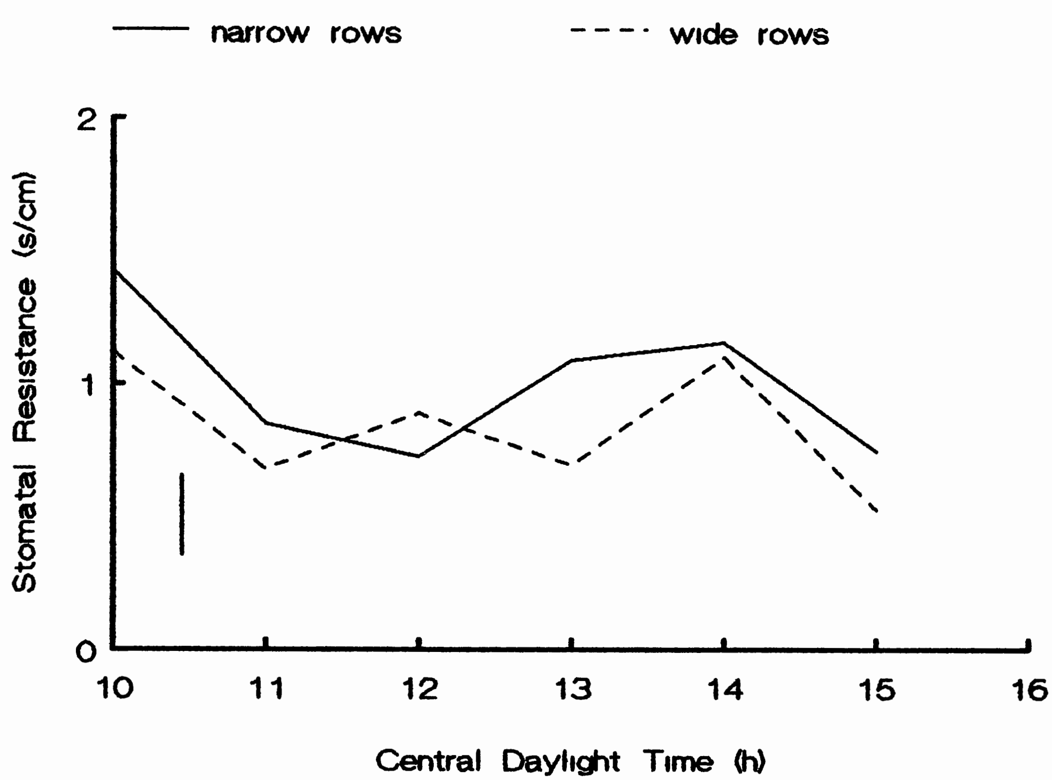

Fig 22. Stomatal resistance on August 9,1988. Vertical line represents standard error.

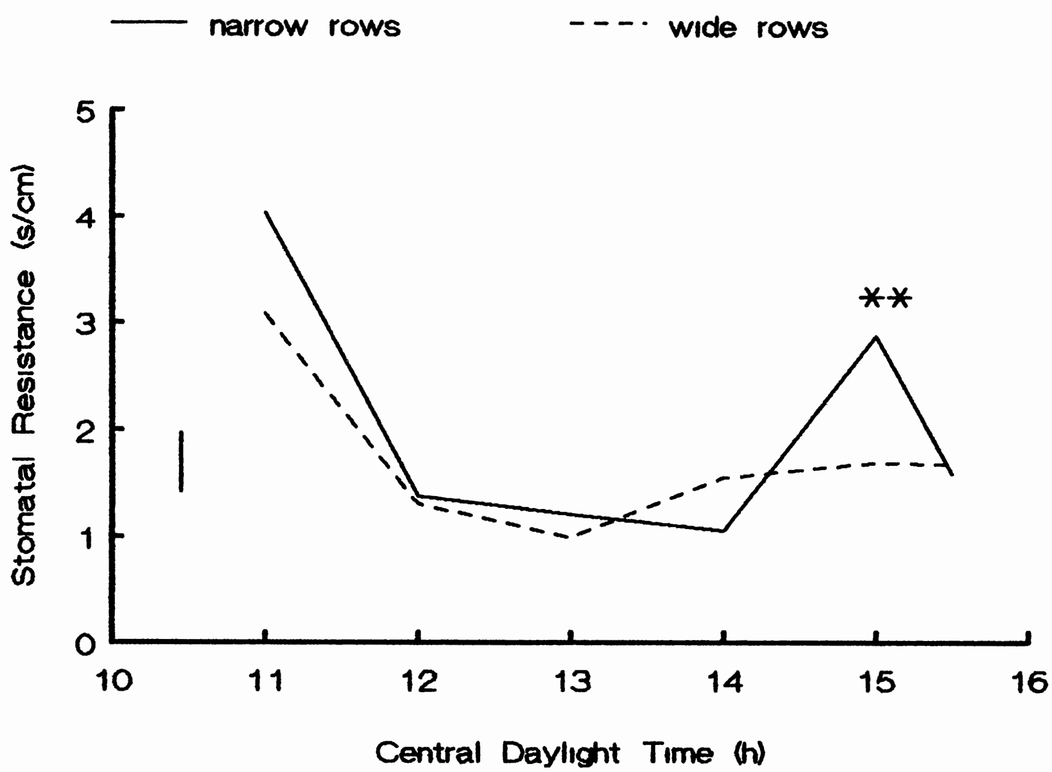

Fig 23. Stomatal resistance on August 18,1988.
Vertical line represents standard error.
**: Significance at alpha=0.05.

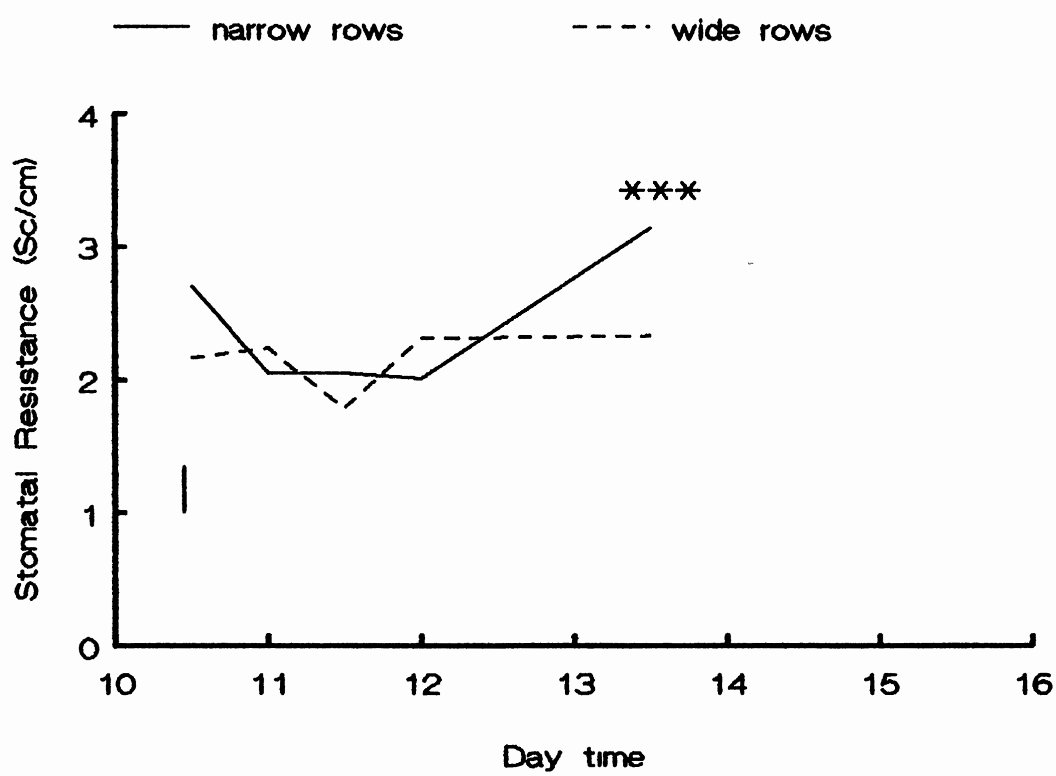

Fig 24. Stomatal resistance on August 16,1989.
Vertical line represents standard error.
***: Significance at alpha<=0.01.

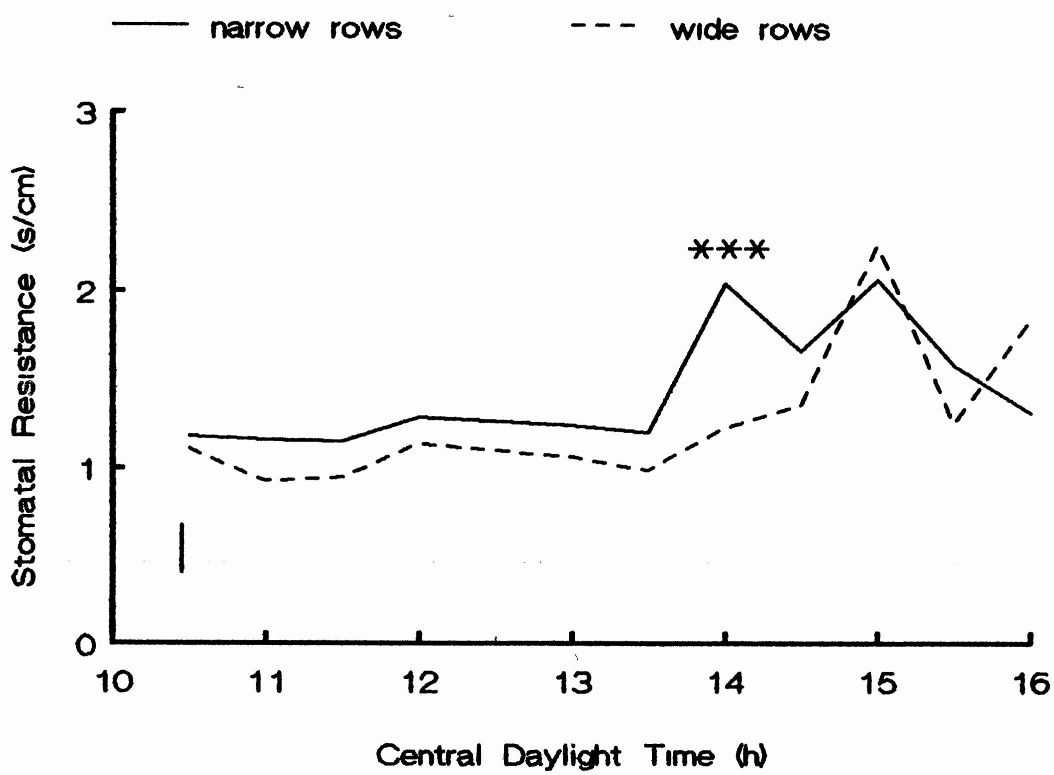

Fig 25. Stomatal resistance on August 6,1991.
Vertical line represents standard error.
***: Significance at alpha<=0.01.

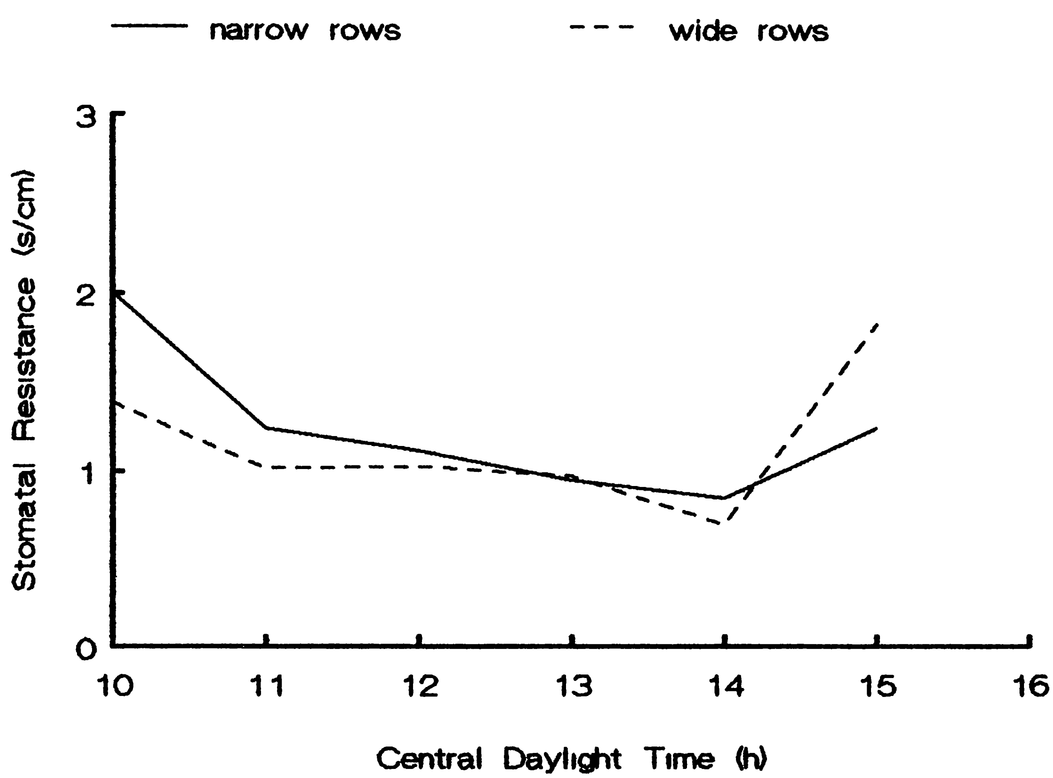

Fig 26. Stomatal resistance on August 12, 1986.

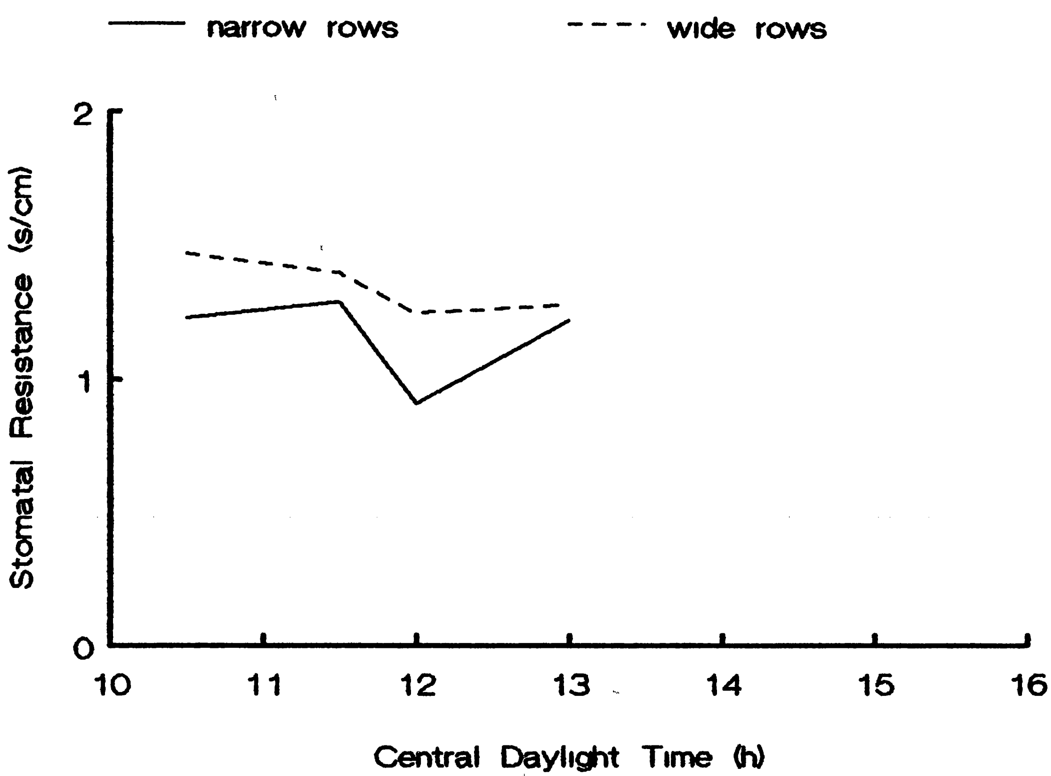

Fig 27. Stomatal resistance on July 20, 1987.

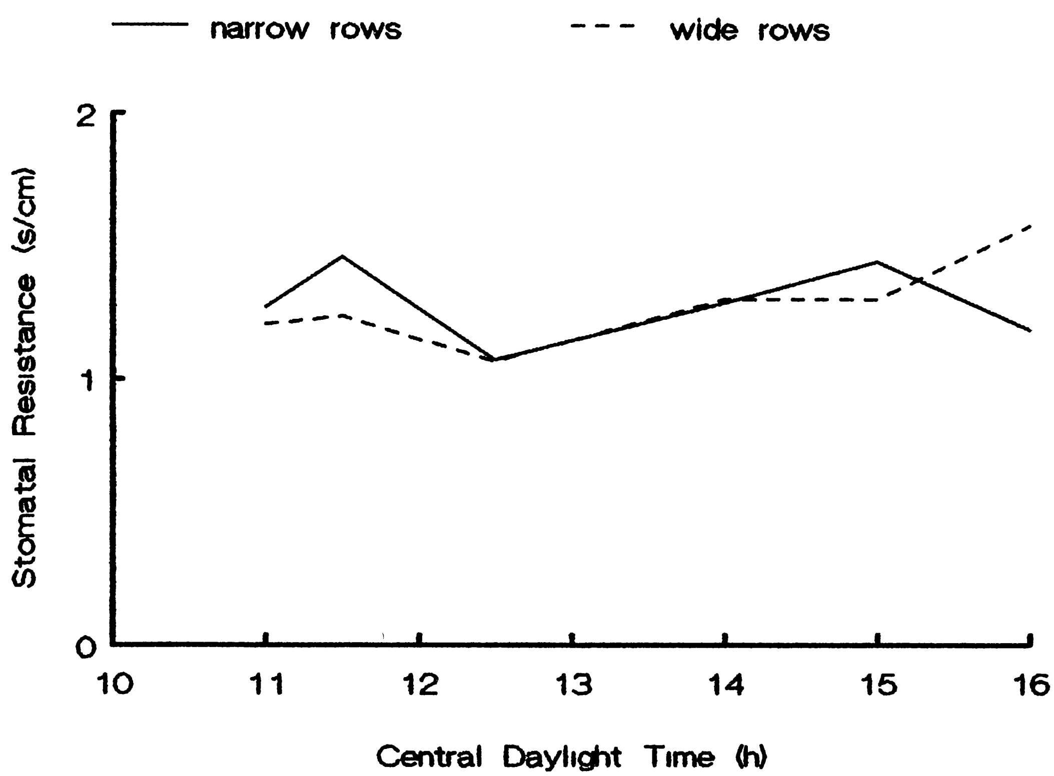

Fig 28. Stomatal resistance on July 22, 1987.

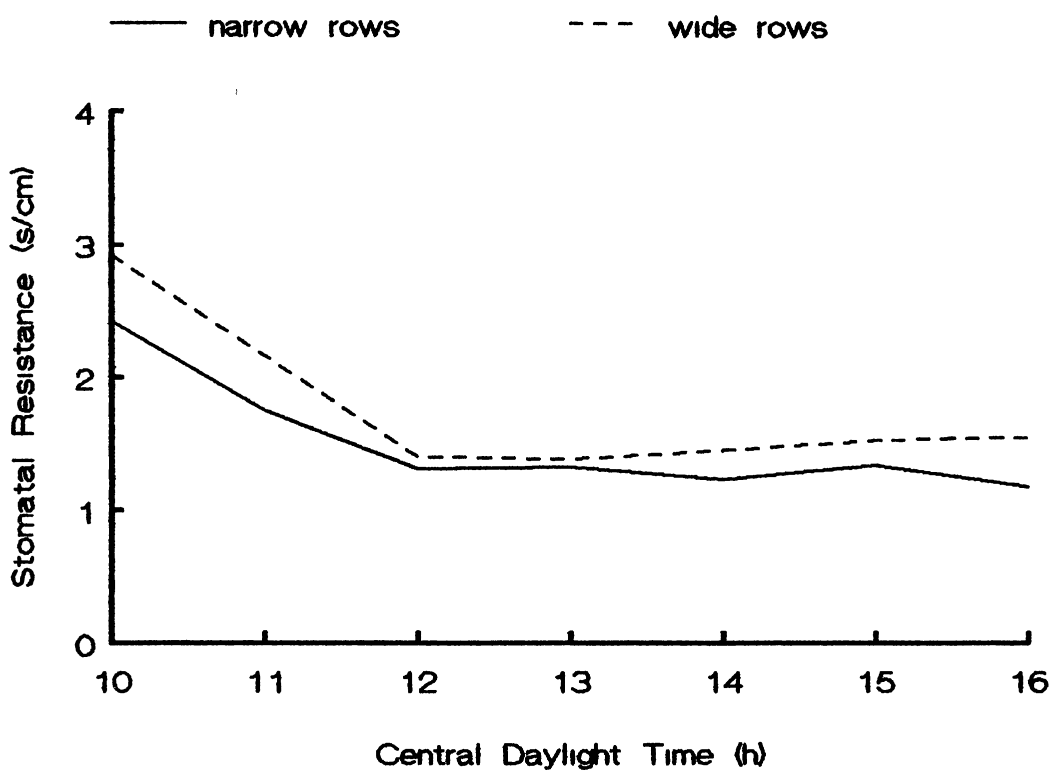

Fig 29. Stomatal resistance on August 15, 1988.

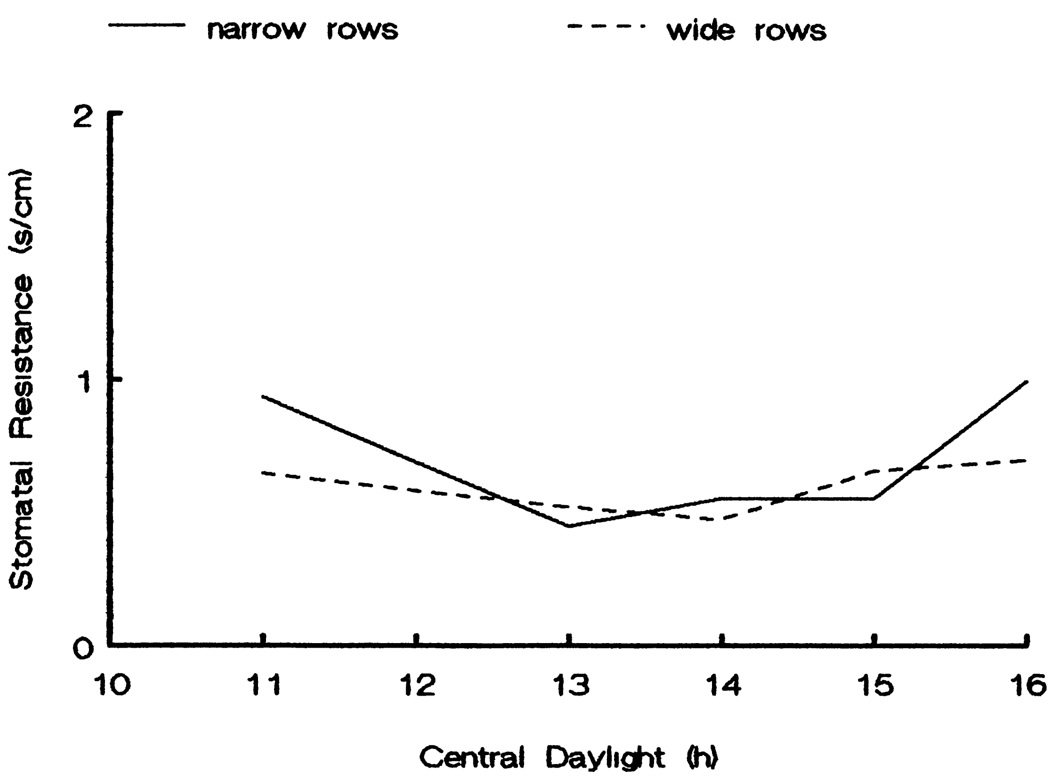

Fig 30. Stomatal resistance on August 10, 1988.

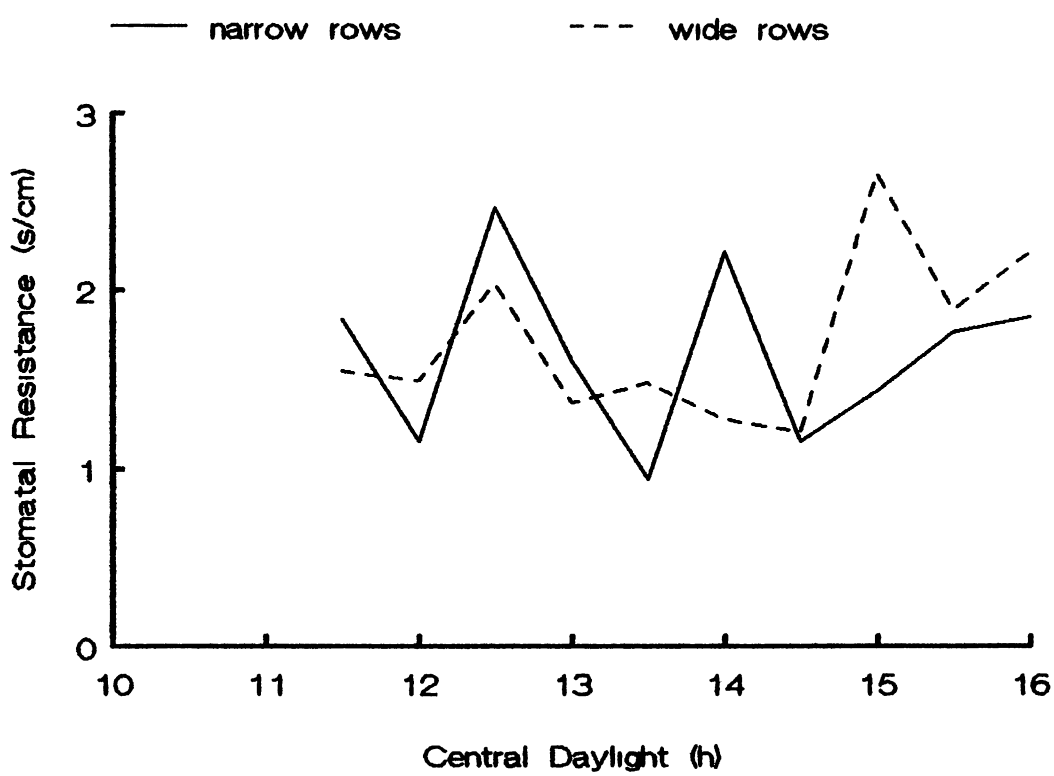

Fig 31. Stomatal resistance on August 21, 1989.

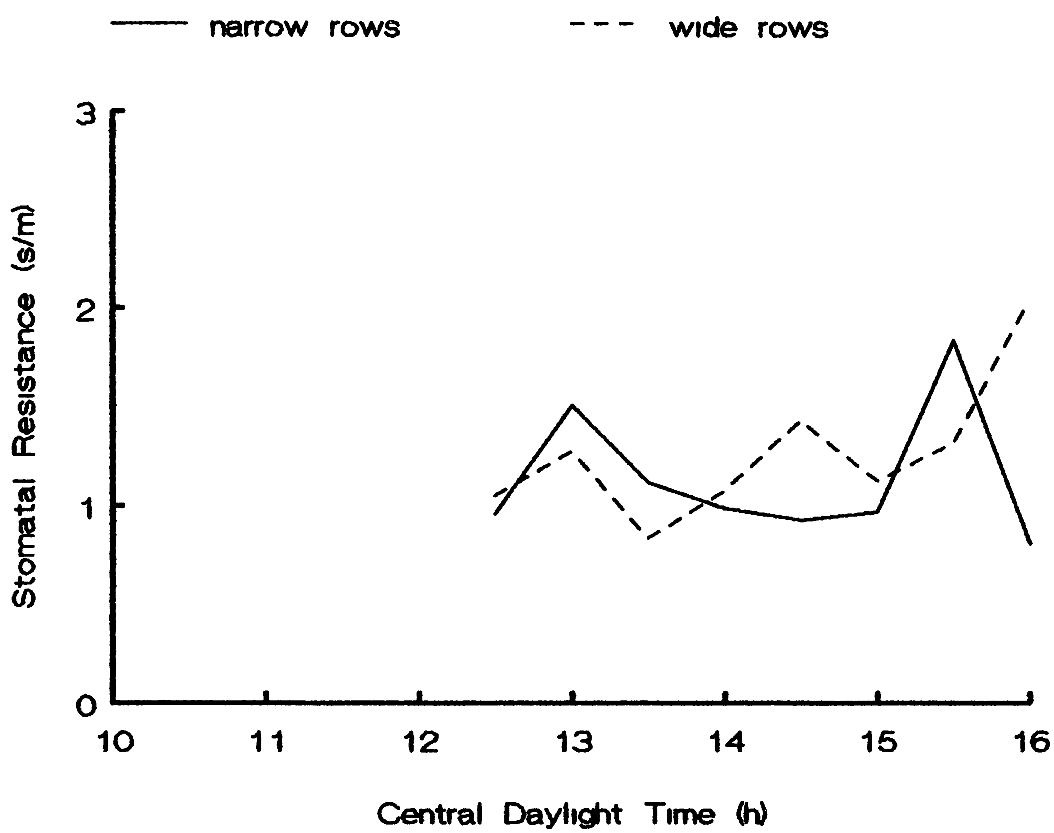

Fig 32. Stomatal resistance on August 8, 1989.

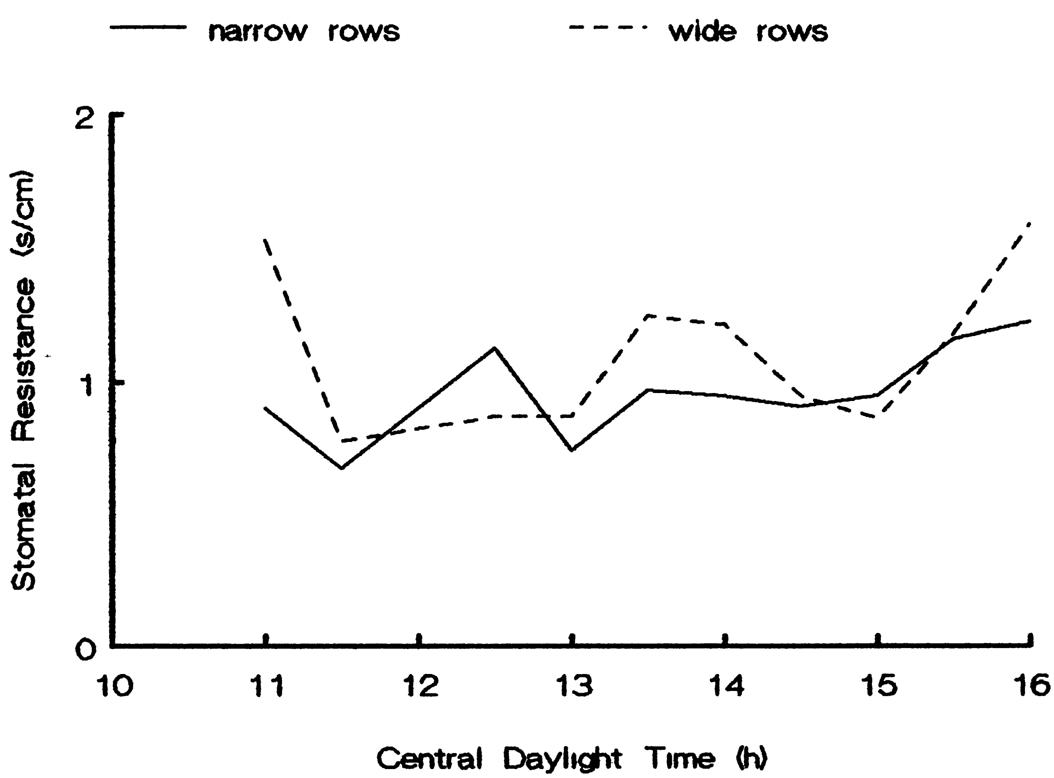

Fig 33. Stomatal resistance on July 19, 1990.

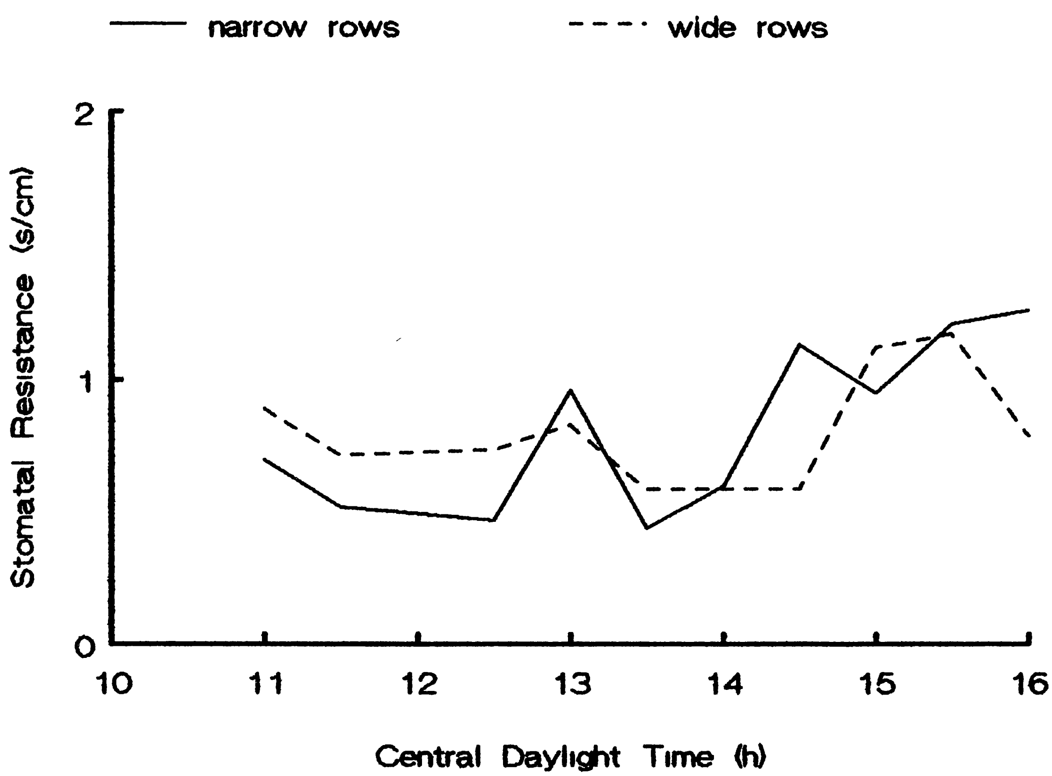

Fig 34. Stomatal resistance on August 21, 1990.

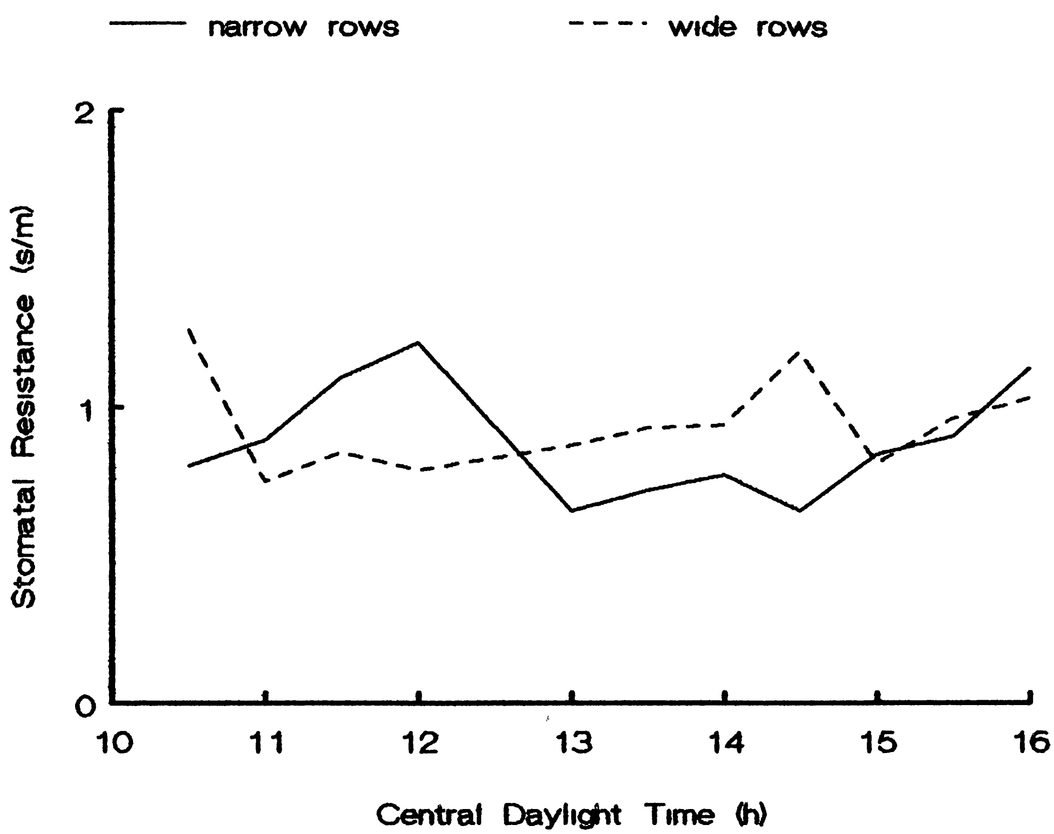

Fig 35. Stomatal resistance on August 7, 1991.

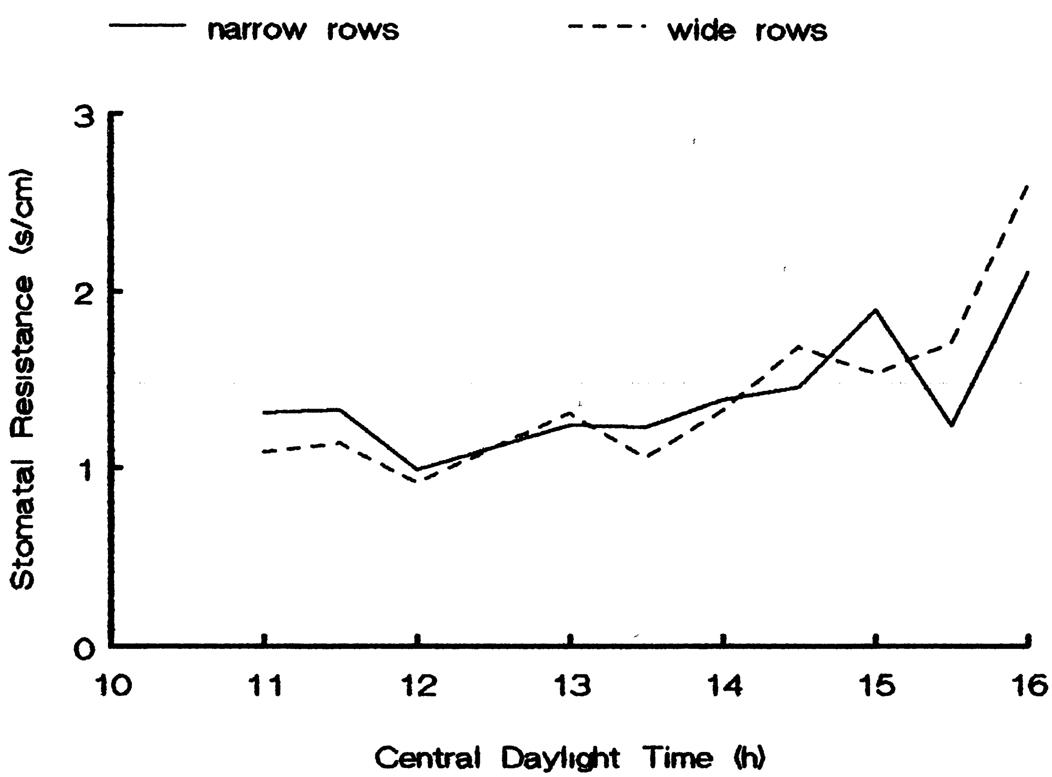

Fig 36. Stomatal resistance on August 12, 1991.

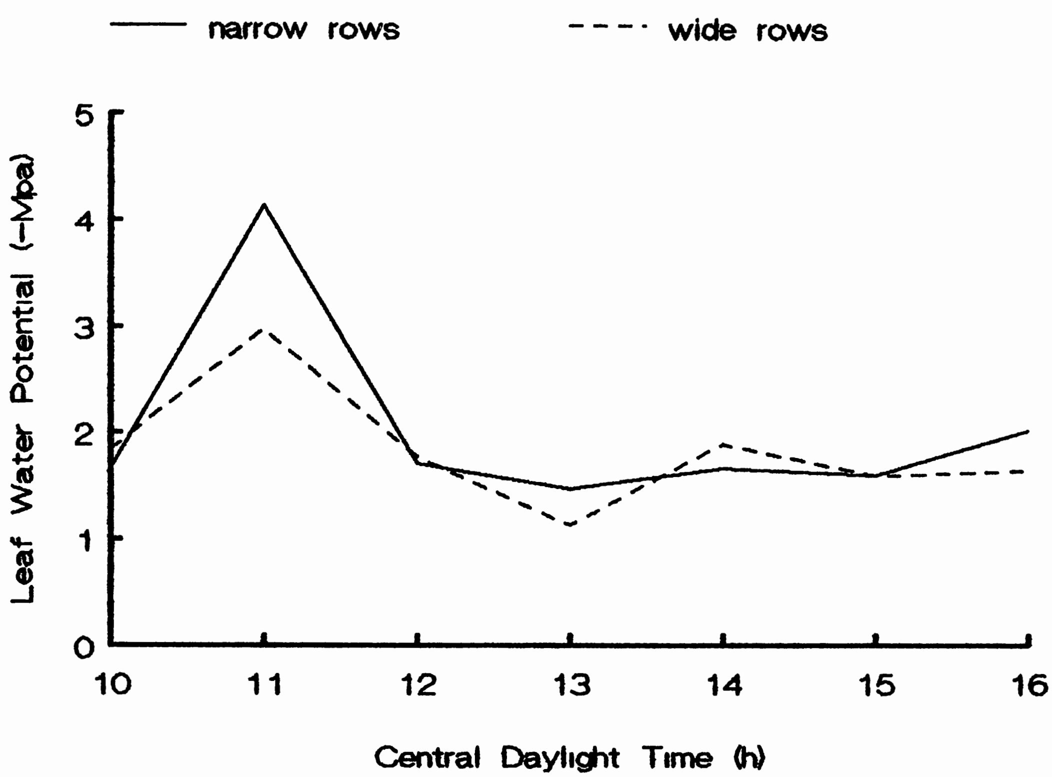

Fig 37. Leaf water potential on August 20, 1986.

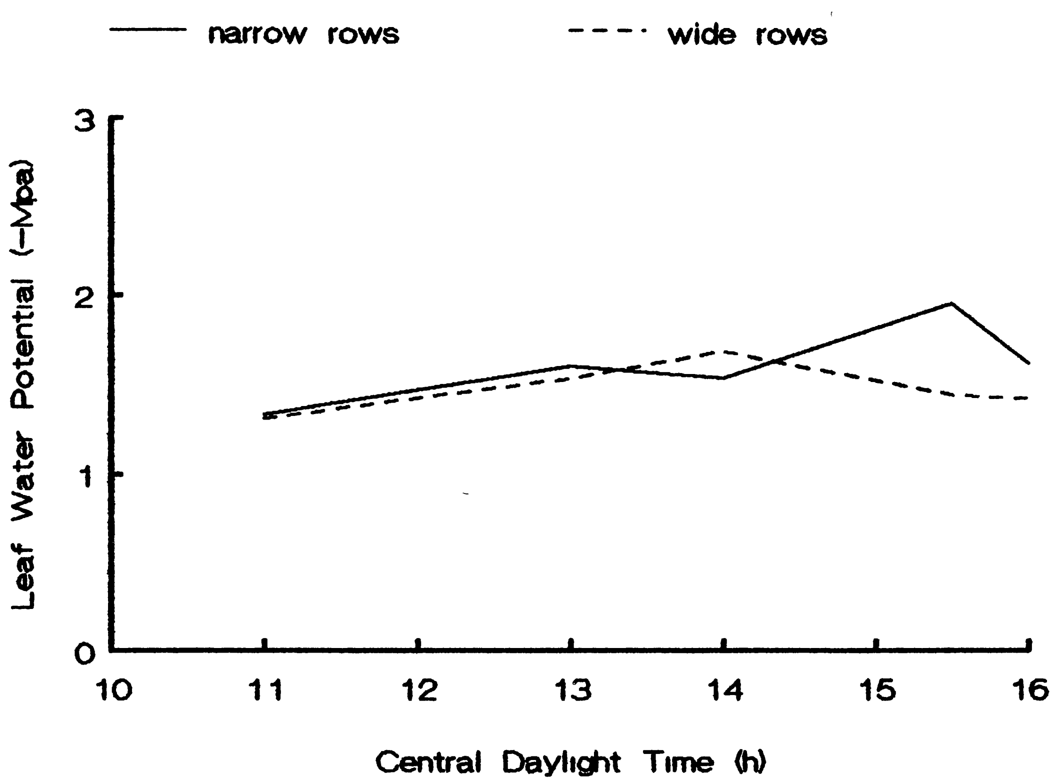

Fig 38. Leaf Water potential on August 5, 1987.

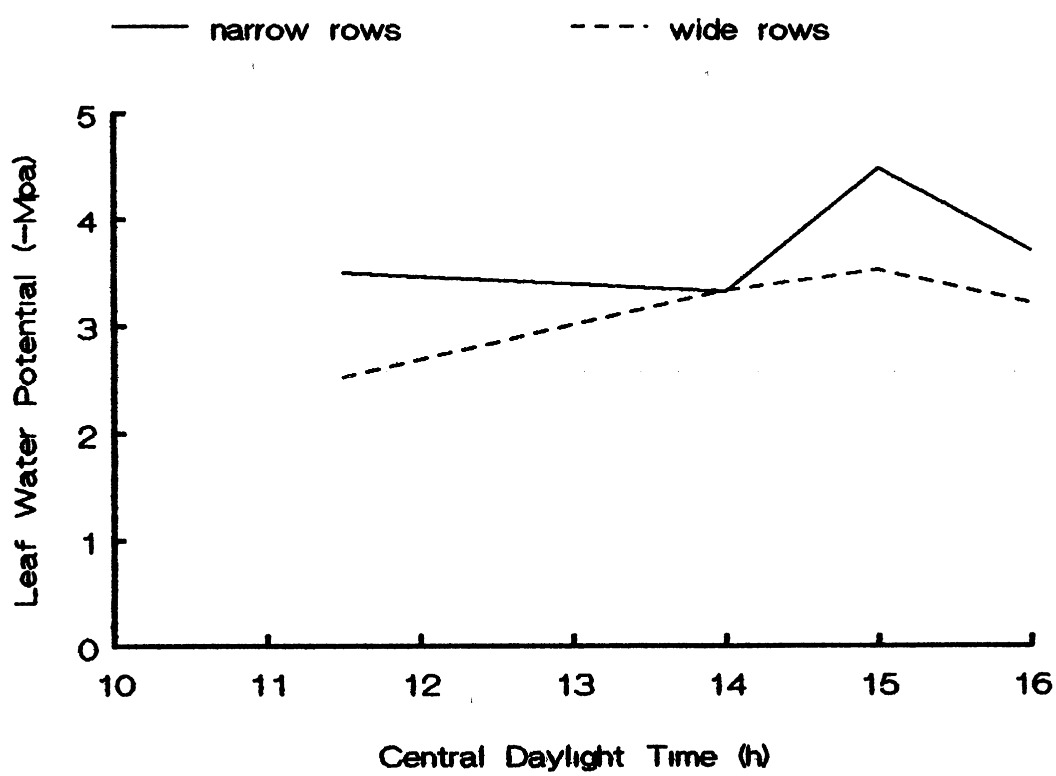

Fig 39. Leaf water potential on August 2,1988.

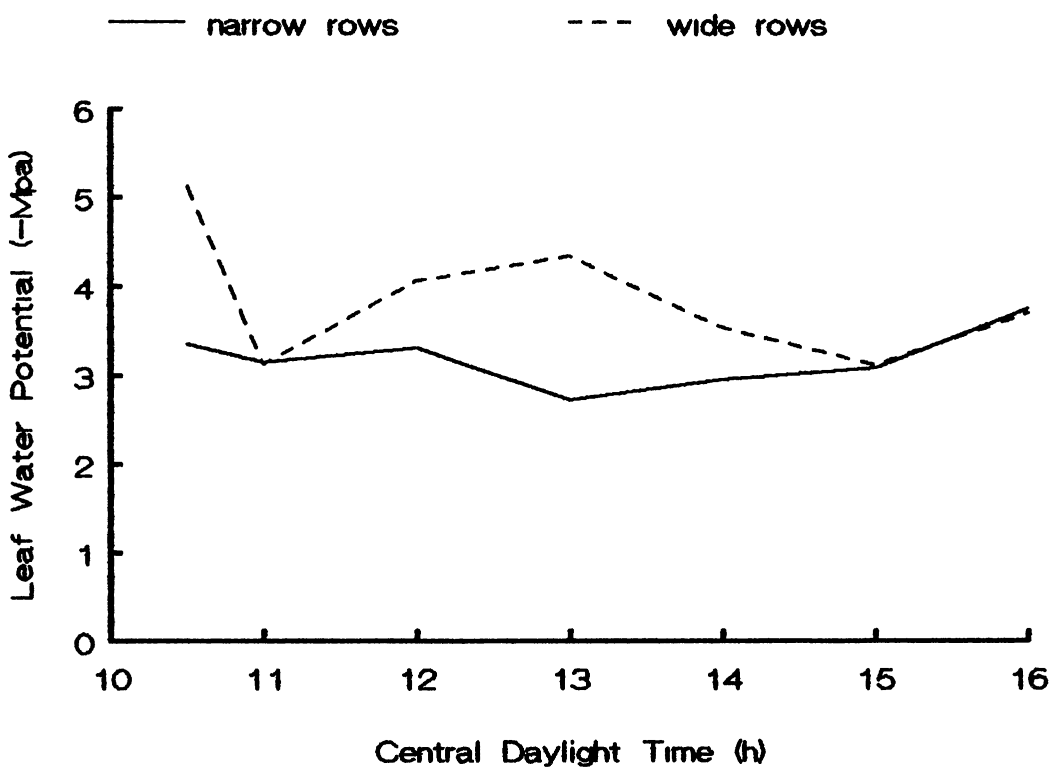

Fig 40. Leaf water potential on August 3, 1988.

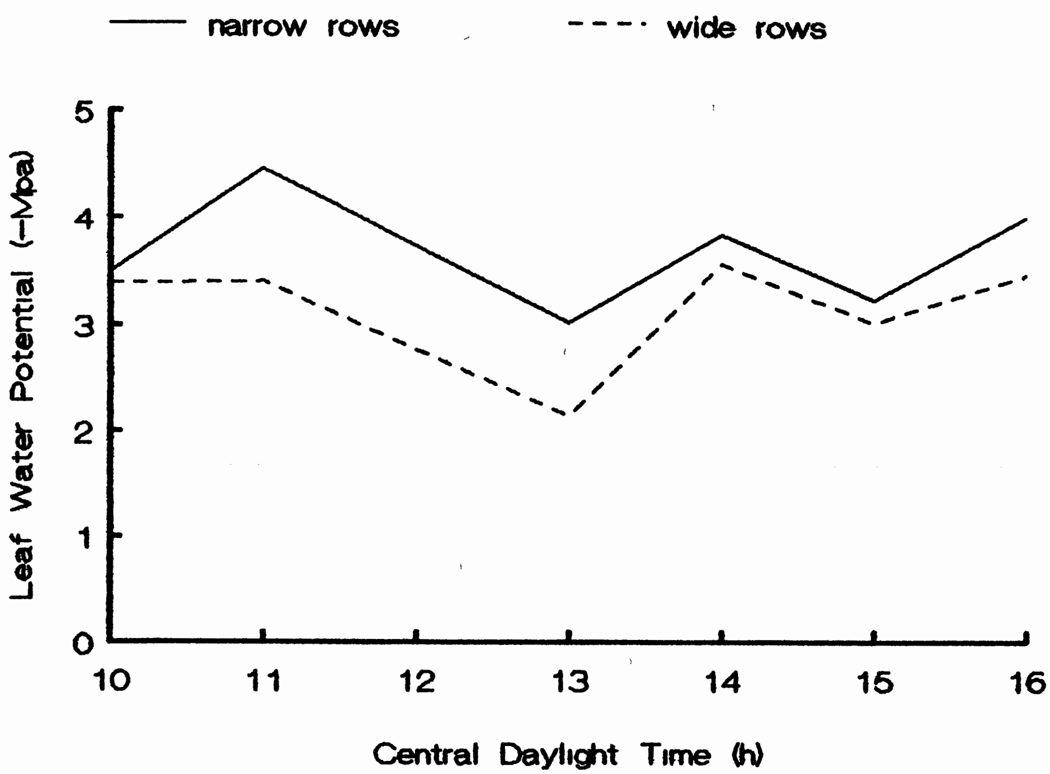

Fig 41. Leaf water potential on August 4, 1988.

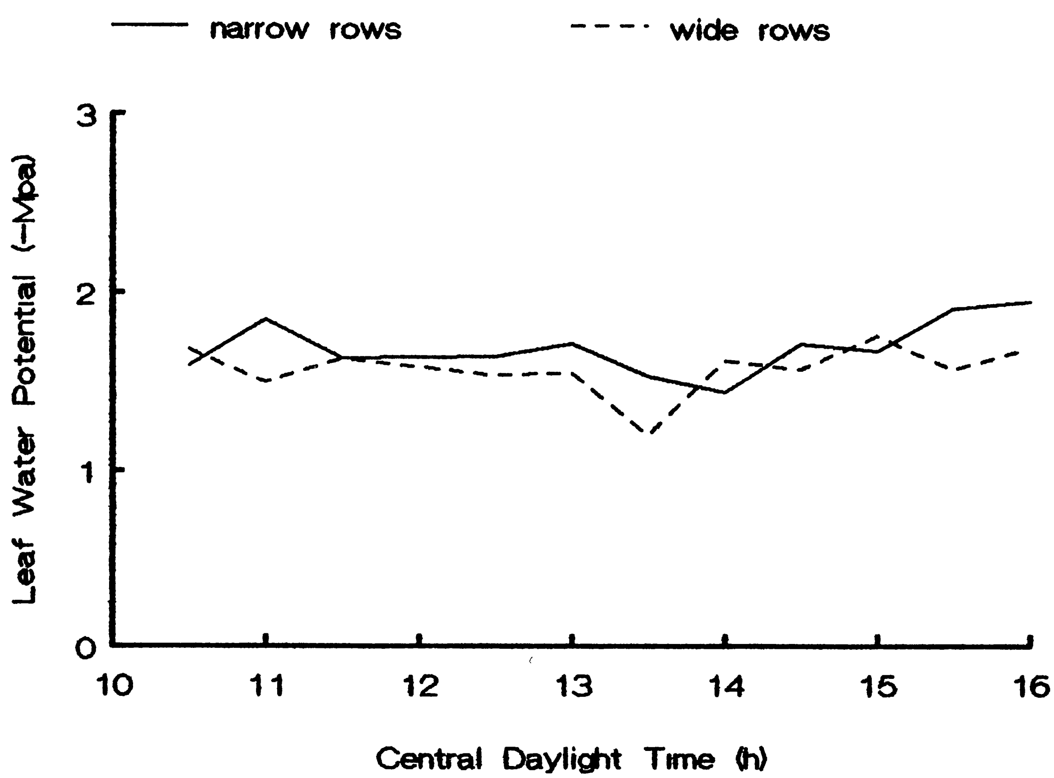

Fig 42. Leaf water potential on July 16, 1990.

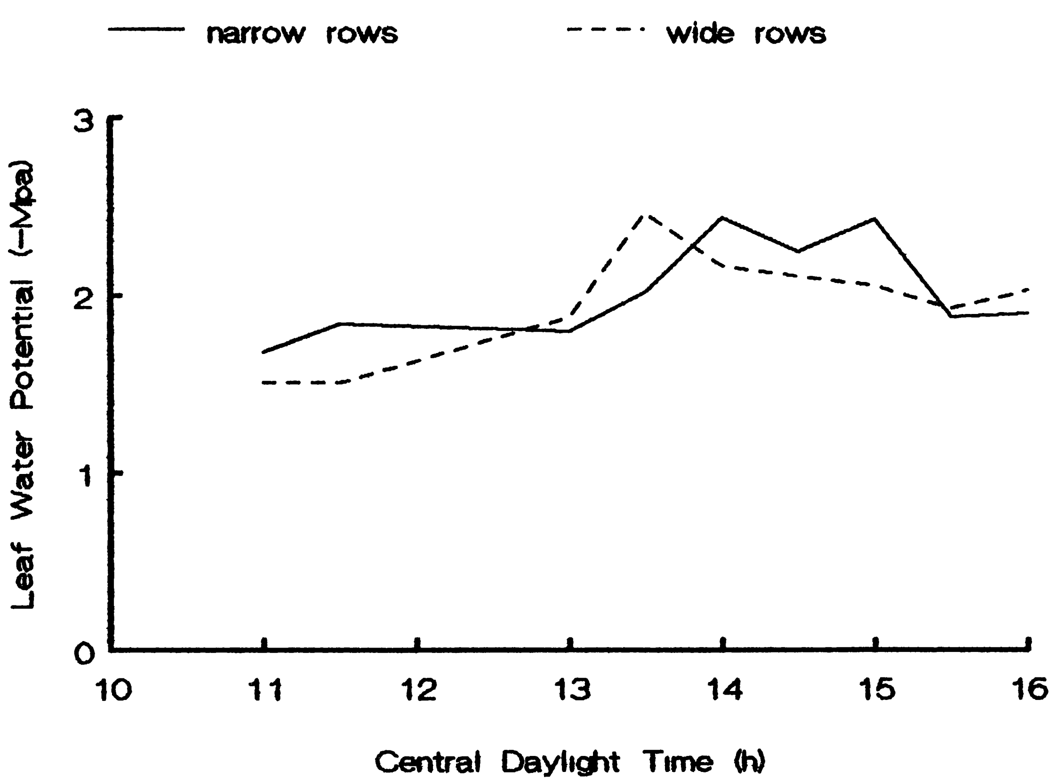

Fig 43. Leaf water potential on July 26, 1990.

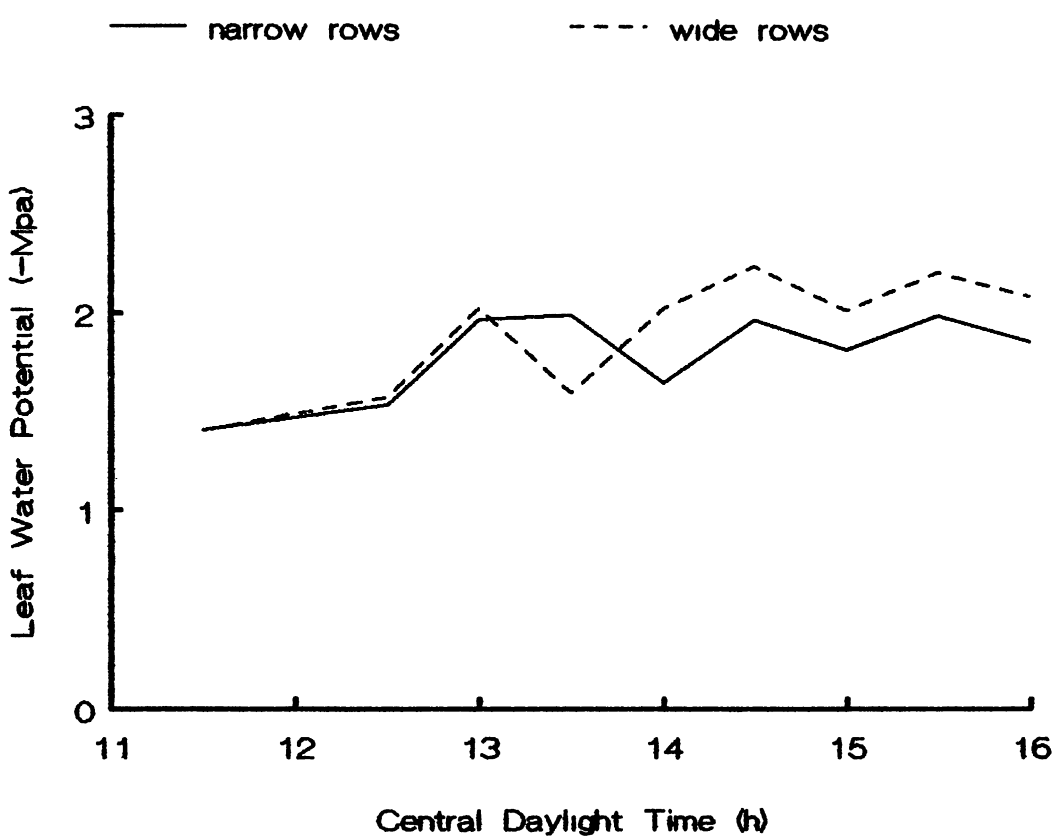

Fig 44. Leaf water potential on August 2, 1990.

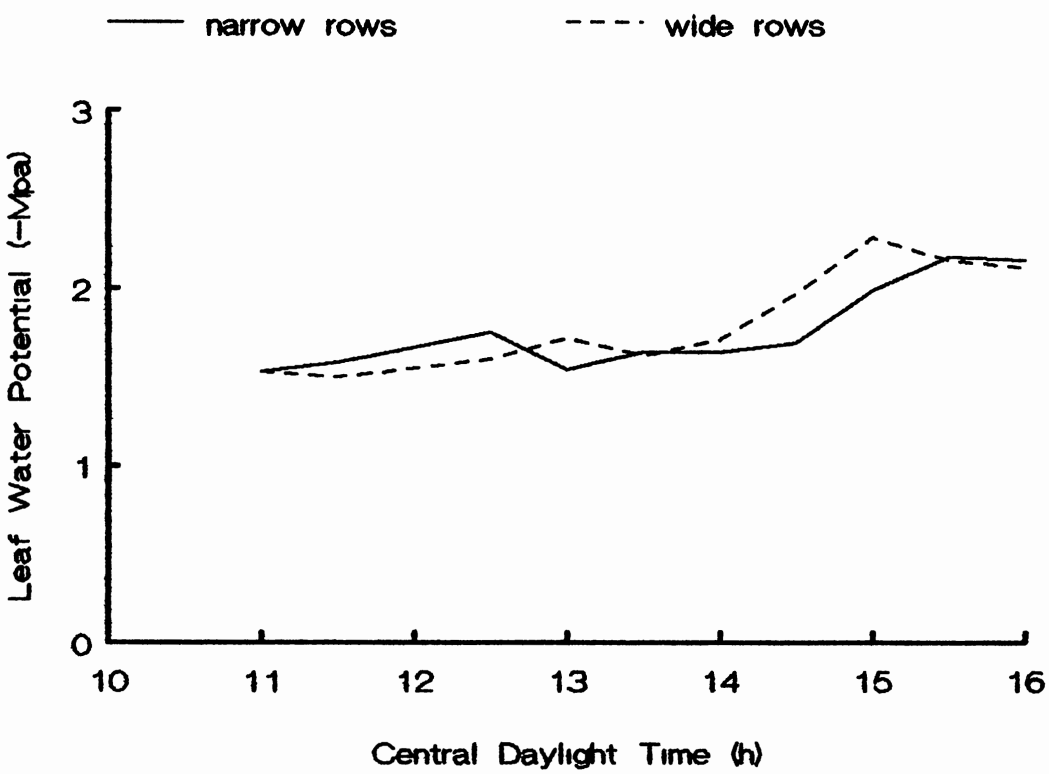

Fig 45. Leaf water potential on August 8, 1990.

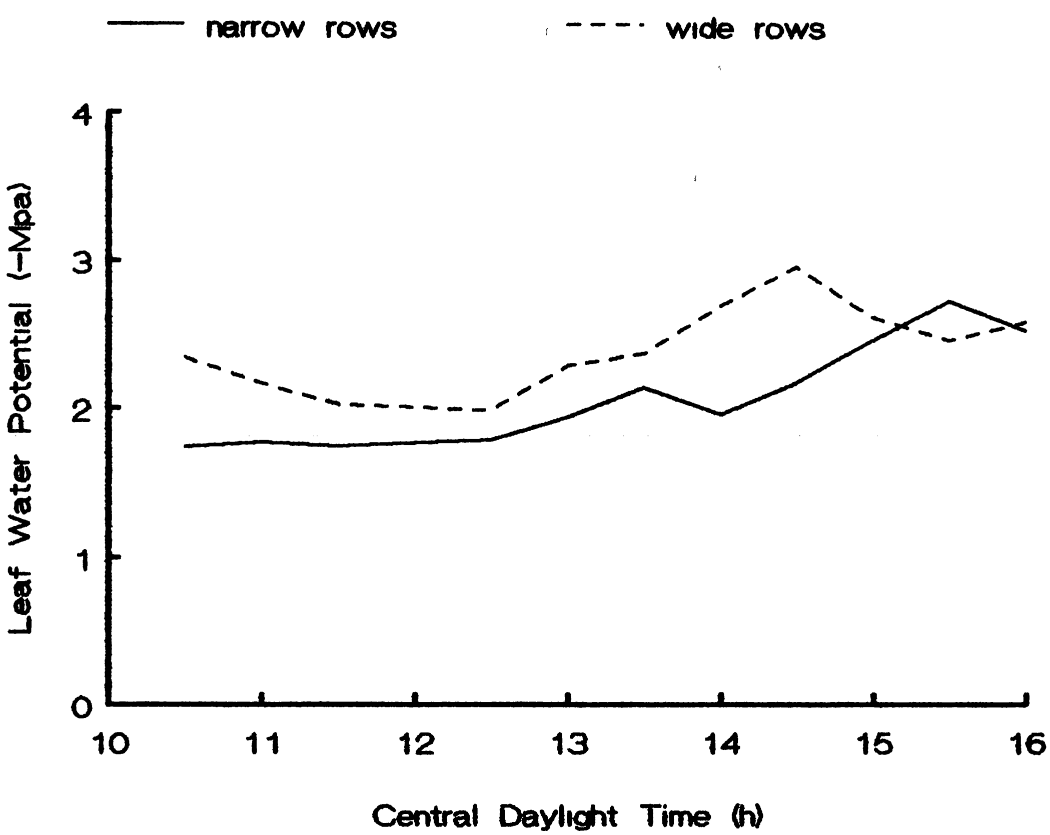

Fig 46. Leaf water potential on August 22, 1990.

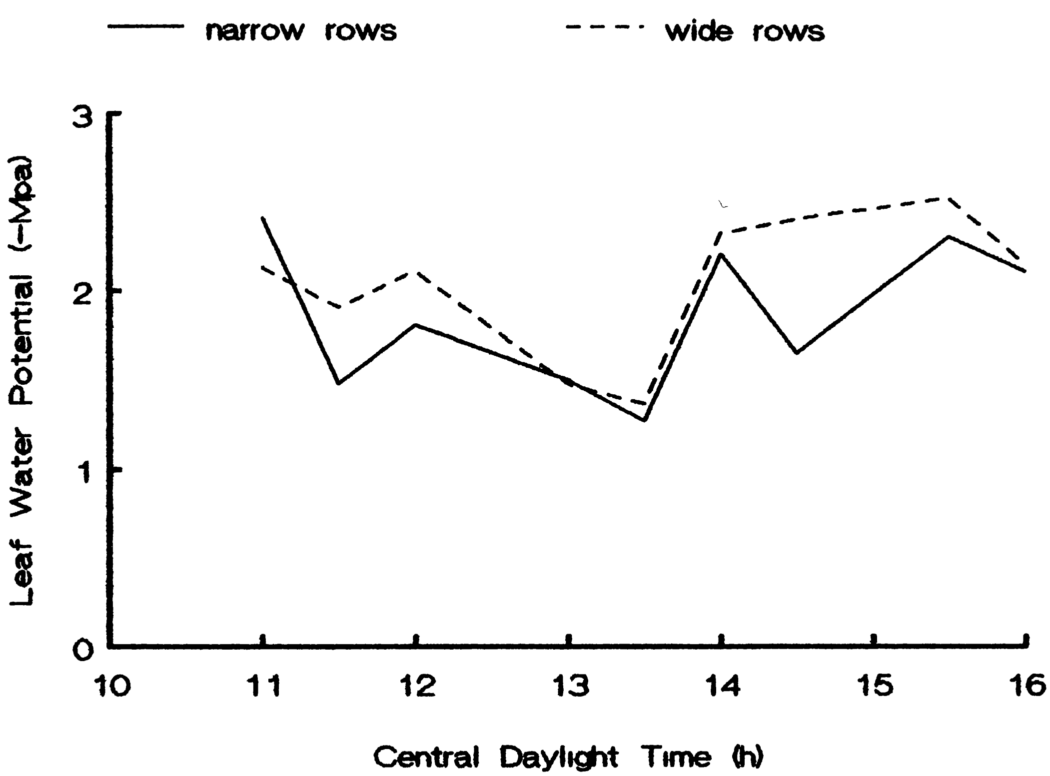

Fig 47. Leaf water potential on August 8, 1991.

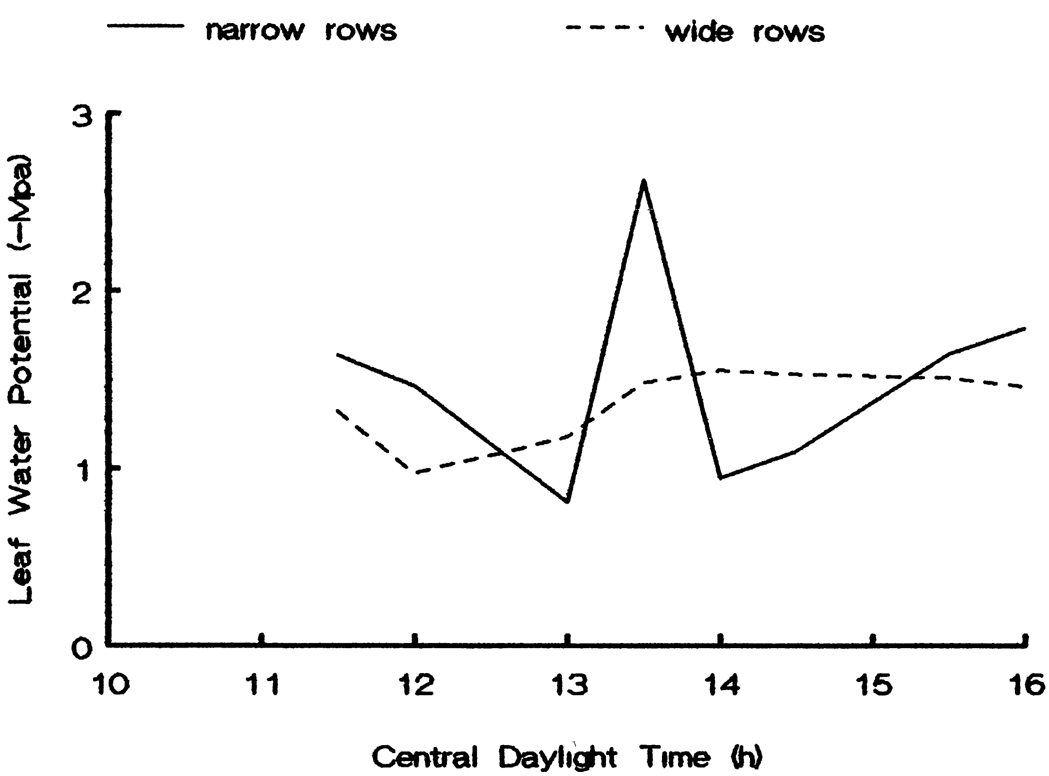

Fig 48. Leaf water potential on August 22, 1991.

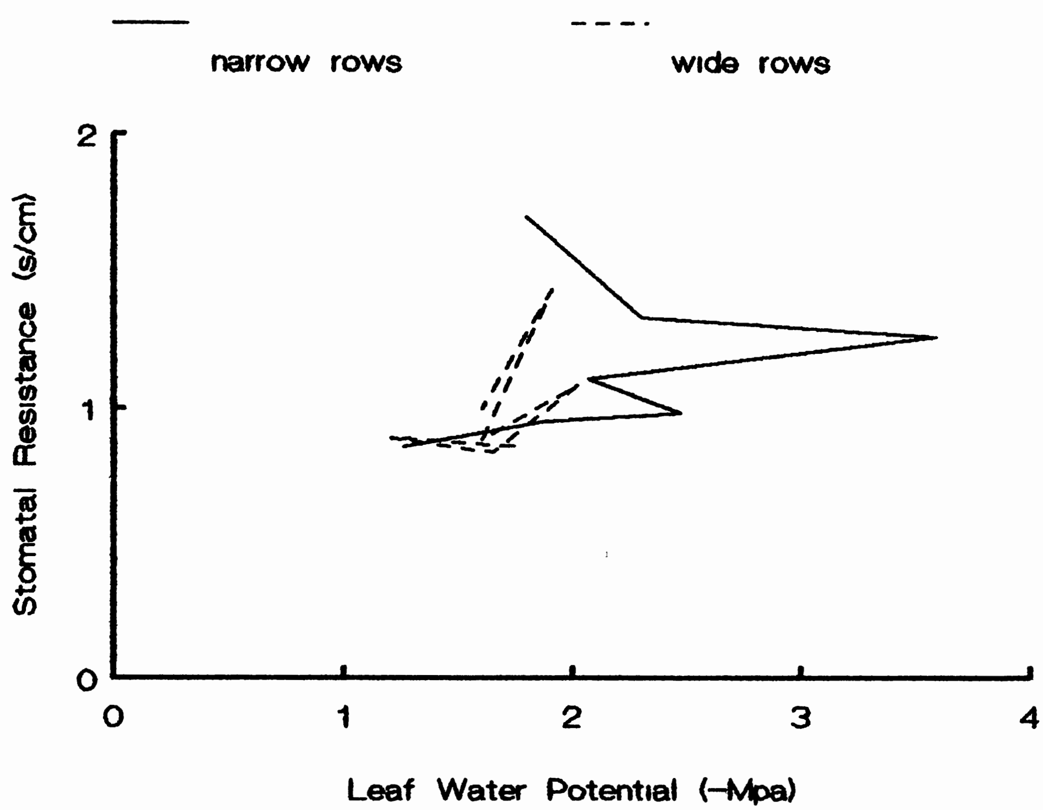

Fig 49. Stomatal Resistance-Leaf water potential relationship on August 20, 1986.

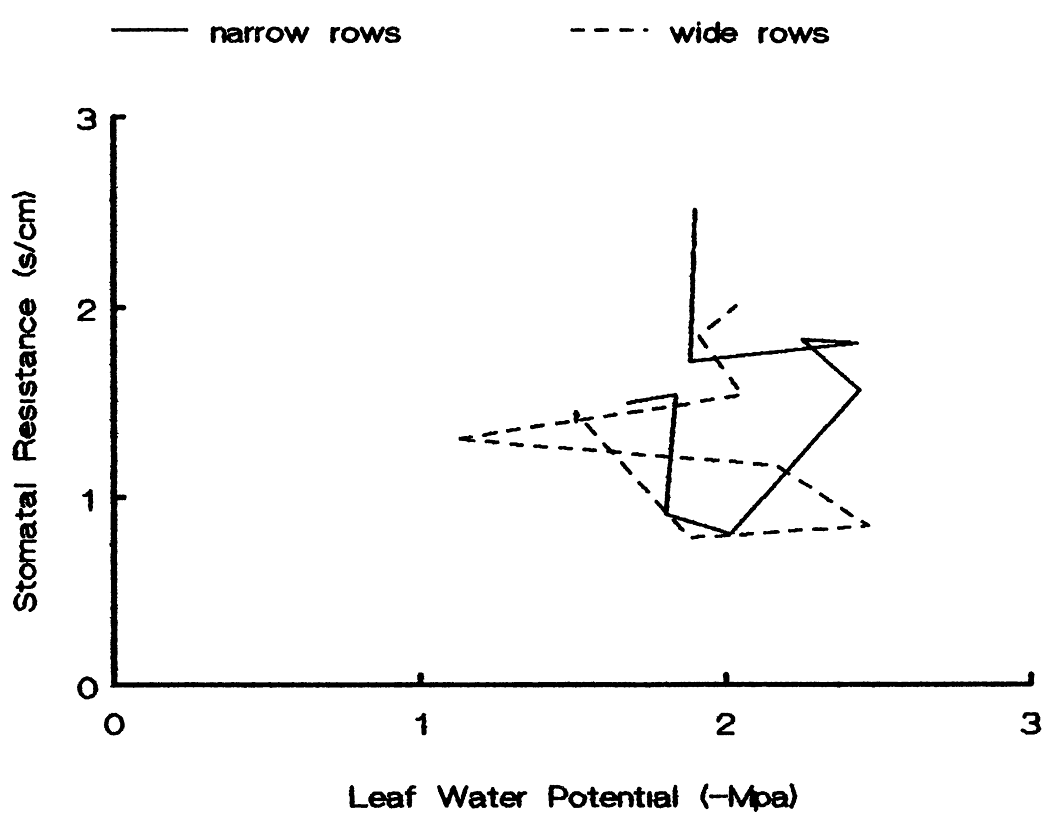

Fig 50. Stomatal Resistance-Leaf water potential relationship on July 26, 1990.

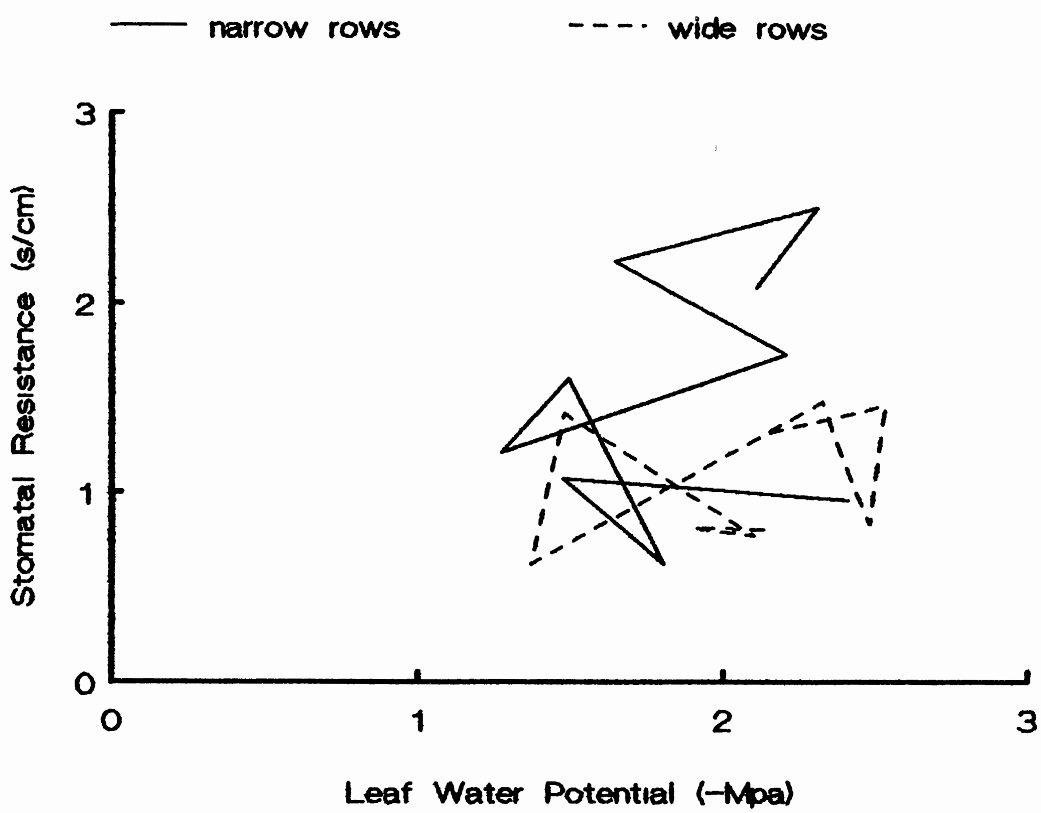

Fig 51. Stomatal Resistance-Leaf water potential relationship on August 8, 1991.

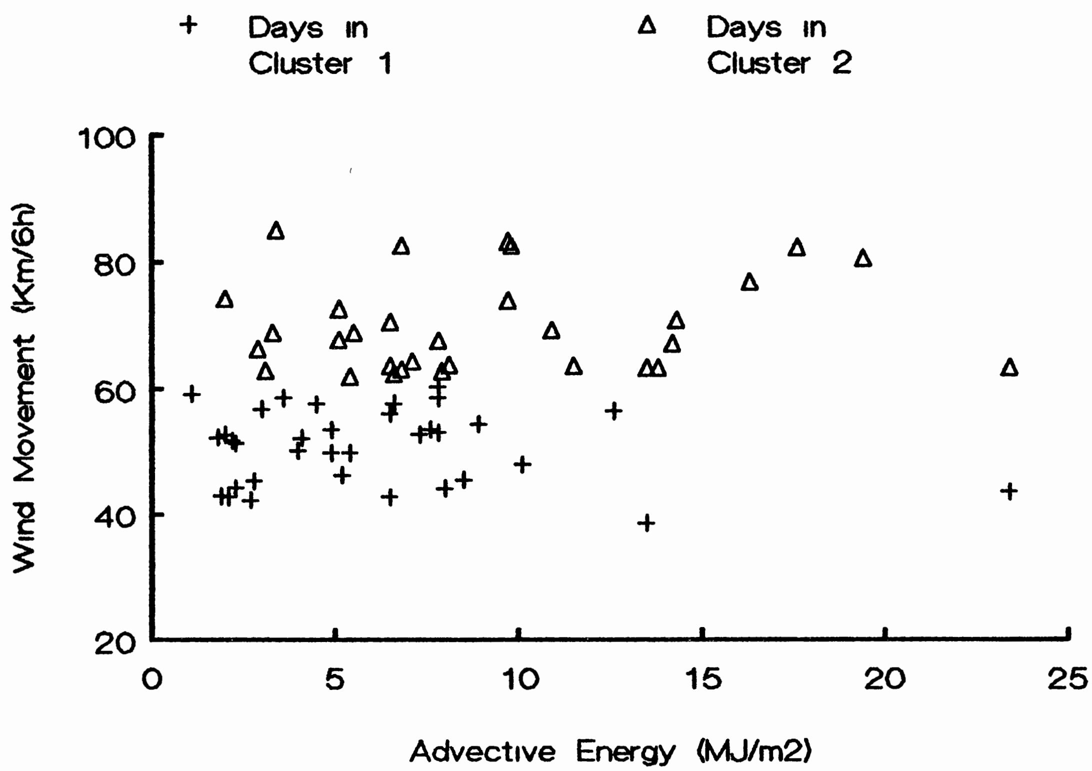

Fig 52. Separation of days based in wind movement and advective energy.

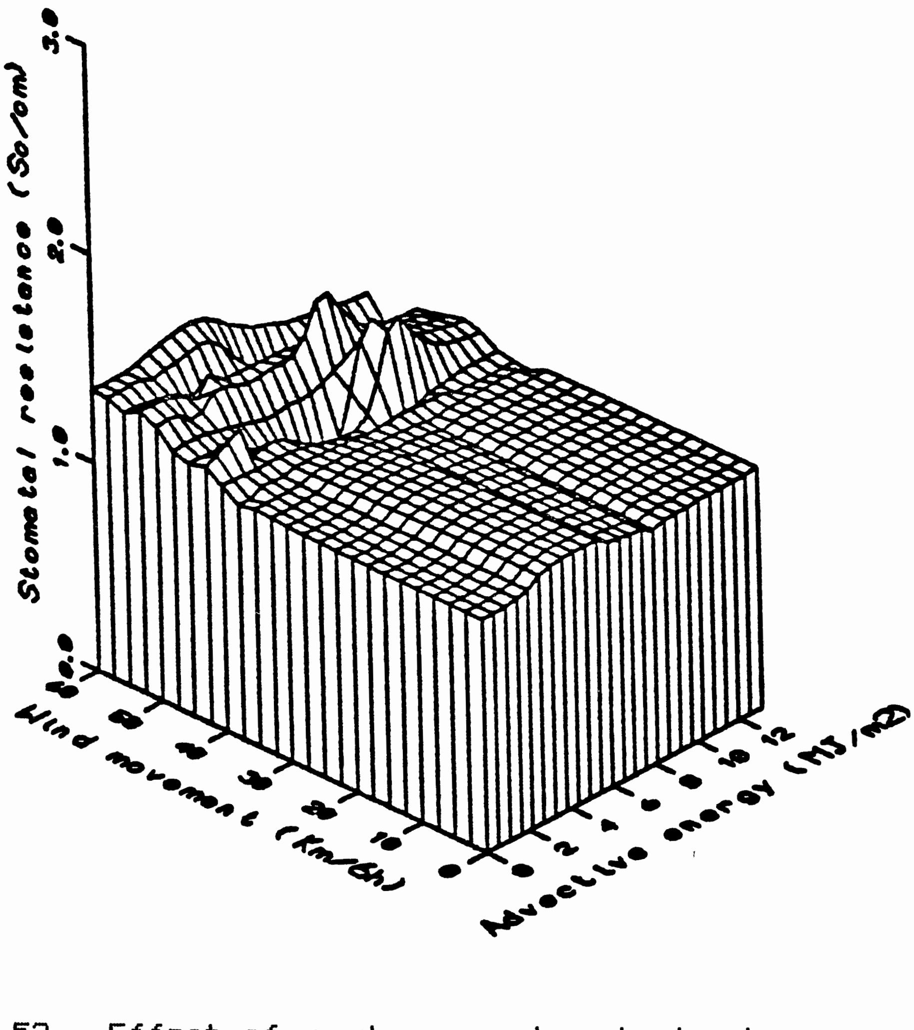

Fig 53. Effect of wind movement and advective energy over stomatal resistance in days from cluster 1.

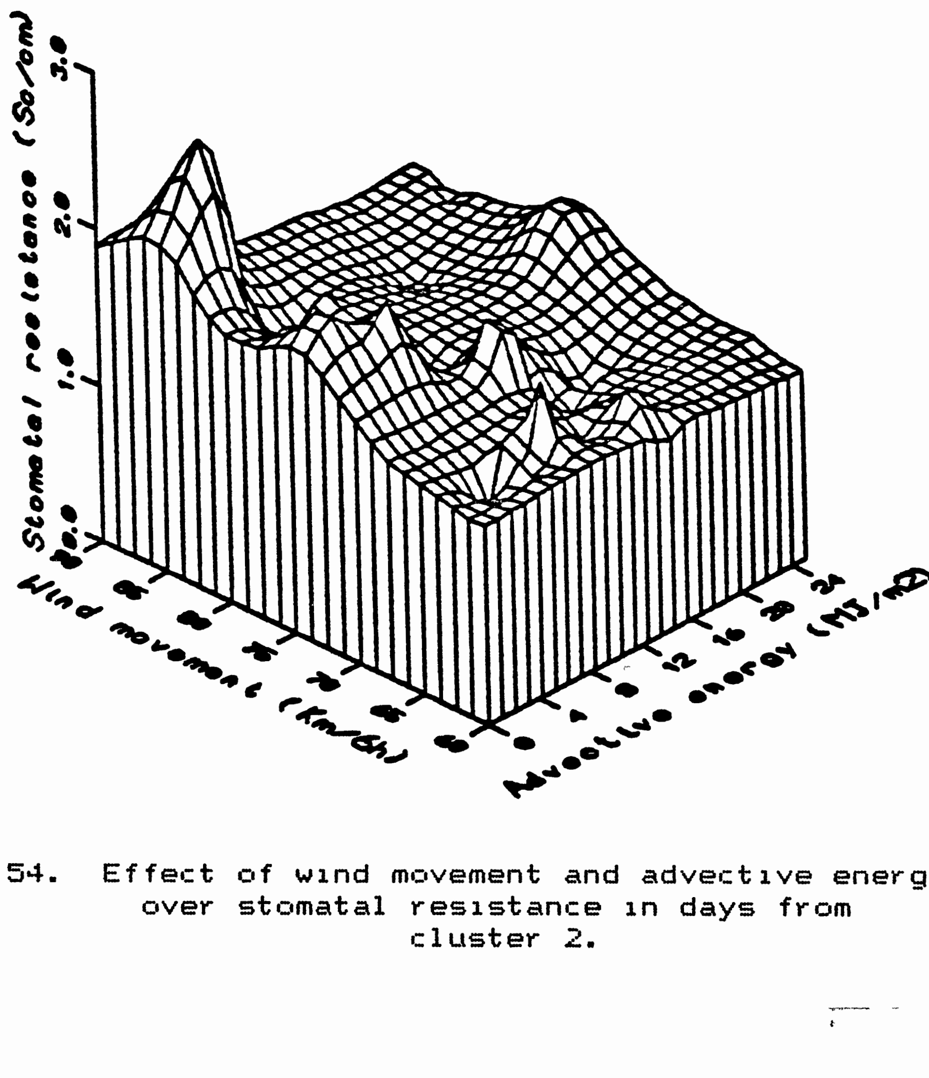

Fig 54. Effect of wind movement and advective energy over stomatal resistance in days from cluster 2.

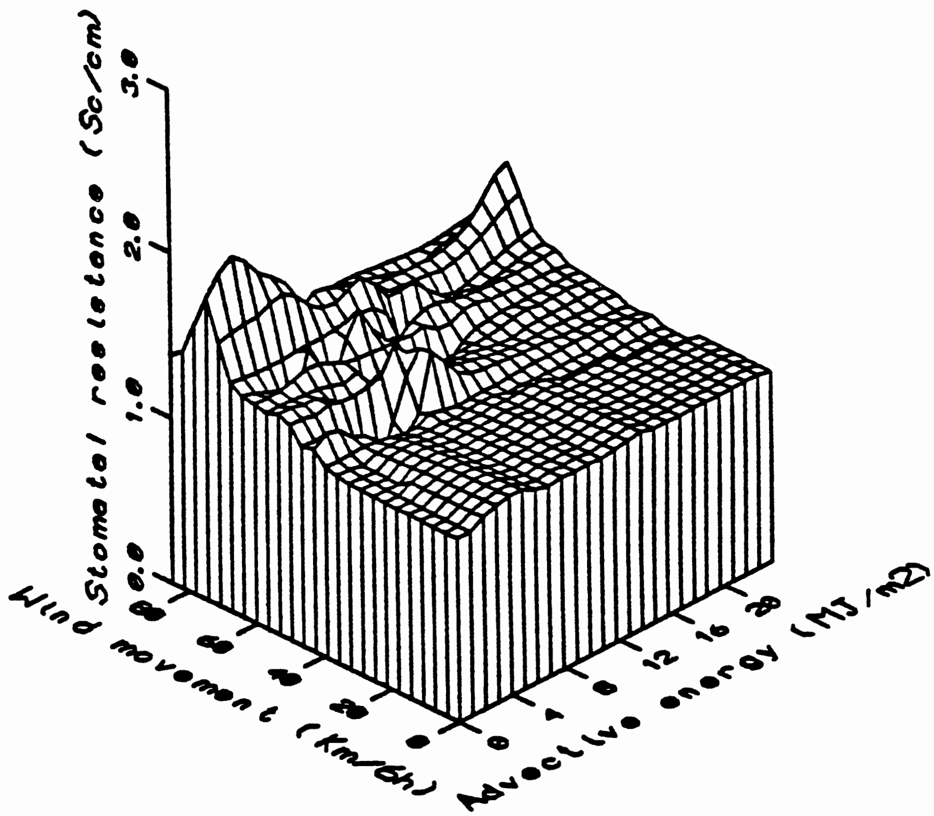

Fig 55. Effect of wind movement and advective energy over stomatal resistance in general data. Clusters 1 and 2 combined.

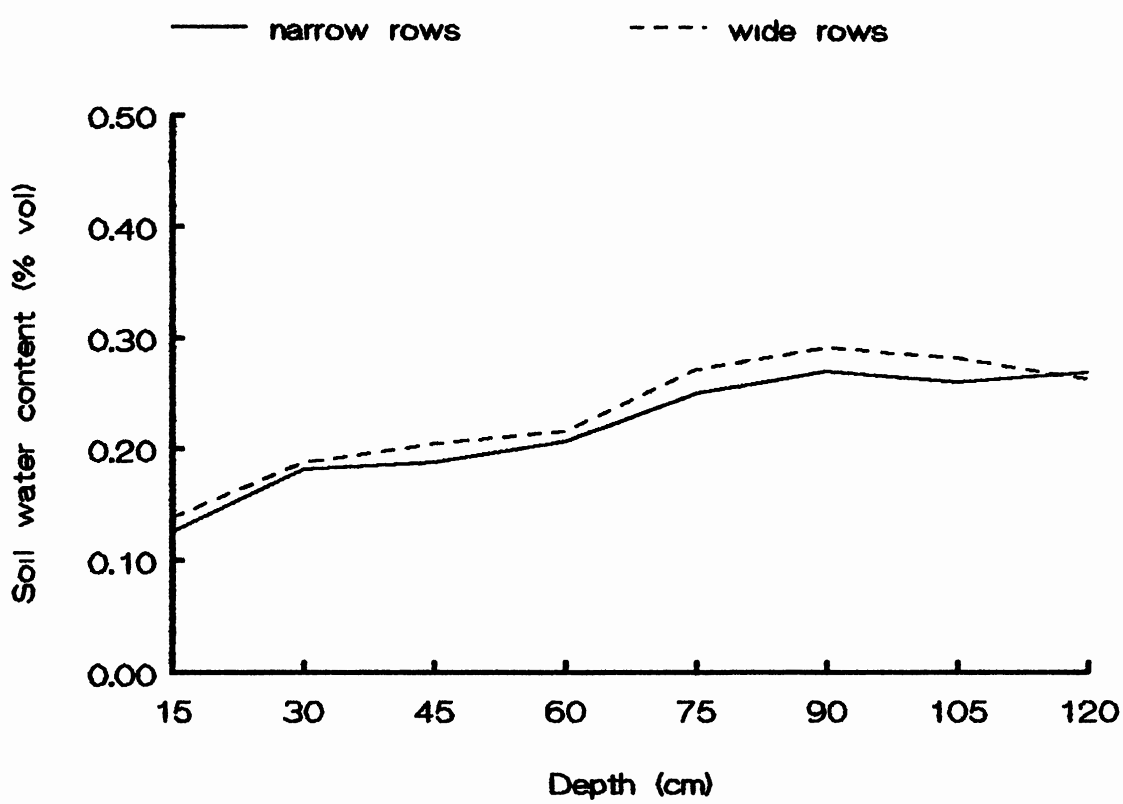

Fig 56. Soil water content from 0 to 120 cm on July 24, 1986.

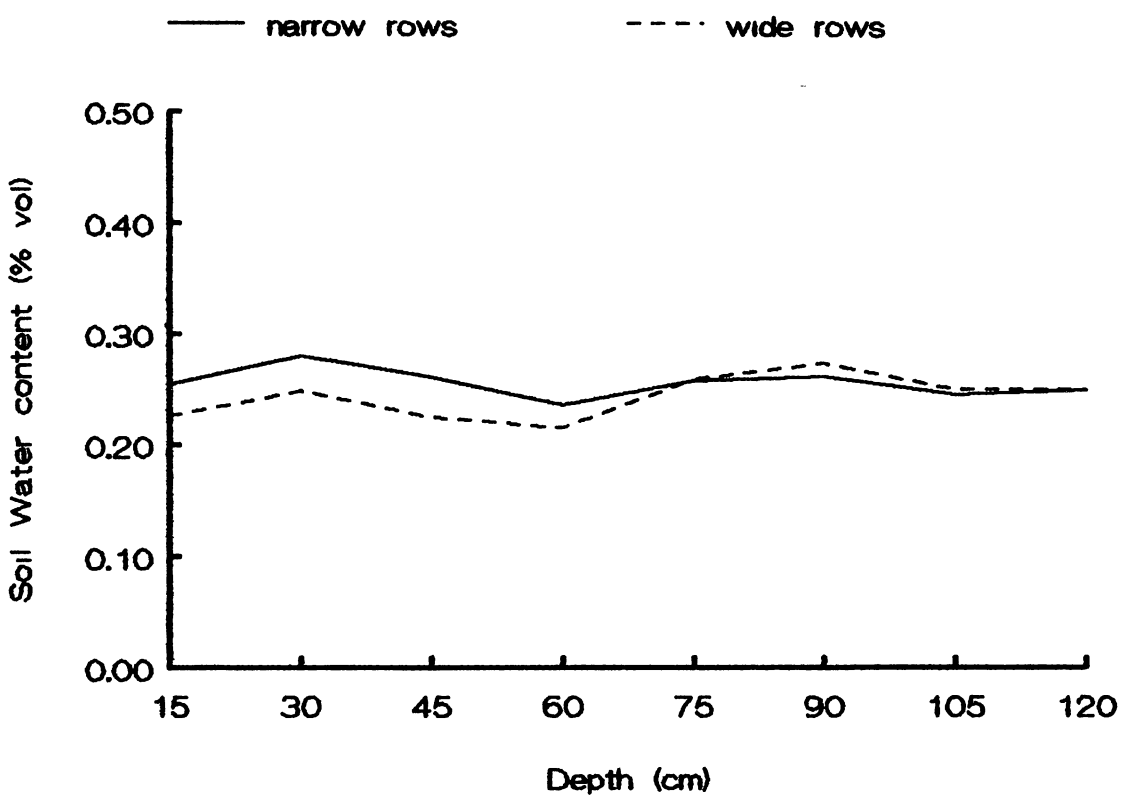

Fig 57. Soil water content from 0 to 120 cm on September 11, 1986.

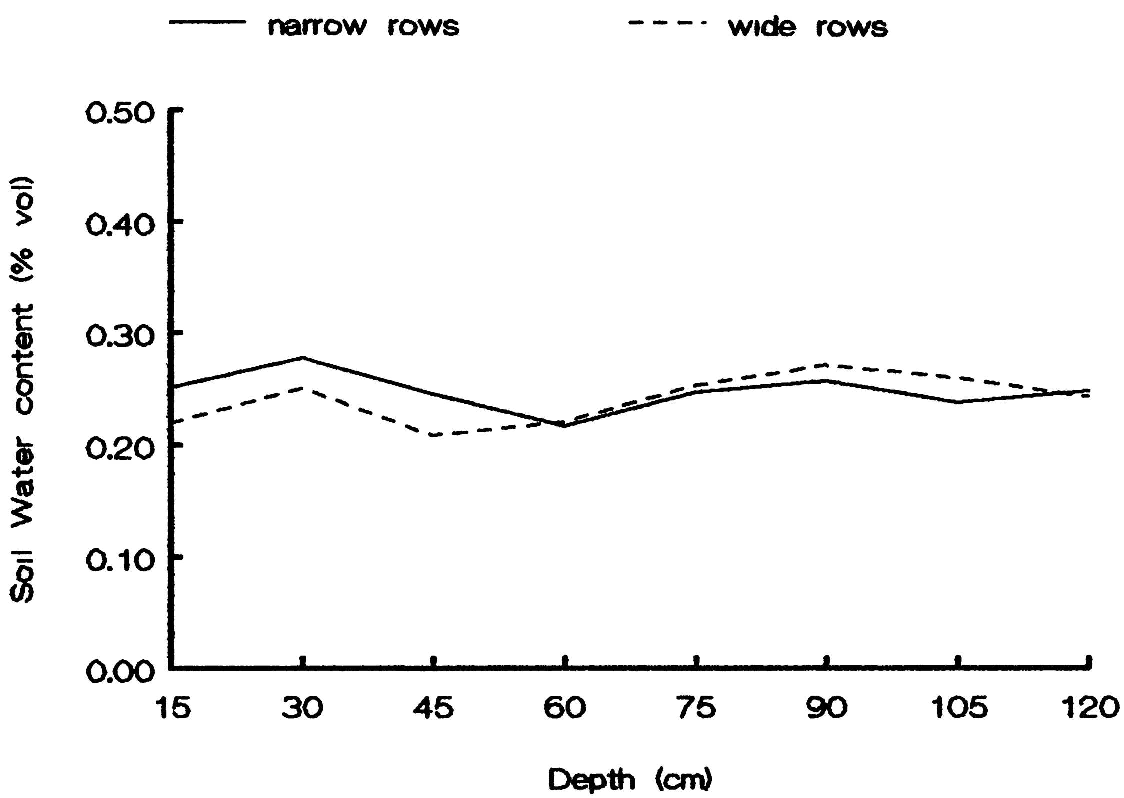

Fig 58. Soil water content from 0 to 120 cm on August 21, 1986.

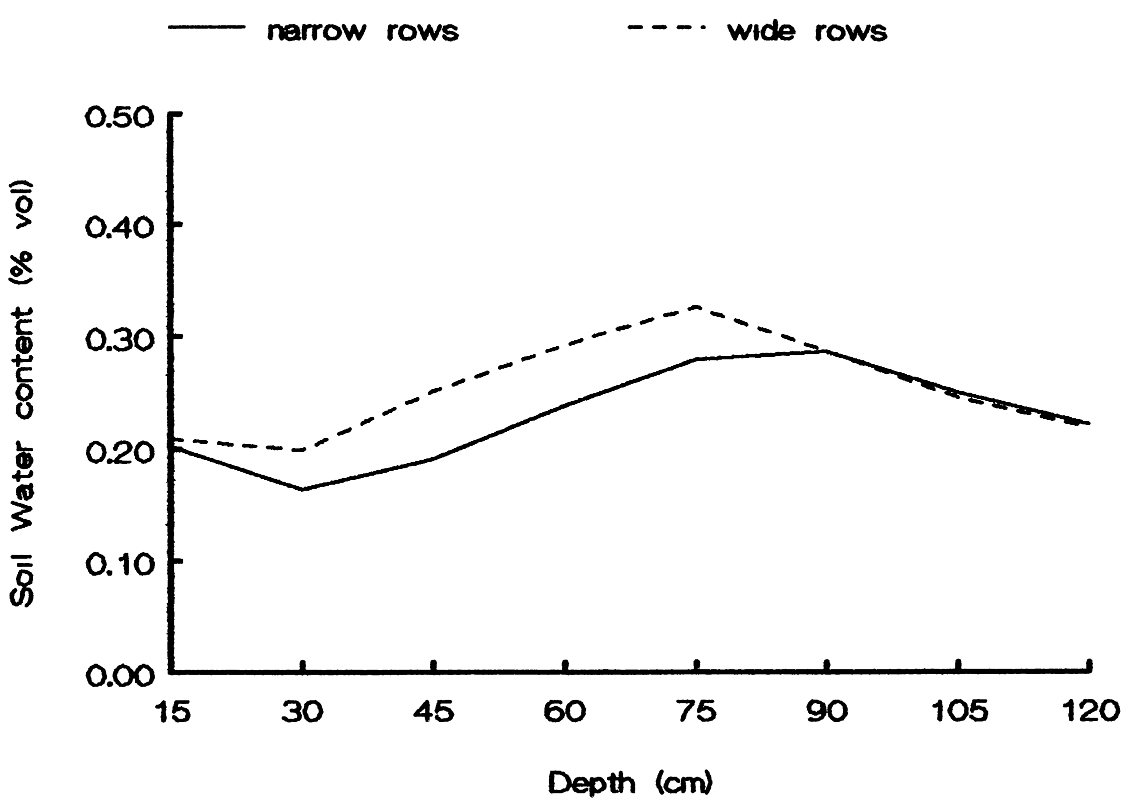

Fig 59. Soil water content from 0 to 120 cm on August 6, 1987.

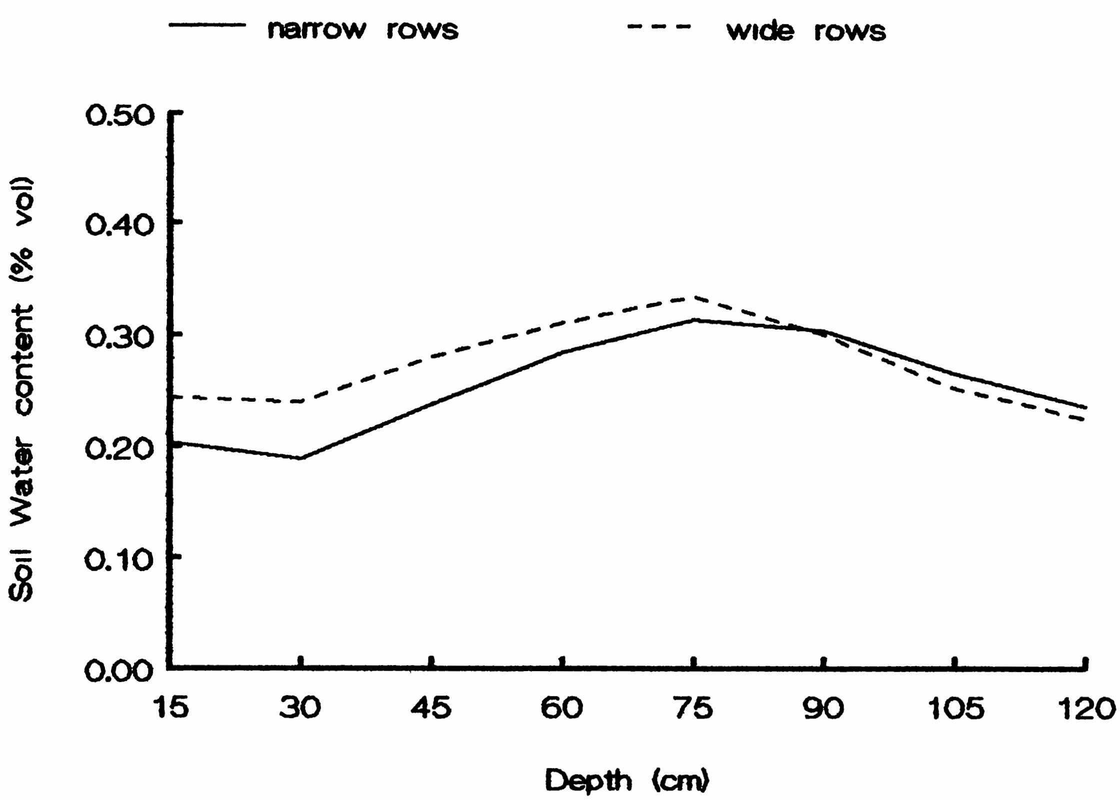

Fig 60. Soil water content from 0 to 120 cm on July 16, 1987.

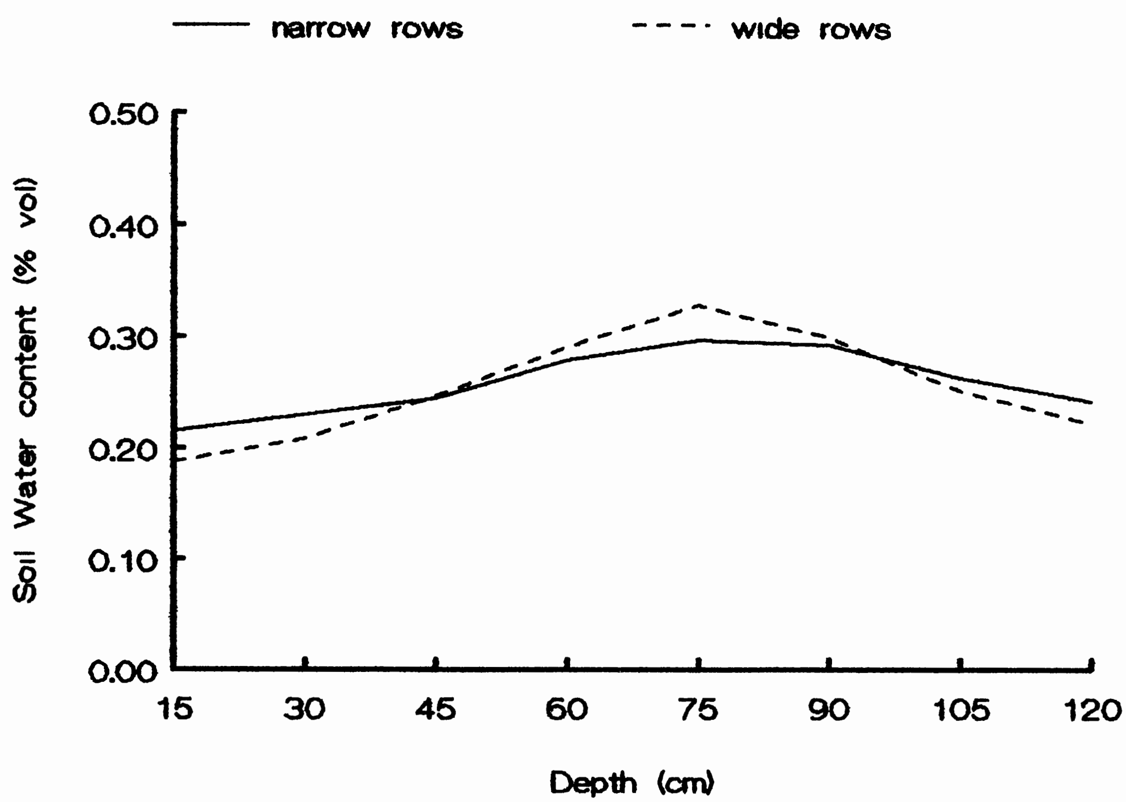

Fig 61. Soil water content from 0 to 120 cm on August 4, 1988.

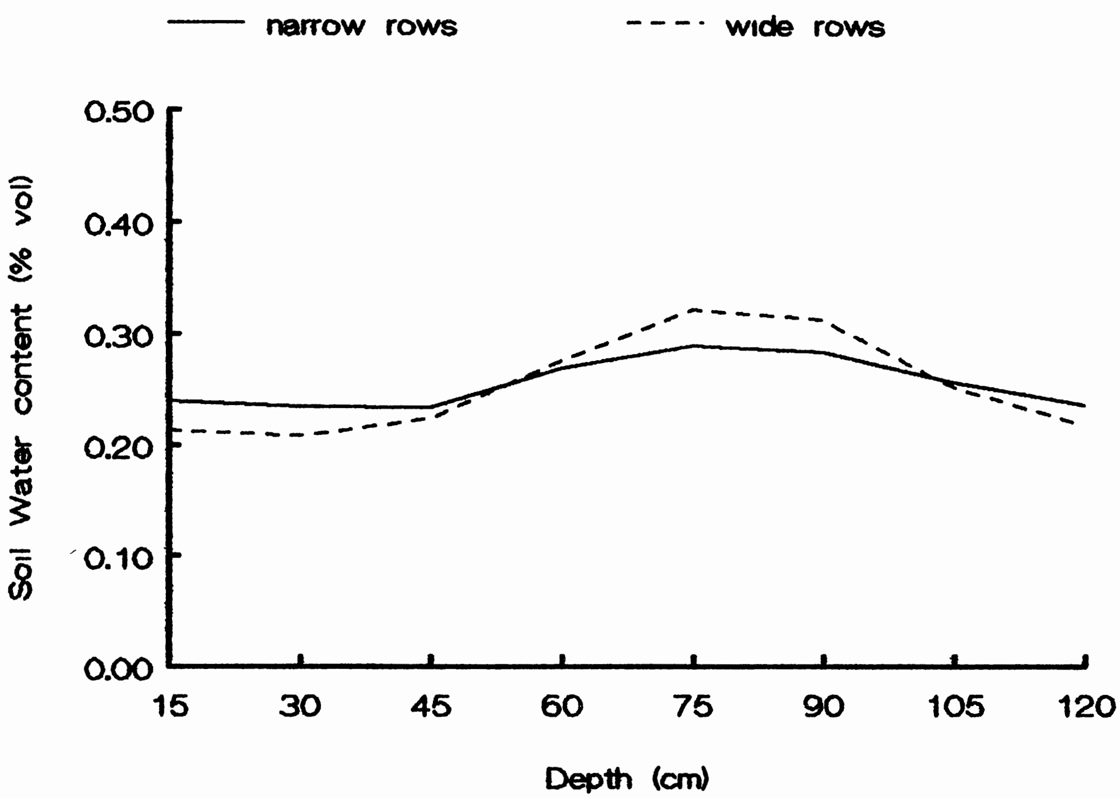

Fig 62. Soil water content from 0 to 120 cm on August 11, 1988.

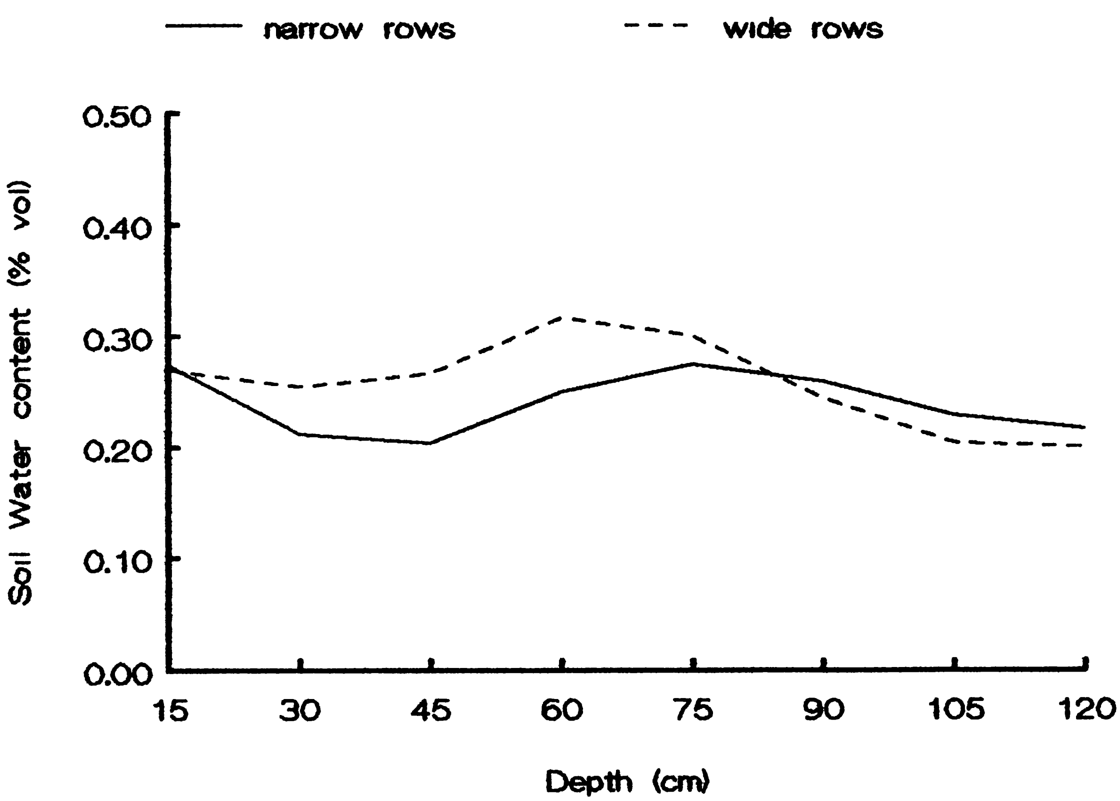

Fig 63. Soil water content from 0 to 120 cm on August 9, 1990.

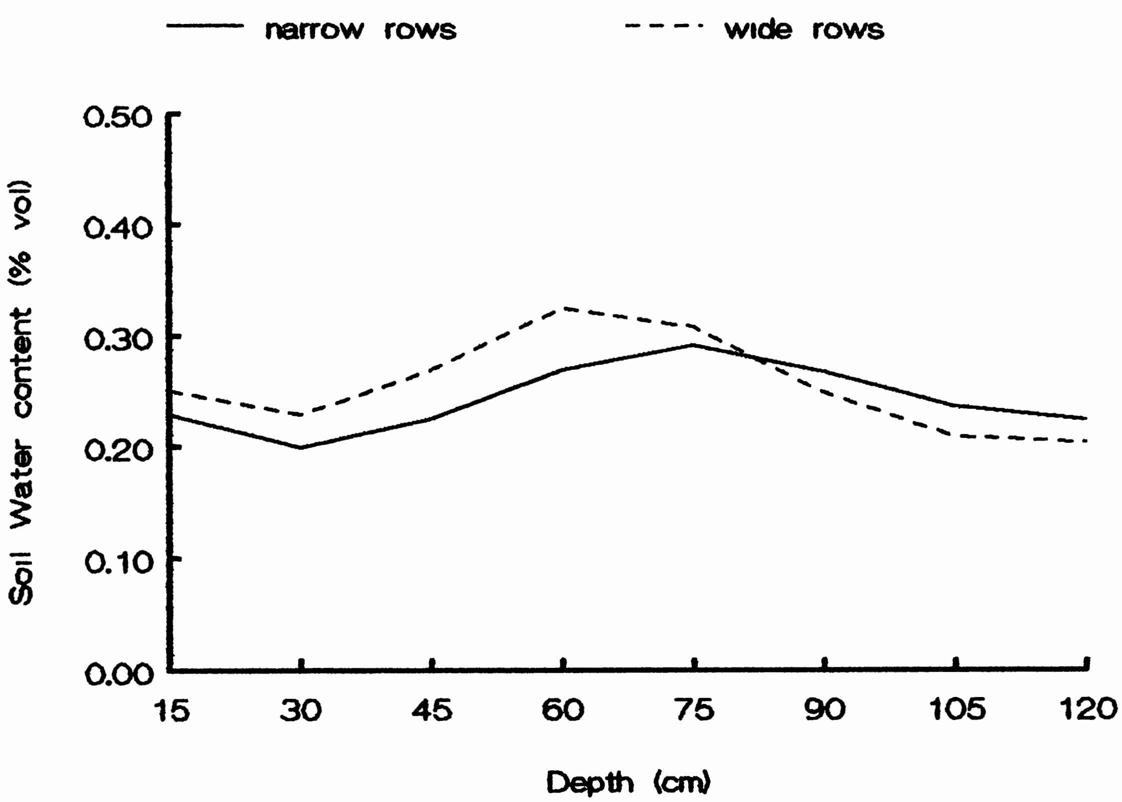

Fig 64. Soil water content from 0 to 120 cm in July 19, 1990.

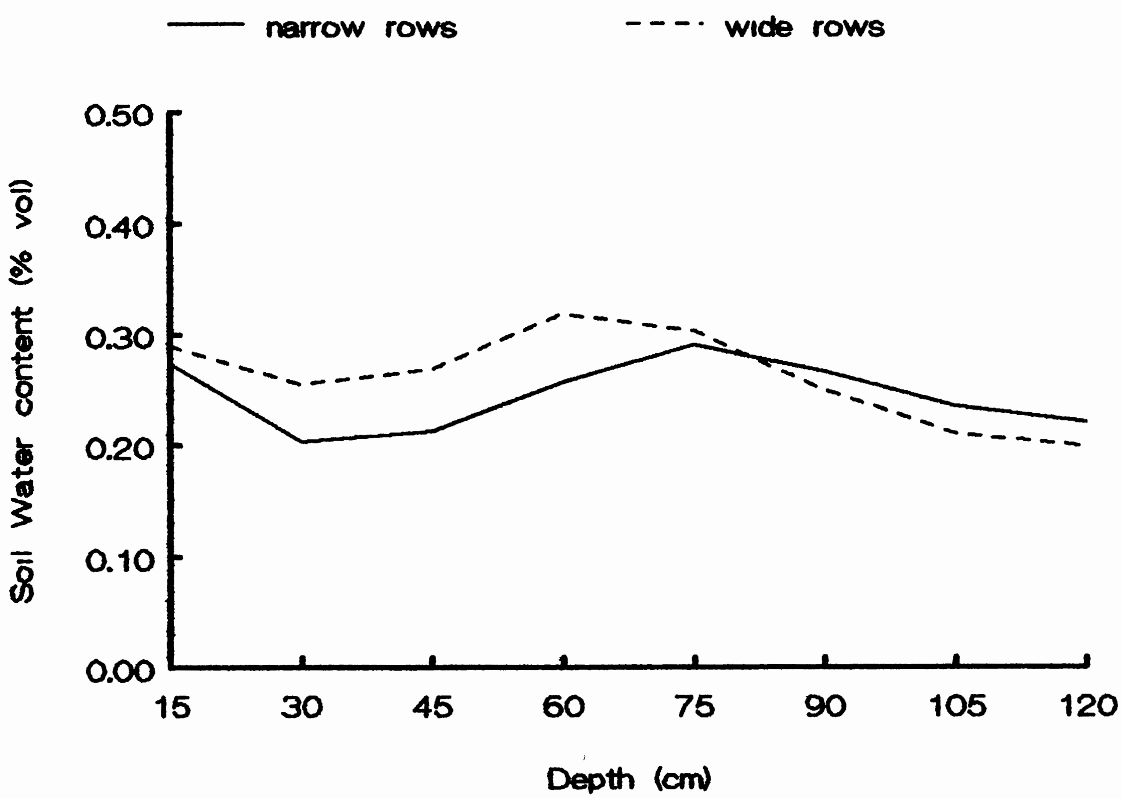

Fig 65. Soil water content from 0 to 120 cm in July 26, 1990.

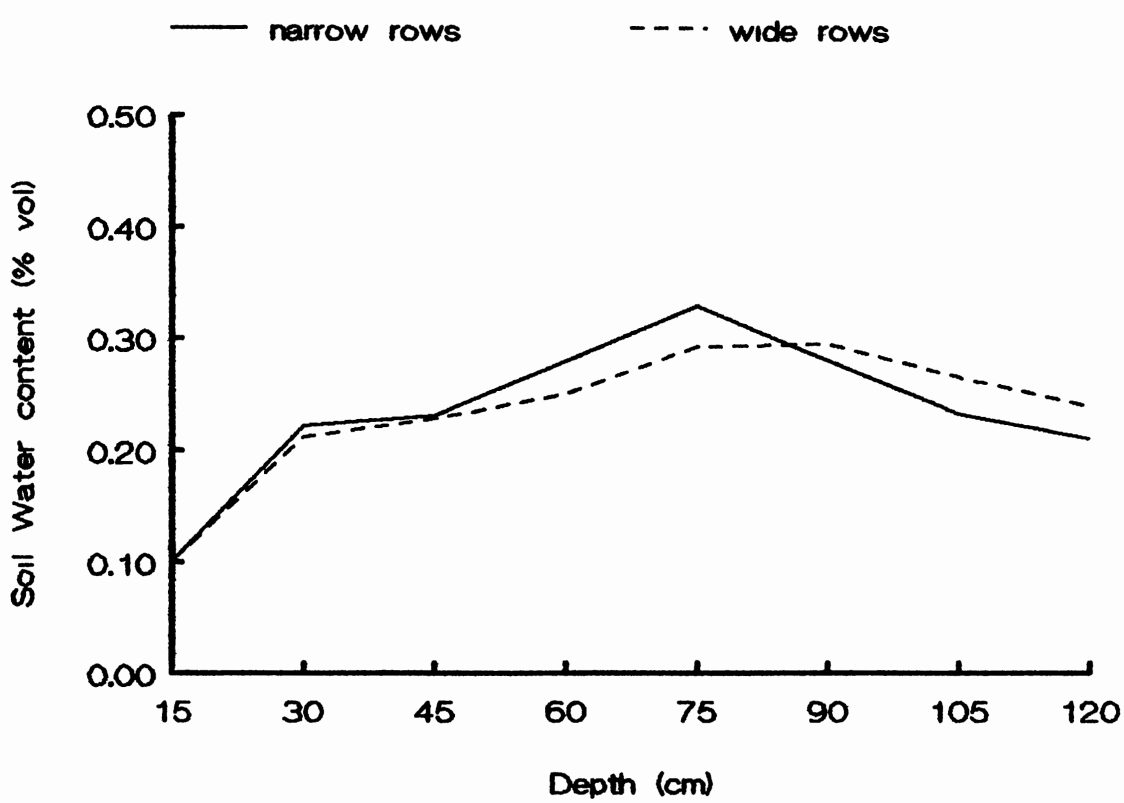

Fig 66. Soil water content from 0 to 120 cm in August 8, 1991.

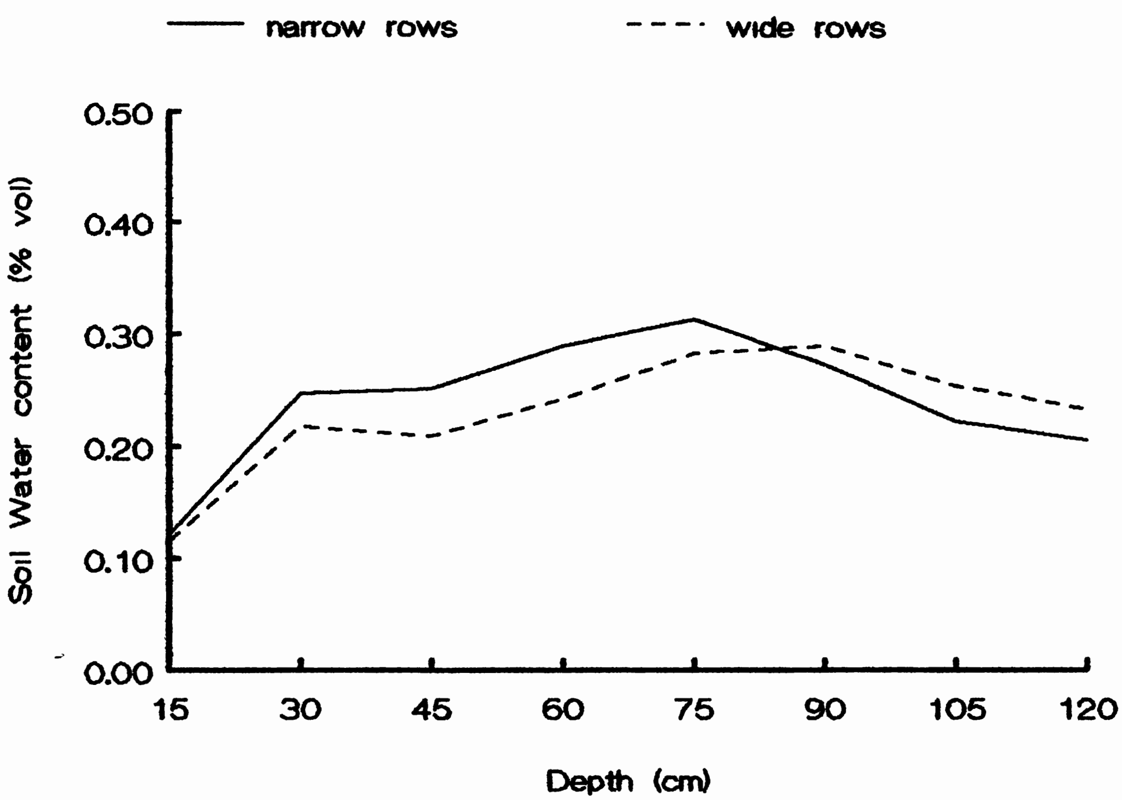

Fig 67. Soil water content from 0 to 120 cm on August 22, 1991.

APPENDIX C

ANALYSIS OF VARIANCE AND MEANS OF STOMATAL RESISTANCE FOR JUL23 1986

S. of V.	d.f.	Mean Square
Time*Treatment	11	8.339 **
Error	24	0.306
C.V. (%)	27.52	

** Significant difference at alpha=0.01

Time	Treatment	MEANS
11	narrow	1.063
11	wide	1.120
12	narrow	0.860
12	wide	1.040
13	narrow	1.386
13	wide	1.046
14	narrow	0.803
14	wide	0.837
15	narrow	3.490
15	wide	2.153
16	narrow	5.586
16	wide	4.743

APPENDIX D

COPPELATION COEFFICIENTS BETWEEN STOMATAL RESISTANCE AND LEAF WATEP POTENTIAL

Year	Date	Correlation coefficient	Prob > |R|
1986	JUL24	-0.594	0.025 *
1986	AUG12	-0.024	0.947
1986	AUG20	0.438	0.155
1986	AUG26	-0.251	0.432
1987	JUL14	0.027	0.949
1987	JUL16	0.006	0.979
1987	JUL20	-0.583	0.224
1987	JUL21	-0.159	0.588
1987	JUL22	0.051	0.904
1987	JUL27	0.226	0.560
1987	JUL29	-0.246	0.397
1987	JUL30	0.831	0.003 **
1987	AUG05	0.232	0.658
1987	AUG06	0.136	0.707
1987	AUG11	-0.340	0.335
1987	AUG12	0.404	0.246
1987	AUG19	-0.587	0.027 *
1988	JUL14	0.356	0.312
1988	JUL21	-0.146	0.688
1988	JUL25	-0.052	0.860
1988	AUG02	-0.108	0.800
1988	AUG03	-0.054	0.874
1988	AUG04	0.413	0.235
1988	AUG08	0.147	0.617
1988	AUG09	-0.223	0.485
1988	AUG10	-0.401	0.250
1988	AUG11	-0.404	0.192
1988	AUG15	-0.672	0.016 *
1988	AUG16	0.390	0.210
1988	AUG17	-0.222	0.537
1988	AUG18	-0.544	0.104
1989	AUG01	-0.396	0.161
1989	AUG02	-0.191	0.650

APPENDIX D (continued)

Year	Date	Correlation coefficient	Prob > |R|
1989	AUG08	-0.133	0.650
1989	AUG09	0.524	0.476
1989	AUG10	-0.324	0.434
1989	AUG17	0.059	0.829
1989	AUG18	0.413	0.309
1989	AUG21	0.463	0.355
1989	AUG28	0.070	0.796
1990	JUL16	0.472	0.065
1990	JUL17	0.231	0.390
1990	JUL19	-0.025	0.922
1990	JUL24	-0.098	0.817
1990	JUL25	0.179	0.478
1990	JUL26	0.040	0.880
1990	AUG01	0.059	0.828
1990	AUG02	0.053	0.858
1990	AUG21	0.841	0.364
1991	JUL30	0.878	0.122
1991	JUL31	-0.212	0.398
1991	AUG01	0.062	0.833
1991	AUG05	-0.485	0.041
1991	AUG06	0.484	0.042
1991	AUG07	0.161	0.524
1991	AUG08	0.137	0.614
1991	AUG12	0.650	0.003 **
1991	AUG15	0.205	0.414
1991	AUG19	-0.022	0.936
1991	AUG21	0.241	0.335
1991	AUG22	0.272	0.307

* Significance at alpha=0.05
** Significance at alpha=0.01

APPENDIX E

ANALYSIS OF VARIANCE AND MEANS FOR POTENTIAL EVAPOTRANSPIRATION

	YEAR 1986							
	AUG26		JUL23		JUL24		AUG20	
S.of V.	d.f.	M.S.	d.f.	M.S.	d.f.	M.S.	d.f.	M.S.
Time	5	.405	6	1.15	5	.087	5	.237
Treatment	1	.045**	1	.077**	1	.030**	1	.022**
Error	5	.0007	6	.0009	5	.00015	5	.001
C.V. (%)		1.73		1.44		1.00		2.36
Narrow row mean:		.065		.086		.049		.055
Wide row mean:		.070		.092		.053		.058

6 Significance at alpha=0.05
** Significance at alpha=0.01

	AUG12	
S.of V.	d.f.	M.S.
Time	4	.187
Treatment	1	.021**
error	4	.00026
C.V. (%)		1.075
Narrow row mean:		1.448
Wide row mean:		1.539

* Significance at alpha=0.05
** Significance at alpha=0.01

APPENDIX E (continued)

	YEAR 1987							
	JUL14		JUL16		JUL20		JUL21	
S.of V.	d.f.	M.S.	d.f.	M.S.	d.f.	M.S.	d.f.	M.S.
Time	3	.040	10	.095	2	.011	6	.096
Treatment	1	.000	1	.000	1	.0013**	1	.007**
error	3	.0001	10	.0003	2	.0000	6	.0001
C.V. (%)		1.45		2.20		0.043		1.512
Narrow row mean:		1.448		0.734		1.853		0.810
Wide row mean:		1.539		0.736		1.882		0.854

* Significance at alpha=0.05
** Significance at alpha=0.01

	JUL22		JUL27		JUL29	
S.of V.	d.f.	M.S.	d.f.	M.S.	d.f.	M.S.
Time	3	.053	4	.014	6	.096
Treatment	1	.007	1	.013	1	.031**
error	3	.041	3	.003	6	3.774
C.V. (%)		23.44		5.642		3.774
Narrow row mean:		0.894		1.051		0.984
Wide row mean:		0.835		0.975		0.890

* Significance at alpha=0.05
** Significance at alpha=0.01

APPENDIX E (continued)

	JUL30		AUG06		AUG11	
S.of V.	d.f.	M.S.	d.f.	M.S.	d.f.	M.S.
Time	4	.068	4	.058	4	0.045
Treatment	1	.042**	1	.059	1	0.005**
error	4	.001	4	.029	4	.00006
C.V. (%)		3.368		16.768		0.850
Narrow row mean:		1.112		0.931		0.906
Wide row mean:		0.982		1.084		0.949

* Significance at alpha=0.05
** Significance at alpha=0.01

	AUG12		AUG19	
S.of V.	d.f.	M.S.	d.f.	M.S.
Time	4	.102	6	.024
Treatment	1	.002*	1	.003**
error	4	.00015	6	.00006
C.V. (%)		1.345		0.943
Narrow row mean:		.901		.827
Wide row mean:		.931		.855

* Significance at alpha=0.05
** Significance at alpha=0.01

APPENDIX E (continued)

YEAR 1988								
	JUL14		JUL21		JUL25		AUG02	
S.of V.	d.f.	M.S.	d.f.	M.S.	d.f.	M.S.	d.f.	M.S.
Time	4	3.049	4	.023	6	.049	4	.260
Treatment	1	27.39	1	.010**	1	.023**	1	.002
error	4	6.039	4	.0002	6	.0002	4	.0005
C.V. (%)		4.27		1.408		1.582		2.384
Narrow row mean:		.951		.883		.988		.923
Wide row mean:		4.26		.946		.907		.954

* Significance at alpha=0.05
** Significance at alpha=0.01

	AUG03		AUG04		AUG08		AUG09	
S.of V.	d.f.	M.S.	d.f.	M.S.	d.f.	M.S.	d.f.	M.S.
Time	5	.259	4	.094	6	.186	5	.127
Treatment	1	.012**	1	.0007*	1	.011**	1	.037**
error	5	.0000	4	.00004	6	.00004	5	.00032
C.V. (%)		.856		.402		.366		1.292
Narrow row mean:		1.594		1.619		1.853		1.330
Wide row mean:		1.528		1.637		1.910		1.441

* Significance at alpha=0.05
** Significance at alpha=0.01

APPENDIX E (continued)

	AUG10		AUG11		AUG15		AUG16	
S.of V.	d.f.	M.S.	d.f.	M.S.	d.f.	M.S.	d.f.	M.S.
Time	4	.056	5	.206	5	.643	5	.302
Treatment	1	.005**	1	.081**	1	.006**	1	.023**
error	4	.00002	5	.0002	5	.00008	5	.00012
C.V. (%)		.359		1.063		.472		.549
Narrow row mean:		1.231		1.362		1.927		1.993
Wide row mean:		1.278		1.525		1.972		2.081

* Significance at alpha=0.05
** Significance at alpha=0.01

	AUG17		AUG18	
S.of V.	d.f.	M.S.	d.f.	M.S.
Time	4	.147	4	.355
Treatment	1	.010**	1	.00081*
error	4	.0002	4	.0001
C.V. (%)		1.088		.942
Narrow row mean:		1.249		1.069
Wide row mean:		1.314		1.087

* Significance at alpha=0.05
** Significance at alpha=0.01

APPENDIX E (continued)

	AUG01		AUG08		AUG10	
S.of V.	d.f.	M.S.	d.f.	M.S.	d.f.	M.S.
Time	6	.071	6	.090	3	.020
Treatment	1	.0001	1	.042**	1	.0011**
error	6	.0003	6	.00084	3	.00001
C.V. (%)		1.465		3.644		.515
Narrow row mean:		1.243		.741		.682
Wide row mean:		1.237		.851		.658

* Significance at alpha=0.05
** Significance at alpha=0.01

	AUG17		AUG18		AUG28	
S.of V.	d.f.	M.S.	d.f.	M.S.	d.f.	M.S.
Time	7	.201	3	.125	7	.0053
Treatment	1	.00008	1	.0018*	1	.121**
error	7	.00002	3	.00007	7	.00007
C.V. (%)		.557		.996		.427
Narrow row mean:		1.047		.837		1.888
Wide row mean:		1.043		.868		2.063

* Significance at alpha=0.05
** Significance at alpha=0.01

APPENDIX E (continued)

	YEAR 1989							
	JUL16		JUL17		JUL19		JUL25	
S.of V.	d.f.	M.S.	d.f.	M.S.	d.f.	M.S.	d.f.	M.S.
Time	7	.053	7	0.195	8	.220	3	.075
Treatment	1	.031**	1	.005**	1	.018**	1	.0002
error	7	.00024	7	.00022	8	.0004	3	.0006
C.V. (%)		1.310		1.615		1.547		4.036
Narrow row mean:		1.146		.907		1.255		0.608
Wide row mean:		1.234		.943		1.318		0.615

* Significance at alpha=0.05
** Significance at alpha=0.01

	JUL26		AUG01		AUG02	
S.of V.	d.f.	M.S.	d.f.	M.S.	d.f.	M.S.
Time	7	.190	7	.055	6	.171
Treatment	1	.040**	1	.030**	1	.005**
error	7	.0011	7	.00058	6	.00035
C.V. (%)		2.897		.419		1.782
Narrow row mean:		1.108		1.152		1.070
Wide row mean:		1.209		1.239		1.030

* Significance at alpha=0.05
** Significance at alpha=0.01

APPENDIX E (continued)

	YEAR 1991					
	JUL31		AUG01		AUG05	
S.of V.	d.f.	M.S.	d.f.	M.S.	d.f.	M.S.
Time	8	.038	6	.403	8	.193
Treatment	1	.013**	1	.0018**	1	.0076**
error	8	.00009	6	.000012	8	.00024
C.V. (%)		.475		.162		.816
Narrow row mean:		2.065		2.165		1.905
Wide row mean:		2.118		2.188		1.947

* Significance at alpha=0.05
** Significance at alpha=0.01

	AUG06		AUG07		AUG08		AUG12	
S.of V.	d.f.	M.S.	d.f.	M.S.	d.f.	M.S.	d.f.	M.S.
Time	8	.239	8	.196	8	0.75	8	.139
Treatment	1	.006*	1	.001**	1	.091**	1	.018**
error	8	.0009	8	.00017	8	.00017	8	.0003
C.V. (%)		1.60		.691		.211		1.644
Narrow row mean:		1.866		1.906		1.756		1.086
Wide row mean:		1.903		1.923		1.800		1.150

* Significance at alpha=0.05
** Significance at alpha=0.01

APPENDIX E (continued)

	AUG15		AUG19		AUG21		AUG22	
S.of V.	d.f.	M.S.	d.f.	M.S.	d.f.	M.S.	d.f.	M.S.
Time	8	.105	7	.083	8	.063	8	1.452
Treatment	1	.004**	1	.009**	1	.0003	1	.016**
error	8	.0002	7	.00002	8	.0005	8	.00034
C.V. (%)		1.128		.254		1.929		.693
Narrow row mean:		1.317		1.584		1.149		1.092
Wide row mean:		1.346		1.631		1.157		1.103

* Significance at alpha=0.05
** Significance at alpha=0.01

VITA

Joaquin Sanabria-Rodriguez

Candidate for the Degree of

Doctor of Philosophy

Thesis: STOMATAL BEHAVIOR INFLUENCED BY ROW SPACING IN IRRIGATED GRAIN SORGHUM

Major Field: Soil Science

Biographical:

Personal Data: Born in Bogota, Colombia. April 7, 1955, the son of Mr. Joaquin Sanabria and Mrs. Susana Rodriguez.

Education: Graduated from The Leon XIII High School, Bogota, Colombia in 1973. Received the degree of Agronomist Engineer from the Universidad Nacional de Colombia, Bogota, Colombia in 1981. Received Master of Science degree in Statistics from Oklahoma State University, Stillwater, Oklahoma, U.S.A., in 1986. Completed requirements for the Doctor of Philosophy degree in Soil Science at Oklahoma State University in May, 1992.

Professional Experience: Agronomist Engineer in the Statistics Division of The Instituto Colombiano Agropecuario, ICA, Colombia, since August 1981. Research Assistant, Agronomy Department, Oklahoma State University, from May 1991 to May 1992.