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USE OF LEAF RESISTANCE FOR PREDICTING IRRIGATION SCHEDULING

by

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Use of Leaf Resistance for Predicting Irrigation Scheduling
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INTRODUCTION

Use of soil water measurement as an indicator of irrigaion has beed widely adopted for many years. However, from the physiological processes viewpoint the actual response of plant water should be determined from plant water measurements (Slayter, 1967). Clark et al. (1971) stated that the time to irrigate should be based upon a plant measurement rather than on a soil moisture measurement such as a tensiometer.

Since the 1940's numerous new approaches on plant water measurement have been developed for scheduling irrigations. Hagan and Laborde (1964) gave a comprehensive literature review on the use of plant measurements as indicators of irrigation need, as shown in Appendix A.

Measurements of plant water provide a basic approach for scheduling irrigation, but the lack of adequate and convenient instrumentation has handicapped the research in this aspect.

Kanemasu and Tanner (1969) designed a portable diffusion resistance porometer which can measure the leaf resistance very rapidly.

Measurement of leaf resistance is one of the fundamental approaches to plant water balance. Stomata act as a main outlet for transpiration and reflect the actual response of the plant to the water status and to the environmental conditions.

The growing season of sorghum in Kansas is from May to

September. During this period, the daily temperature and solar radiation are high and much water is lost in evapotranspiration. When to irrigate and thereby provide an adequate water supply to the sorghum becomes a major problem.

The purpose of this study was to determine the relationship between soil water potential and leaf resistance, the characteristics of leaf resistance, and the possibility of using leaf resistance for scheduling irrigation of grain sorghum.

The study was conducted from May 17 to September 15, 1971 at the Evapotranspiration Research Field located 14 kilometers south of Manhattan, Kansas. The site has an alluvial silt loam soil. Grain sorghum was planted on June 1 and harvested on September 15.

Leaf resistance were measured on plants grown in pots where soil moisture was controlled and on plants in the field with a leaf diffusion porometer. Soil moisture level in the pots was calculated from the weight of the pots which were weighed frequently on a balance.

Soil moisture level in the field was measured directly by gravimetric samples and a neutron probe and indirectly from soil moisture tension measured by tensiometers. Instruments were installed to measure the following environmental factors: wind velocity, solar radiation, air temperature and vapor pressure. The field was irrigated by a solid set sprinkler irrigation system. During the growing season over 5000 individual leaf resistances were measured.

REVIEW OF LITERATURE

Soil Water Measurements

Soil water measurements have served as an indicator of irrigation for several years. There are three methods in use and these will be decribed in the following sections.

Soil Water Content

Soil water content may be determined by the gravimetric method or by use of the neutron probe. Irrigations can be scheduled by allowing a given soil moisture depletion. The gravimetric method is laborious and requires 24 to 48 hours to determined soil water content. The neutron probe is an expensive instrument and requires skilled technicians to operate it. As a result, neither method has been widely accepted by irrigation farmers.

Soil Appearance and Feel

The original concept using appearance and feel of soil as an indication of soil moisture was first developed by US. Soil Conservation Service technicians. As shown in Appendix B, this method provides a rough estimate of soil moisture by soil appearance and feel. Field experience is required to use this method as an indicator of irrigation need. Otherwise, the method becomes inaccurate.

Soil Water Tension

Determination of soil water content by gravimetric sampling or by use of the neutron probe is not a good indicator of irrigation need because the availability of water depends on its potential rather than on the content as a percentage of weight or volume. A sand might be at field capacity (ψ_m = -0.3 bars, where one bar is equal to 1000 centimeters of water tension) with a water content which is below the permanent wilting point percentage (ψ_m = -15 bars) for a clay. Thus, the only reliable indicator of the soil water status in terms of plant growth is its water potential (Kramer, 1969). Soil water tension may be determined by a tensiometer or resistance blocks.

Hillel (1971) reported that using soil water tension as an indicator of irrigation need raised two experimental difficulties:

(a) The distribution of roots is not uniform or constant; therefore, the water tension of the soil does not correspond to the root distribution.

(b) The water tension of the soil in contact with the root is always greater than the average tension, as shown in Figure 1.

Plant Water Measurements

Plants themselves are the best indicators of the need for irrigation. Attempts to estimate plant water stress from measurements of soil moisture or rates of evapotranspiration are

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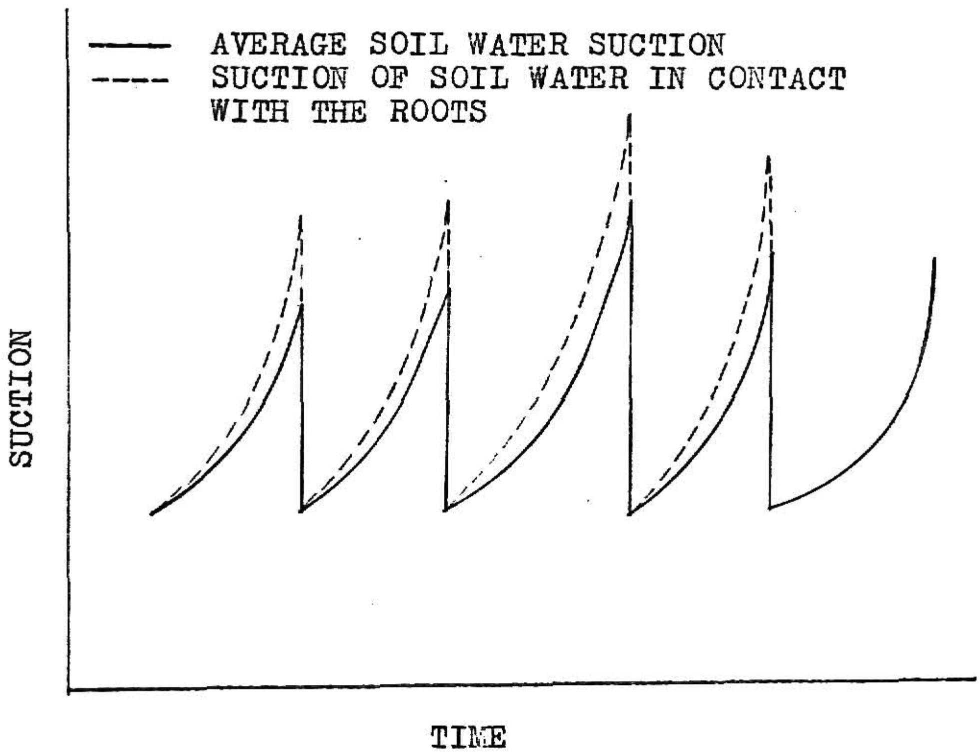


Figure 1. The Variation of Soil Water Suction in the Root Zone during Successive Irrigation Cycles. (after Hillel, 1971)

useful for some purposes. However, they do not supply information reliable enough to evaluate the effects of water supply on plant processes and plant growth. The only reliable indicators of plant water stress are direct measurements made on the plants (Kramer, 1969). There are several methods using the plant as an indicator of water need which will be mentioned in the following sections.

Plant Color

For some crops the distinct color change can be used as an indicator for irrigation. Robins and Domingo (1956), at Prosser, Washington found that field beans might be irrigated by noting leaf color change with a light green color indicating adequate soil water and a dark green color indicating a water deficiency.

Plant Movements

The movement of leaves is due primarily to variations in turgor pressure of plant cells. Changes in leaf angle of sorghum and rolling or other movement of leaves of other species sometimes indicate the development of water stress prior to wilting (Haise and Hagan, 1967).

Exudation

Root pressure directly affects the exudation from topped plants. McDermott (1945) found that exudation from a cut plant ceased at soil water contents above the wilting point. The method provides one of the fundamental approaches for irrigation scheduling but destroys part of the plant tissue.

Fruit Growth

Ladin (1959) found that the rate of apple (Malus sylvestris) fruit growth decreased gradually as water was extracted from the soil. Uriu et al. (1964) reported similar observations with peaches (Prunus persica) and prunes (Prunus domestica).

Leaf Growth

Meidner (1952) stated that leaf thickness changes quickly with variation in leaf water content induced by transpiration, but found no correlation between leaf thickness and soil water tension. Hagan and Haise (1967) stated that measurements of leaf thickness were not a good approach for scheduling irrigation.

Stem and Trunk Growth

Gates (1955) found that stem growth is affected by water stress on tomatoes. Clements and Kubota (1942) and Clements et al. (1952) reported that stem growth of sugarcane decreased with increasing soil water tension. Namken (1971) reported that the amount of stem radial contraction was directly related to the water stress indices of the cotton plant. Stem contraction was more sensitive to plant water stress as stress increased.

Leaf Temperature

Leaf temperature is affected by plant water stress. Tanner

(1963) measured leaf temperature with an infrared thermometer. Clark (1971) recommended irrigating at a leaf-air temperature differential of zero for southern peas.

Water Content

Use of water content as the criterion for irrigation has been reported for sugarcane by Tanimoto (1961). Namken (1965) studied the relative plant water content as a measure of internal water balance of plants to schedule irrigations for cotton.

Stomatal Aperture

The guard cells of plants are very sensitive to water stress. Stomatal aperture is of particular significance as an indicator of water dificits in plants because it influences both photosynthesis and transpiration by its effect on CO_2 and water vapor transport (Slayter, 1967). Oppendeimer and Mendel (1939) reported the infiltration measurements on citrus leaves to be a good indicator of water need.

Osmotic Potential

Osmotic potential has been used as an indicator of water need for many years. Lobov (1951) reports field experiments with cabbages (Brassica oleraces L.). Lobov's method has been modified by Babushkin (1959) who concluded that measurements on exuded sap provide a sound basis for scheduling irrigations especially with tomatoes.

Water Potential

Lang and Barrs (1965) and Rawlins (1966) have described thermocouple psychrometer methods for measuring leaf water potential. Gavande and Taylor (1967) have measured plant potential as influenced by soil water potential and atmospheric environment by using the wet-loop psychrometer. Clark (1971) has measured leaf water potential as an indicator of irrigation need by using a pressure bomb.

Meteorological Approaches

Evaporative Device

Wang (1963) stated that in a macroclimatic evaluation of irrigation need, the major concern has generally been with precipitation and estimated potential evapotranspiration. Although these two factors cannot describe exactly the water requirements of crops, they are able to give a first approximation and have been employed extensively for the scheduling of irrigation in many areas.

Water Needs of Sorghum

Most of the sorghum acreage is in regions having a rainfall of 15 to 30 inches annually. Martin (1941) stated that to produce high yields, grain sorghums will need 22 to 24 inches of water in the southern great plains and 23 to 25 inches in the southwest.

Martin (1941) stated that the drought resistance of the sorghum plant appears to be due to:

1. Ability to stop growth during drought and then resume it when conditions become favorable.
2. Great resistance to drying out.
3. Low water requirement.
4. Ability to make a crop from tillers and branches produced after rain comes.
5. A great number of fibrous roots.

Water Requirements And Stage

The variation of the water requirement of plants is a function of their age and development stage. Robins and Domingo (1953) stated that a soil moisture deficit for one or two days during the tasseling stage reduced the yield of corn by as much as 22 percent.

Razumova (1950) reported experimental data on the water consumption by winter wheat grown at the Poltava Agricultural and Meteorlogical Stations (see Table 1). At ear-flowering, plants need more water than at any other stage of growth. Zaitsev (1940) found that the yield of wheat is a function of the decrease in soil moisture, as shown in Table 2.

Jensen and Musick (1962) found that the rate of water use increased gradually with increasing plant growth and ground cover. The peak water use of sorghum in the southern great plains occurred at the boot-to-flowering stage of plant development.

Table 1. Water Consumption by Winter Wheat in 1938. (after Razumova, 1950)

Inter-phase periods	Duration of period days	Total moisture mm expended during period	Water expenditure mm per day
Renewal of vital activity-shooting	32	40	1.2
Shooting-ear formation	30	101	3.4
Ear flowering	11	58	5.3
Flowering-milk ripenese	10	26	2.6
Milky ripenese - harvest	15	19	1.3

Table 2. Yield of Spring Wheat in Bezenchuk Station as a Function of Soil Moisture. (after Zaitsev, 1940)

Percent of available water	Number of irrigation	Irrigation m^3/ha	Yield grain kg/ha	Yield straw kg/ha
100-75	4	3148	3710	4700
100-65	3	2090	3100	4450
100-60	2	1542	2850	3620

Stomata And Environmental Condition

The opening and closing movement of stomata is due to the turgor pressure of the guard cells. Some environmental conditions can affect the turgor pressure of guard cells and cause the stomata to open or close. These environmental conditions will be described in the following sections.

Carbon Dioxide

Slatyer (1967) stated that the primary factor controlling stomatal aperture was intercellular space CO_2 concentration.

Kozlowski (1968) stated that the stomata tend to close when there is a high level of carbon dioxide in the leaf and they tend to open when carbon dioxide is needed. These reactions seem to be regulated by the photosynthetic rate, especially by that of the turgor pressure of guard cells.

Water Supply

Meidner and Mansfield (1965) and Zelitch (1965) stated the stomatal resistance is directly affected by the water supply, CO_2 concentration and light intensity. The relationship between stomatal resistance and these factors is shown in Figure 2.

Kozlowski (1968) reported that the stomata aperture changes associated with water supply are important, the stomata providing the only effective means for the control of water loss when the water supply to a leaf is restricted. If a leaf is suddenly deprived of its water supply, the first response is a transient opening of the stomata, and this is soon followed by gradual closure. If the water supply is restored, the stomata close further while the leaf water content is increasing, but the stomata slowly reopen after the leaf regains full turgor.

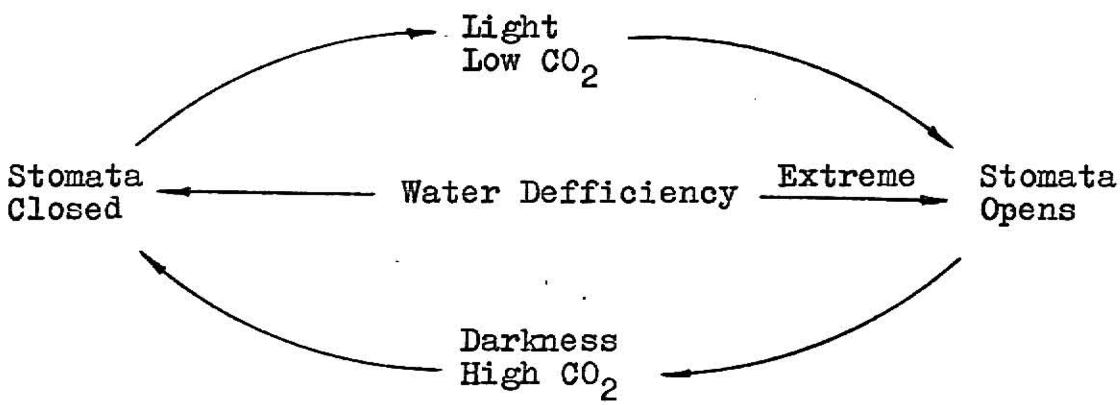


Figure 2. Normal Resistance of Stomata to Light, Carbon Dioxide Concentration and Water Deficiency. (after Sutchliffe, 1968)

Wind Velocity

Slatyer and Bierhuizen (1965) reported that at relatively low wind speeds, the resistance, r_{bL}, of the boundary layer is usually greater than leaf resistance, r_L, with open stomata. Meidner and Mansfield (1968) found that stomatal closure may occur because of wind if transpiration rate increases sufficiently to cause a water deficit in the leaf. Under windy conditions, the external diffusion resistance to CO_2 intake will be reduced and the increased CO_2 concentration which occurs under a water deficit will tend to close the stomata.

Light Intensity

Kuiper (1961) showed a hyperbolic relationship between the stomatal resistance of bean leaves and the light intensity. Kanemasu et al. (1969) stated that the adaxial stomata were more sensitive to light than the abaxial. Whiteman and Koller (1967) found that the stomatal resistance of sunflower leaves was decreased when light was increased from 500 to 1000 foot - candles but a further increase in light resulted in an increase in the stomatal resistance. Kanemasu et al. (1969) measured the abaxial stomatal resistance of snap beans (Phaseolus vulgaris L.) in a growth chamber. The plants were subjected to dark and light cycles by switching on and off the normal growth chamber light. The relationship between light-dark and abaxial stomatal resistance is shown in Figure 3.

Woolley (1966) stated that most stomata close in the dark, when photosynthesis is impossible, and open in the light.

Meidner and Mansfield (1965) investigated the stomatal movement in a succulent and nonsucculent plant (see Figure 4). In a succulent plant, stomata usually open in the light and close in the dark.

Temperature

Sutchliffe (1968) reported that within the range of about 10 to 25^{o}C the effect of temperature is mainly to influence the rate of the opening and closing reactions.

Wang (1963) stated that the leaf temperature is a better

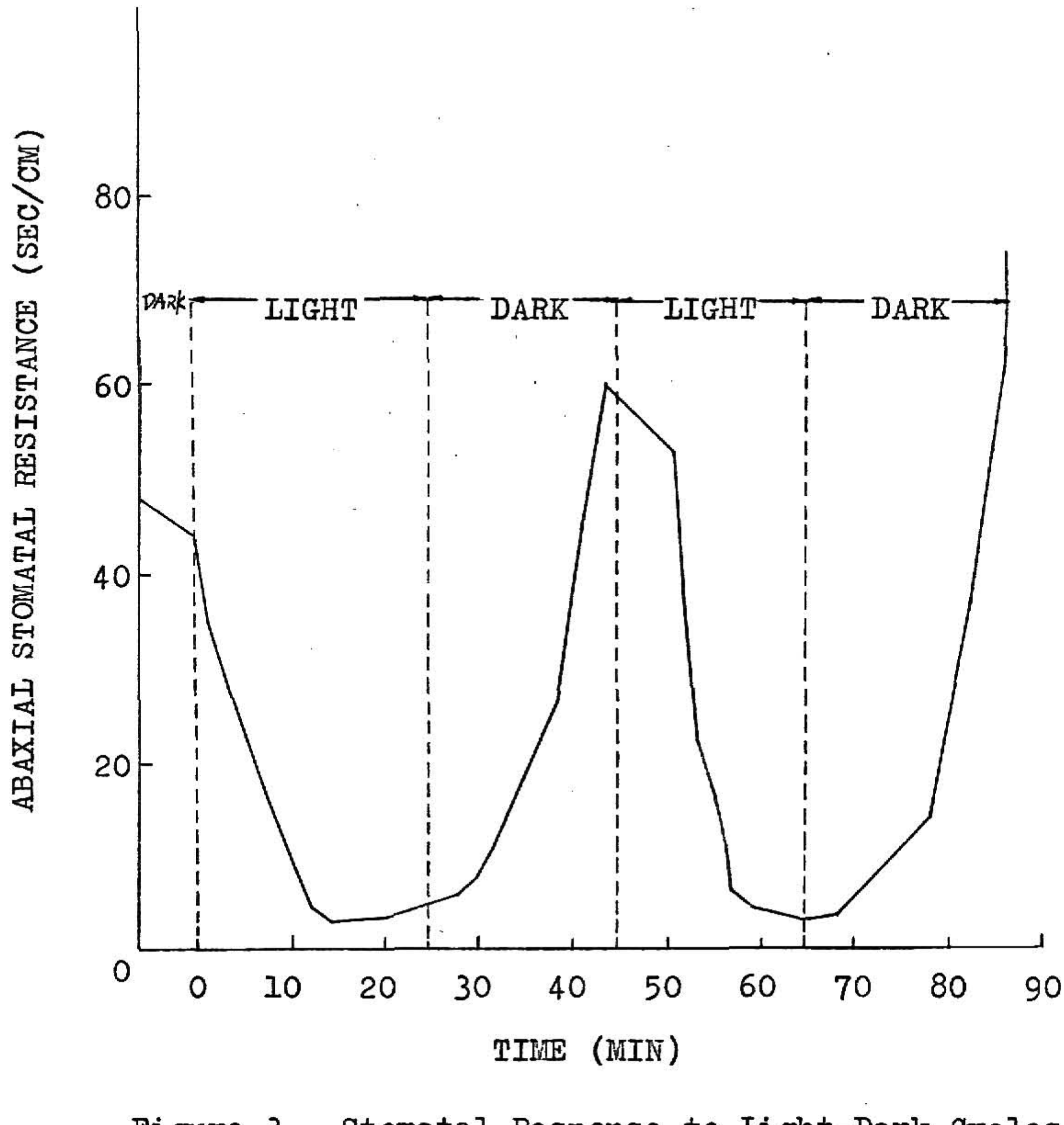


Figure 3. Stomatal Response to Light-Dark Cycles.
(after Kanemasu, 1969)

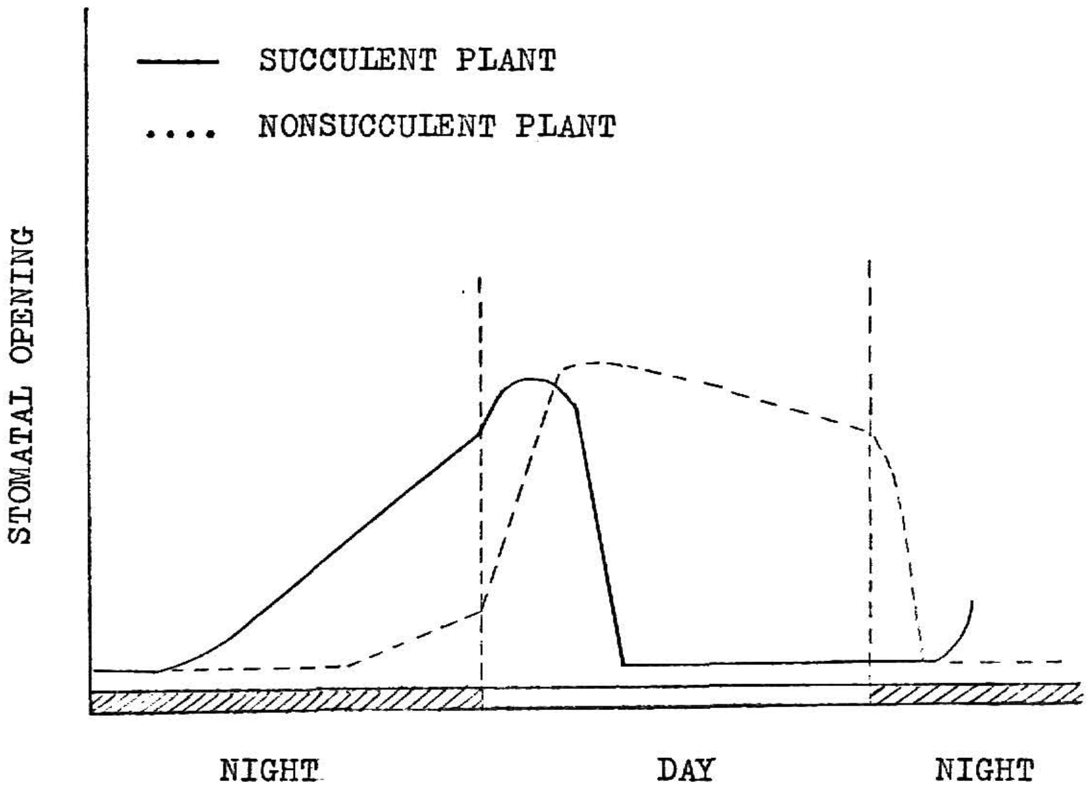


Figure 4. Diagrammatic Representation of the Daily Course of Stomatal Behaviour in a Succulent Plant and Nonsucculent Plant. (after Meidner and Mansfield, 1965)

indicator of temperature than the air temperature. Meidner and Mansfield (1965) found that changes in temperature may have two opposing effects; one, associated with the increase in the CO_2 concentration within the leaf, which causes closure at high temperatures, and the other acting independently of the response to CO_2 which produces greater opening at high temperatures.

Age of Plant

Meidner and Mansfield (1965) stated that the stomata on very yound leaves close tightly in the dark and open slowly to a limited extent in the light. Those on mature leaves are most responsive, closing tightly in darkness and opening rapidly and widely during the light phase of a diurnal cycle. On old leaves the stomata are very sluggish, neither closing greatly in the dark nor opening widely in the light.

Relative Humidity

Wilson (1948) found that the effect of relative humidity on stomatal aperture was very small indeed at temperatures of 15°C and below; even at 30°C the stomatal remained fully open in a high light intensity as the relative humidity changed in the range of 50 to 100 percent.

Transpiration And Stomata

Kramer (1969) reported that transpiration is reduced by about 30 percent when the stomata are 50 percent closed and 75 percent when the stomata are 90 percent closed.

Bange (1953) investigated the relationship between stomatal aperture and transpiration of Zebrina leaves under moving and still air conditions, as shown in Figure 5.

Leaf Water Potential And Stomata

Slatyer (1967) reported that water deficit may not affect greatly the stomatal resistance until a critical leaf-water potential is reached, and as the water potential decreases further, there is a progressive increase in leaf resistance.

Kanemasu et al. (1969) found the relationship of leaf-water potential to leaf resistance in the growth chamber, as shown in Figure 6.

Water Movement Through Soil-Plant-Atmosphere

Water movement from the soil, through the plant, and to the atmosphere occurs along a path of continuously decreasing potential energy. This path includes a number of distinct segments, each of which can be described in terms of a flow equation (Hillel, 1971).

Van den Honert (1948) attempted to develop a unifying theory to identify the factors controlling water movement through the plant, based on an analogy to the flow of current in an electrical conductor. According to Ohm's law

$$\text{current} = \frac{\text{potential}}{\text{resistance}}$$

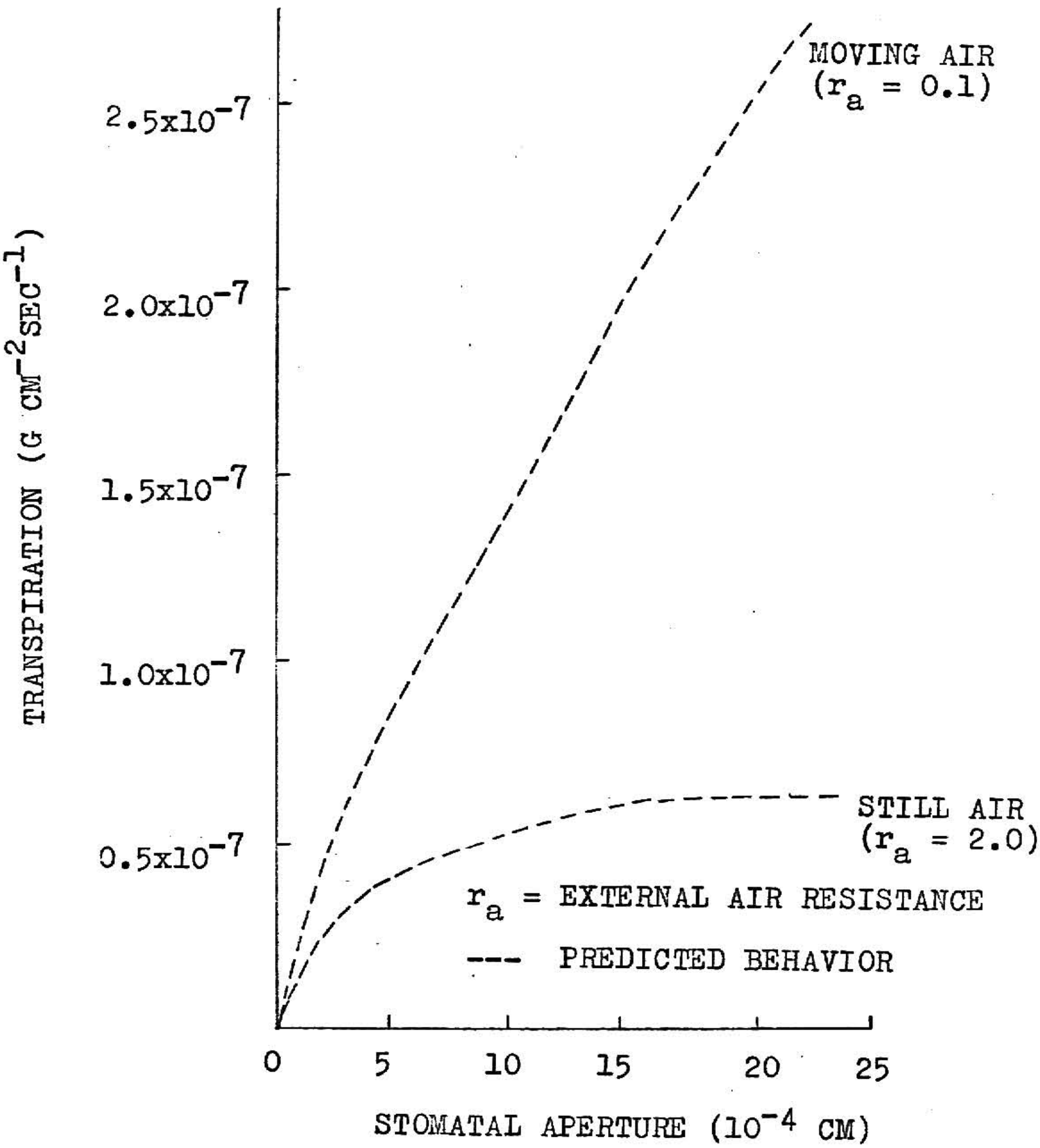


Figure 5. Influence of Stomatal Aperture on Transpiration of Zebrina Leaves under Moving and Still Air Conditions. (after Bange, 1953)

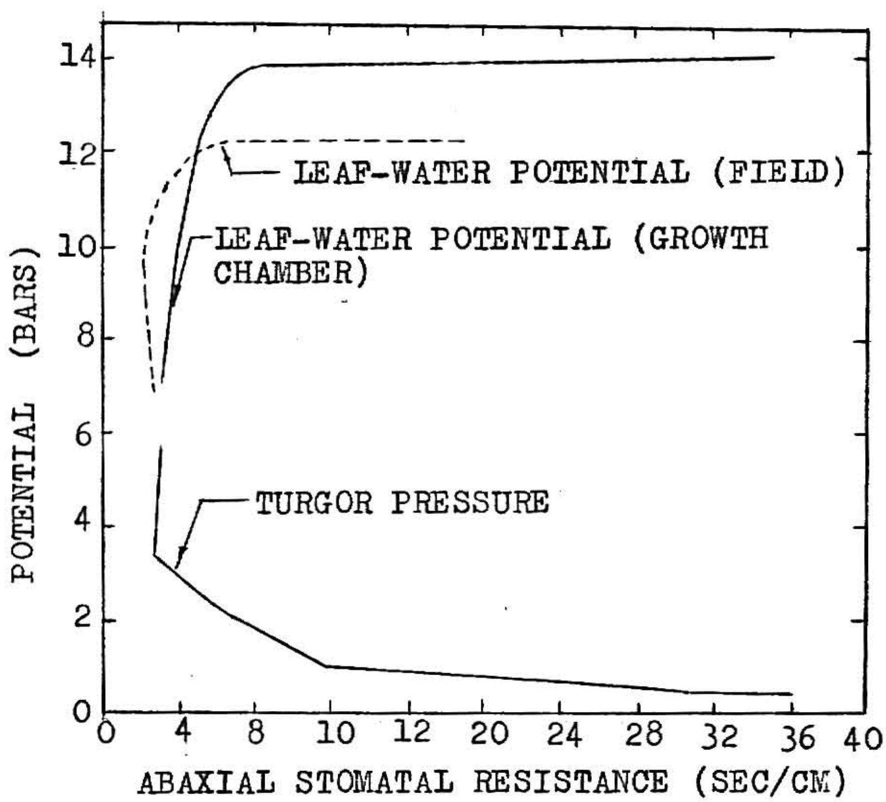


Figure 6. Relationship Between Abaxial Stomatal Resistance and Leaf-Water Potential and Turgor Pressure of Growth Chamber Plants. (after Kanemasu, 1969)

and Van den Honert wrote an expression for steady flow as follows:

$$\text{Rate of water movement } (q) = \frac{U_{soil} - U_{root\ surface}}{r_{soil}}$$

$$= \frac{U_{root\ surface} - U_{xylem}}{r_{root}}$$

$$= \frac{U_{xylem} - U_{leaf}}{r_{xylem} + r_{leaf}}$$

$$= \frac{U_{leaf} - U_{air}}{r_{leaf} + r_{air}}$$

where U is the potential and r is the resistance.

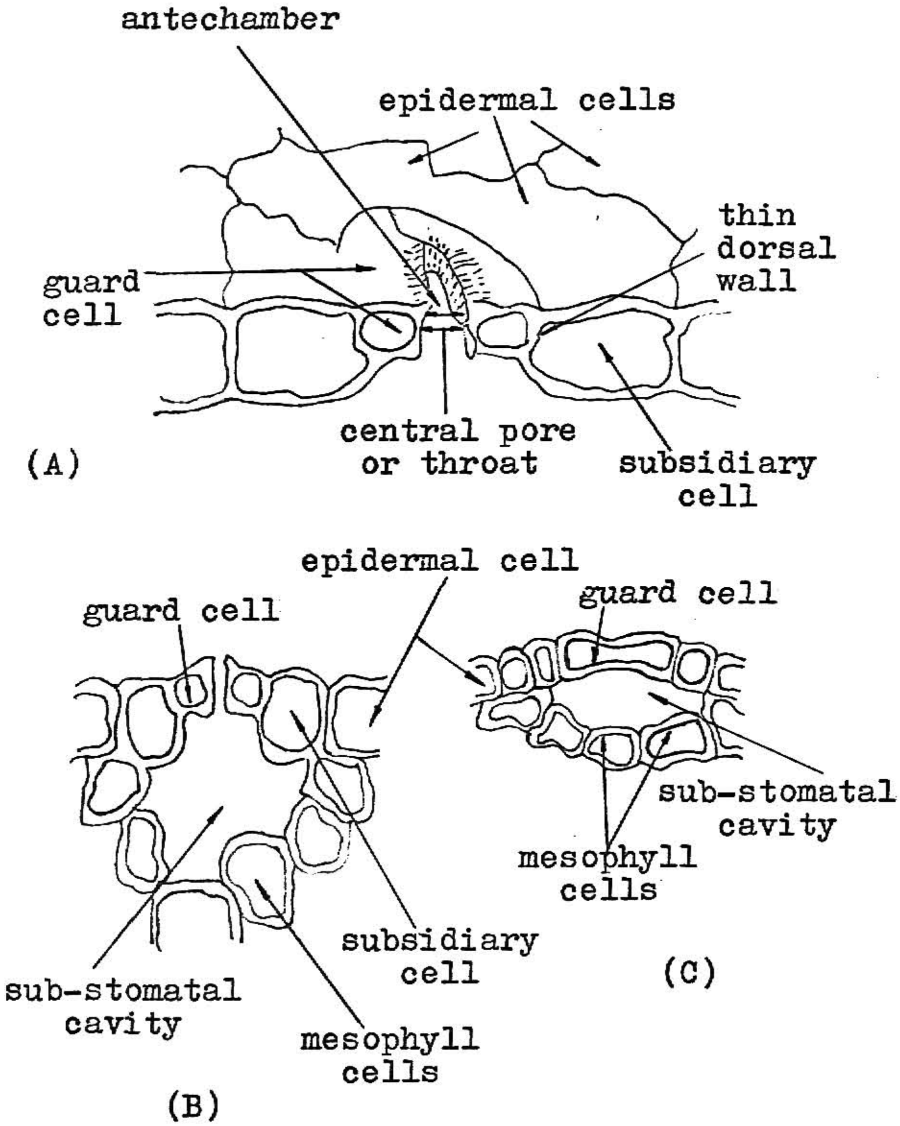
Kramer (1969) and Rose (1966) have used this expression in various ways, but have been unable to describe adequately the resistances in the plant. Several limitations to this equation have been summarized from Kramer (1969) as follows: (1) a steady-state condition seldom exists in plants; (2) it assumes a constant resistance regardless of flow rates; and (3) it neglects the phase change from liquid to vapor in the leaf. Regardless of these limitations, this is still the best theoretical description of the water flow through plants

Leaf Resistance

The stomatal resistance (r_S) is the sum of resistances in the mesophyll cell (r_M), the intercellular space (r_i) and the stomatal pore (r_P) (see Figure 7). Kozlowski (1968) pointed out that the total internal leaf resistance, r_L, is given by

$$1/r_L = 1/r_C + 1/(r_S + r_V + r_W)$$

where r_L, r_C, r_V, r_W are the resistance of leaf, cuticle, substomatal cavities and cellwalls, respectively.



(A) SECTION THROUGH ELLIPTICAL STOMATA SHOWN AS PERSPECTIVE DIAGRAM,
(B) TRANSVERSE SECTION THROUGH AN ELLIPTICAL STOMATA AND THE SUB-STOMATAL CAVITY,
(C) LONGITUDINAL SECTION THROUGH ONE GUARD CELL AND THE SUB-STOMATAL CAVITY OF AN ELLIPTICAL STOMATA.

Figure 7. The Transverse and Longitudinal Section of an Elliptical Stomata. (after Meidner and Mansfield, 1968)

INVESTIGATION

This study was conducted from May 17 to September 15, 1971, at the Evapotranspiration Research Field located 14 km south of Manhattan, Kansas. The site has an alluvial silt loam soil. A two-hectare field was planted to sorghum (Sorghum biclor L. Meoench cv. Pioneer 846) in north-south rows spaced 91 cm apart at an average linear density of 11 plants per meter. The crop was harvested on September 15 with a yield of 6200 kg per ha.

Leaf resistances were measured both on field and potted plants by a leaf diffusion porometer. Instruments were installed to measure environmental factors. A sprinkler irrigation system was used to provide the field with water. During the growing season over 5000 individual leaf resistances were measured.

Objectives

The objectives of the study were:

1. To find the characteristics of leaf resistance of a sorghum plant.
2. To develop a relationship between soil water potential and leaf resistance.
3. To evaluate the use of leaf resistance as a criterion for irrigation scheduling.

Theory

The leaf resistance, r_L, is obtained by

$$1/r_L = 1/r_{ad} + 1/r_{ab}$$

or

$$r_L = (r_{ad} \times r_{ab})/(r_{ad} + r_{ab})$$

where r_{ad} and r_{ab} are the leaf resistance of the adaxial (upper surface) and abaxial surface (lower surface). The average leaf resistance of the whole plant, r_A, is given by

$$\frac{1}{r_A} = \left(\frac{1}{r_{L1}} + \frac{1}{r_{L2}} + \frac{1}{r_{L3}} + \ldots\ldots + \frac{1}{r_{Ln}} \right)/n = C_A$$

$$= (C_{L1} + C_{L2} + C_{L3} + \ldots\ldots + C_{Ln})/n$$

or

$$r_A = \frac{n}{\left(\frac{1}{r_{L1}} + \frac{1}{r_{L2}} + \frac{1}{r_{L3}} + \ldots\ldots + \frac{1}{r_{Ln}} \right)}$$

where:

r_A = Average leaf resistance

C_A = Average leaf conductance

C_{L1} = Conductance of individual leaves

n = Number of leaves

Instruments And Equipment

Leaf resistance was measured by a stomatal diffusion porometer designed by Kanemasu et al. (1969). Figure 8 shows a commercial diffusion porometer (Lambda Instruments CO., INC. 2933 N. 36th Lincoln, Nebraska 68504) similar to the one used in this study. For a leaf resistance less than 5 sec/cm (low resistance) the time lapse was measured for the ammeter reading of the porometer to change from 2 to 10 μa which corresponds to a change in relative humidity within the sensor chamber from approximately 22.5 to 29 percent. For a leaf resistance greater than 5 sec/cm (high resistance) the time lapse was measured for the ammeter reading to increase from 2 to 6 μa which corresponds to a relative humidity change from approximately 18 to 20 percent.

A calibration curve was used to transform the time lapse value to leaf resistance. The effect of air temperature was calculated from the vapor pressure gradient between the saturated surface and the air in the vapor cup and the amount of water vapor that must diffuse into the cup to result in a given change in relative humidity (Kanemasu et al., 1969).

Field soil moisture was determined daily at different depths (15, 30, 45, 60, 90, 120, 150 cm) by gravimetric samples, neutron probe and tensiometer readings. Figure 9 shows the location of field tensiometers.

A Gill type anemometer was used to measure the wind speed

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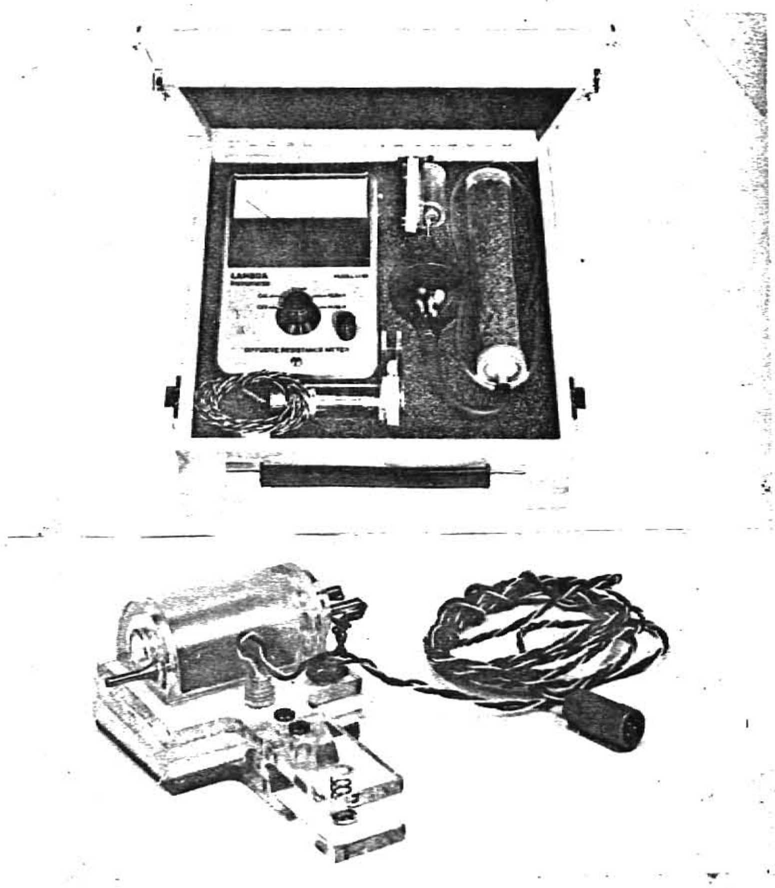

Figure 8. Leaf-Diffusion Porometer

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Figure 9. Location of Field Tensiometers

2 meters above the ground. Hemispherical net radiometers and solar radiometers were installed 60 cm above the plant canopy to measure the net radiation and solar radiation.

A solid-set sprinkler irrigation system was installed for field irrigation. Figure 10 shows the sprinkler irrigation system in the field.

Procedure

The purpose of this study was to investigate the use of leaf resistance of sorghum as an indicator of irrigation need. This section describes the technique used in achieving the objective.

From May 17 to May 31, 1971 instruments were installed for measuring the environmental factors namely, wind velocity, radiation, air temperature, and vapor pressure. Tensiometers were installed on the experimental plot and holes for a neutron probe were prepared after sorghum planting.

Field Measurements

Due to the fact that the leaf surface was small, no leaf resistance measurements were taken before June 23. From June 24 to August 30, a daily measurement of leaf resistance was observed, along with daily measurement of environmental factors. Appendix C gives plant height and number of leaves during the growing season.

Leaf resistance was measured at the center of the leaf for the following reasons: (i) to insure that the leaf surface has two square centimeters of area for measurement, (ii) to avoid

Figure 10. Sprinkler Irrigation System at Evapotranspiration Research Field

measuring on the leaf rib, and (iii) it is more convenient for the measurement to be taken on the center portion of the leaf than on the tip or base.

Potted Plant Measurements

In order to control the level of soil moisture, sorghum seedlings were transplanted into pots 30 cm deep filled with field top soil so that the soil moisture content could be controlled by irrigation.

During the period June 1 to July 31, the pots were buried level with the soil surface in the field. From August 1 to September 15 the field canopy closed and the pots were allowed to sit on the field surface in the canopy shade. Figure 11 shows the potted plants in the field.

The soil water potential was estimated from the average soil moisture content in the pots and a soil water release curve determined in the laboratory.

Result And Discussion

Field Measurements

During the early season, adaxial and abaxial leaf resistance were measured along the leaf length (tip, center and base). Figure 12 and Figure 13 are the typical curves of these measurements. The adaxial resistance was observed to be higher than the abaxial resistance and the highest resistance was observed to occur on the base of the leaf.

Figure 11. Potted Plants at Evapotranspiration Research Field

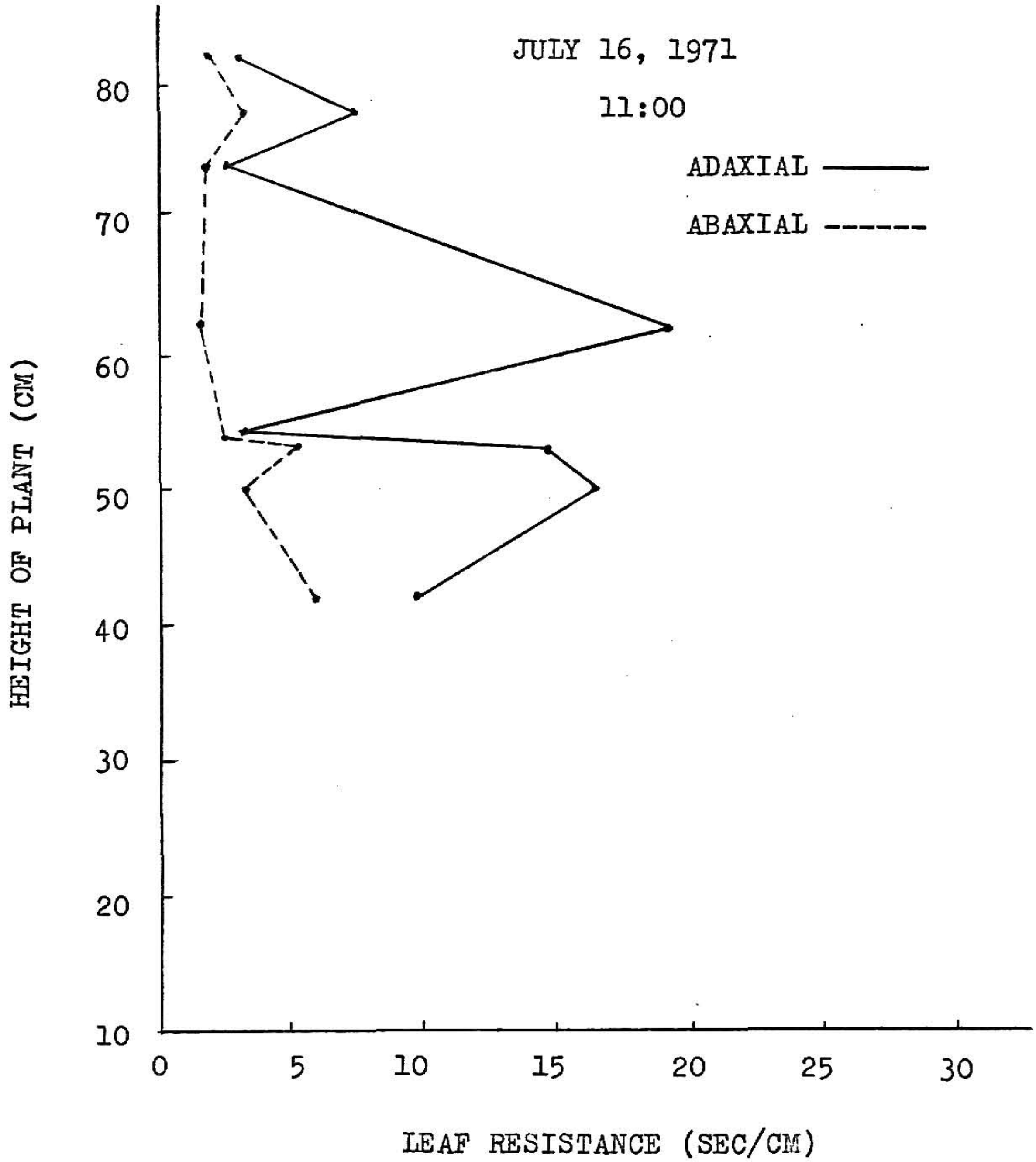

Figure 12. Adaxial and Abaxial Leaf Resistance at Different Heights of Sorghum Plant.

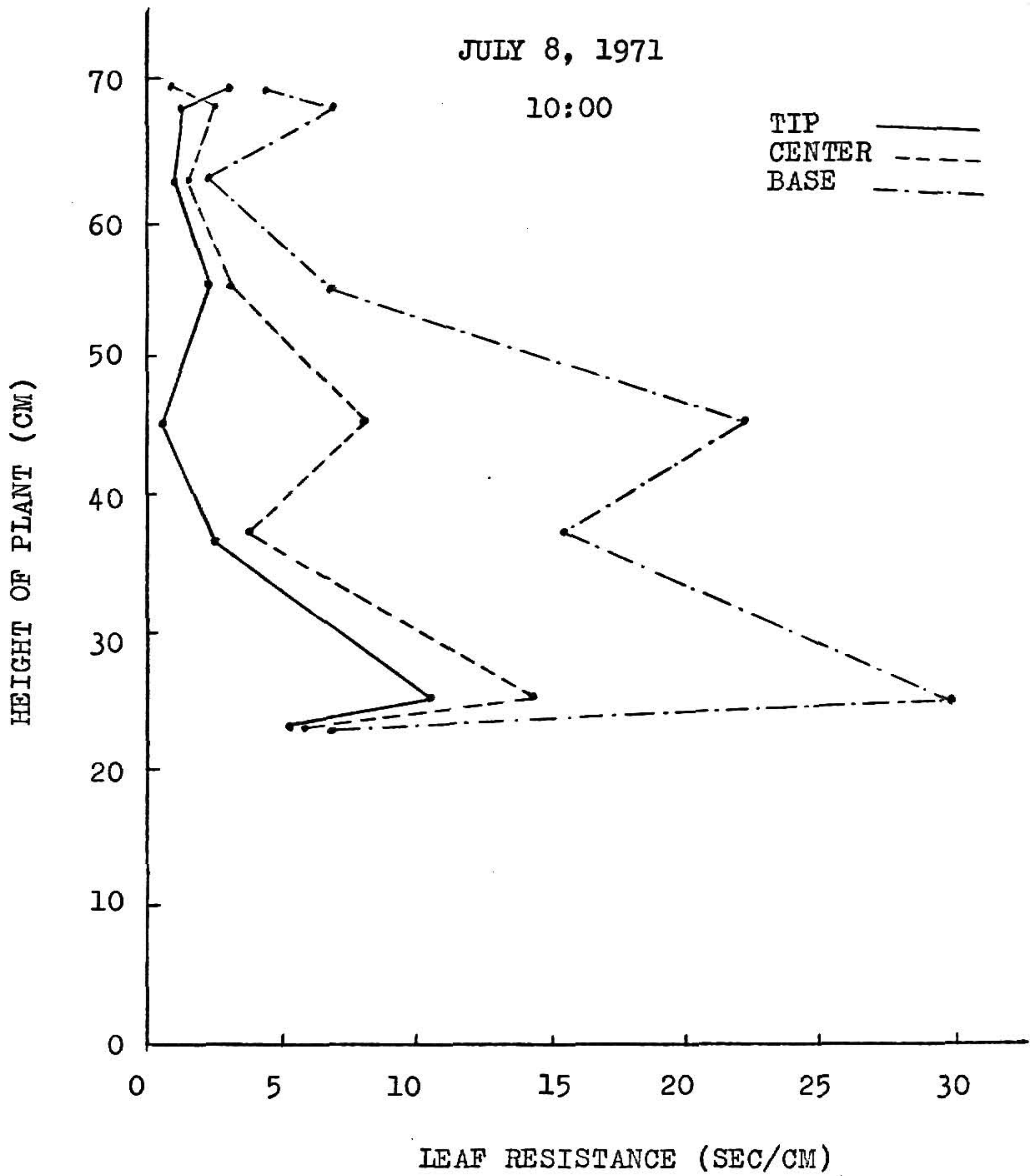

Figure 13. Adaxial Leaf Resistance and Height of Sorghum Plant.

It is widely recognized that water deficit will affect the leaf resistance. Figure 14 shows the changes of leaf resistance when there is no water supply from the roots. Leaf resistance was measured before cutting the roots and 15 minutes after cutting. Both adaxial and abaxial leaf surfaces were measured along the leaf length (tip, center and base). As it became impossible for the plant to obtain water through the roots, the stomata closed rapidly to prevent transpiration from the leaf.

A temporal variation of leaf resistance was measured on July 30, 1971, every 20 minutes on the same leaf. As indicated in Figure 15 and Figure 16, the leaf resistance was low during midday and was uniform. However, the leaf resistance in the early morning and late afternoon changed rapidly. This is because in the late afternoon, leaf resistance was affected by different levels of light intensity and water stress. On the other hand, during the early morning the leaf surface was wetted by dew and water evaporated from the leaf surface affecting the measurement of leaf resistance.

On July 14, 1971, leaf resistance was measured on ten plants which were grouped together. Measurements were made on the last collared leaf of each plant. The standard deviation of leaf resistance was 0.4 sec/cm, as shown in Figure 17.

An hourly observation of average leaf resistance was taken on July 31, 1971 (see Figure 18). The average leaf resistance from 11 am to 2 pm was uniform.

Average leaf resistance during the growing season is

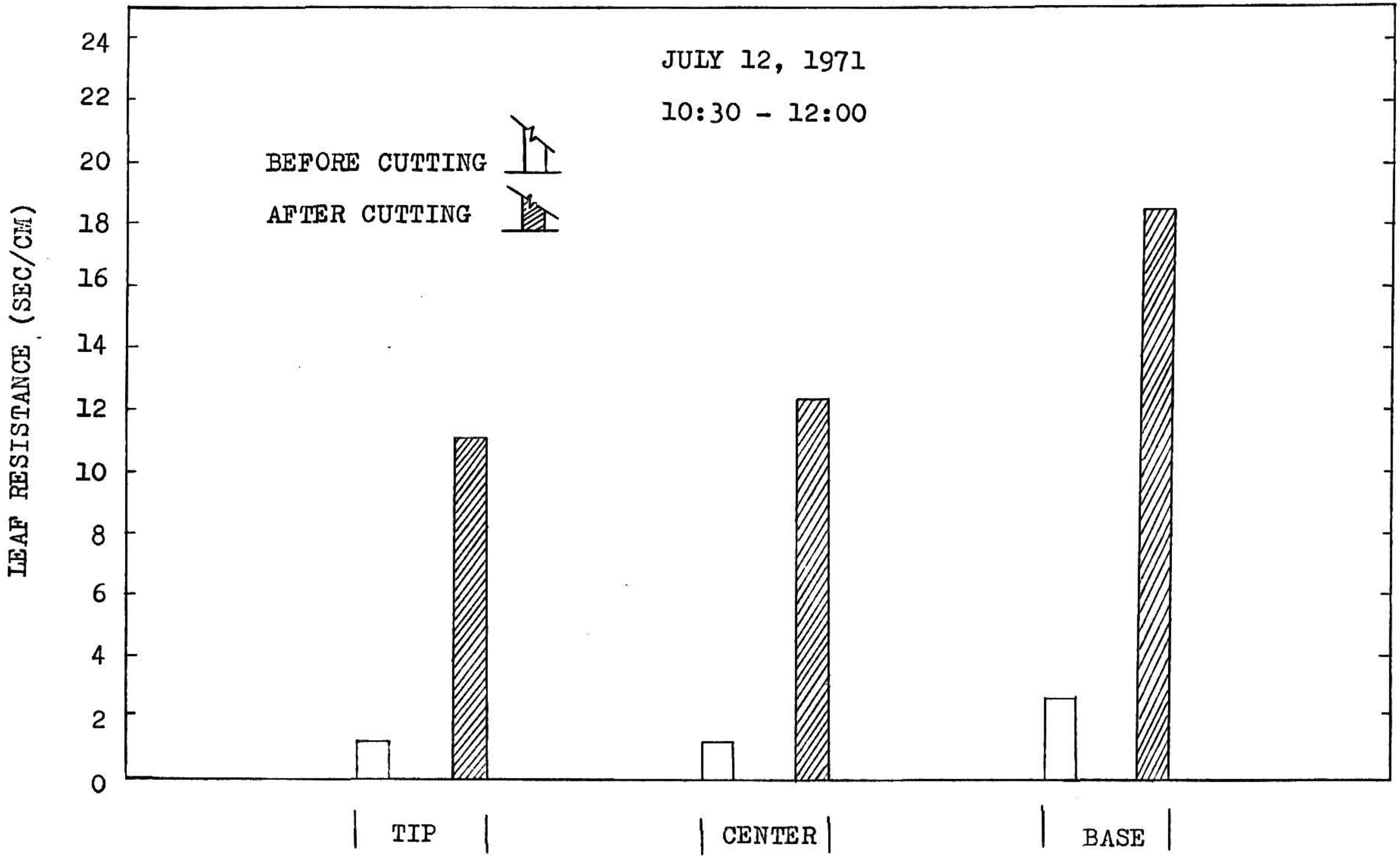

Figure 14. Leaf Resistance Measurements before Cutting Roots and 15 Minutes after Cutting Roots of Sorghum Plant.

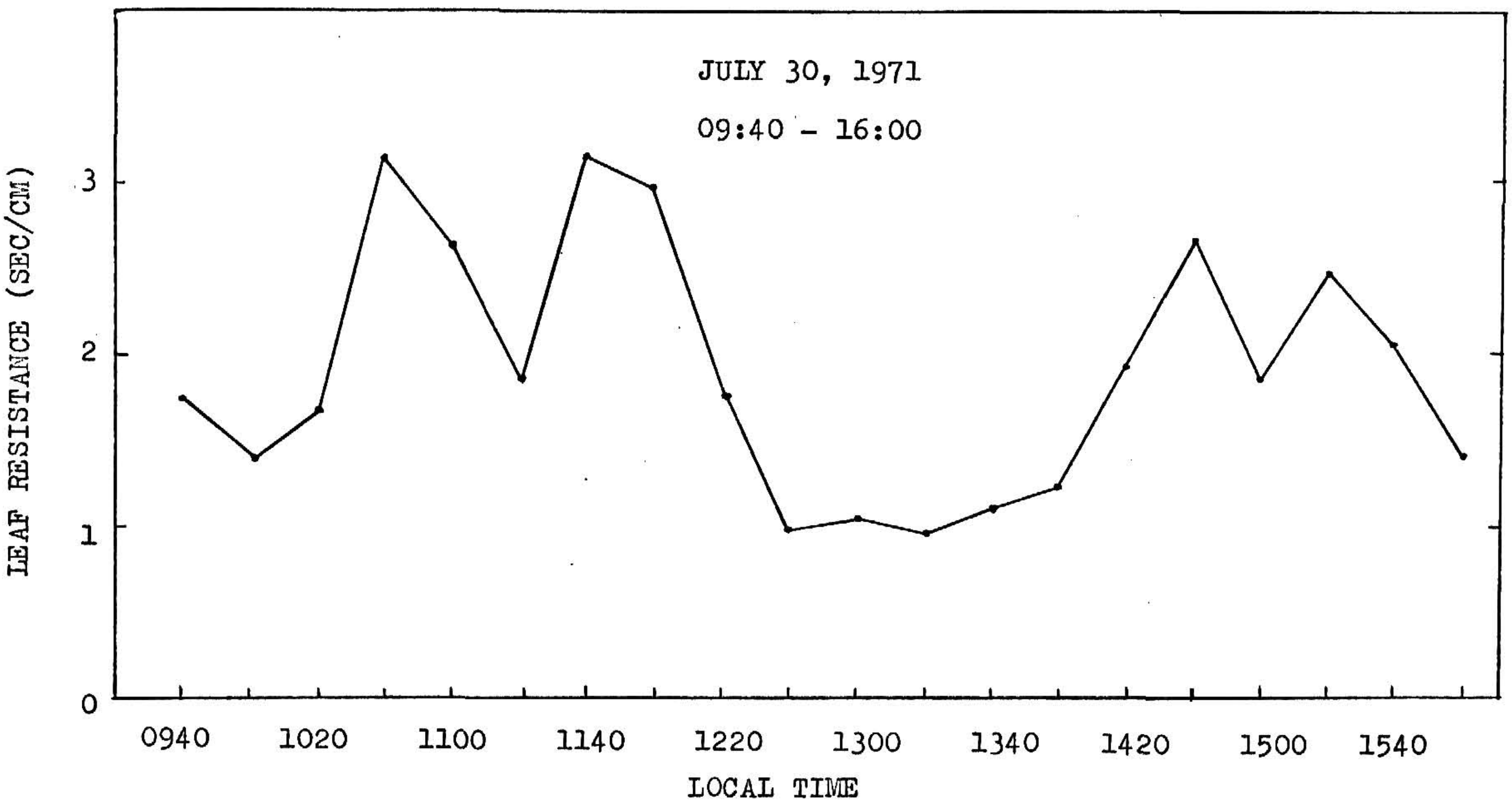

Figure 15. Trends of Leaf Resistance of Sorghum Leaves Measured Every 20 Minutes on the Same Leaf.

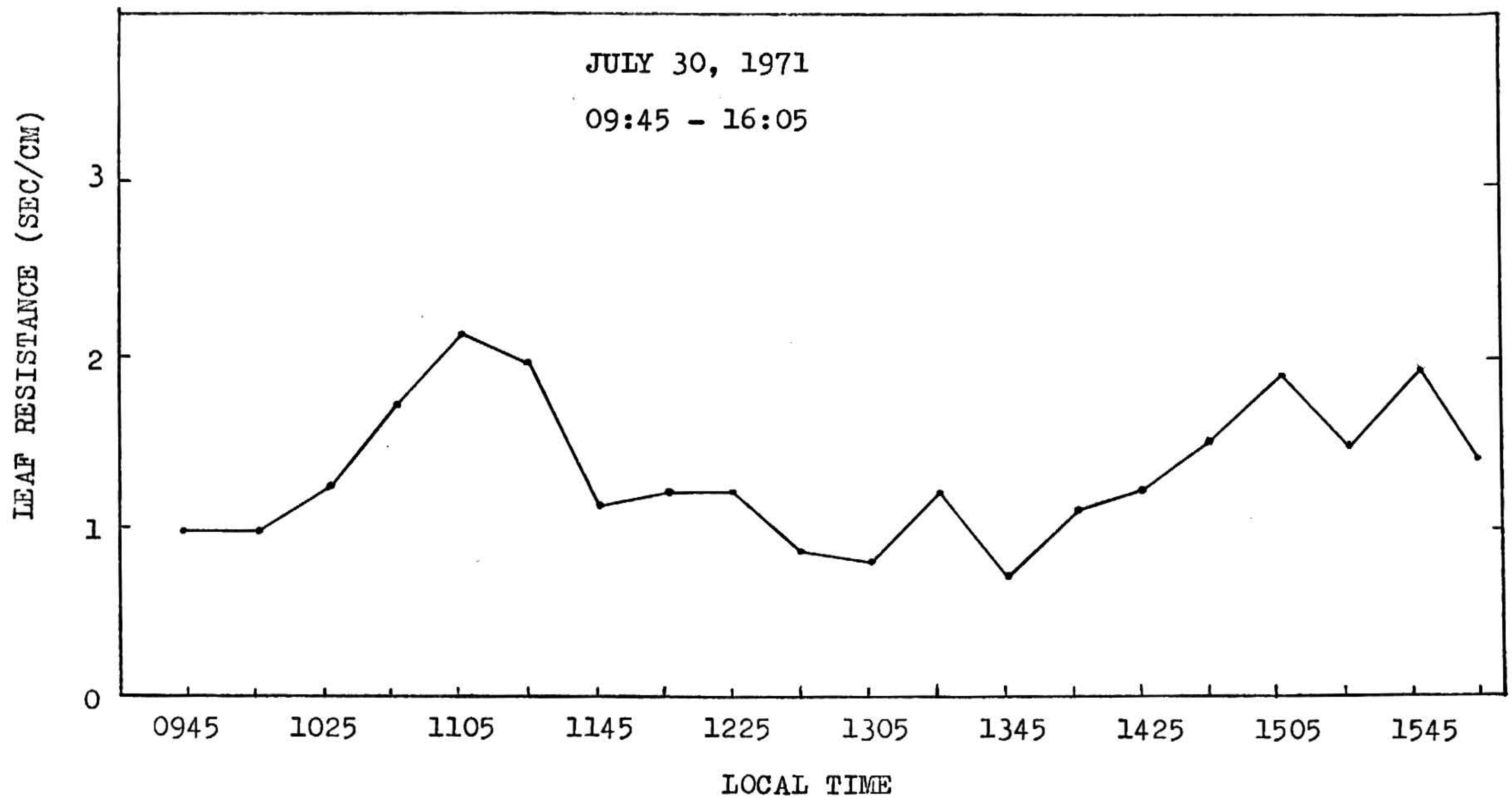

Figure 16. Trends of Leaf Resistance of Sorghum Leaves Measured Every 20 Minutes on the Same Leaf.

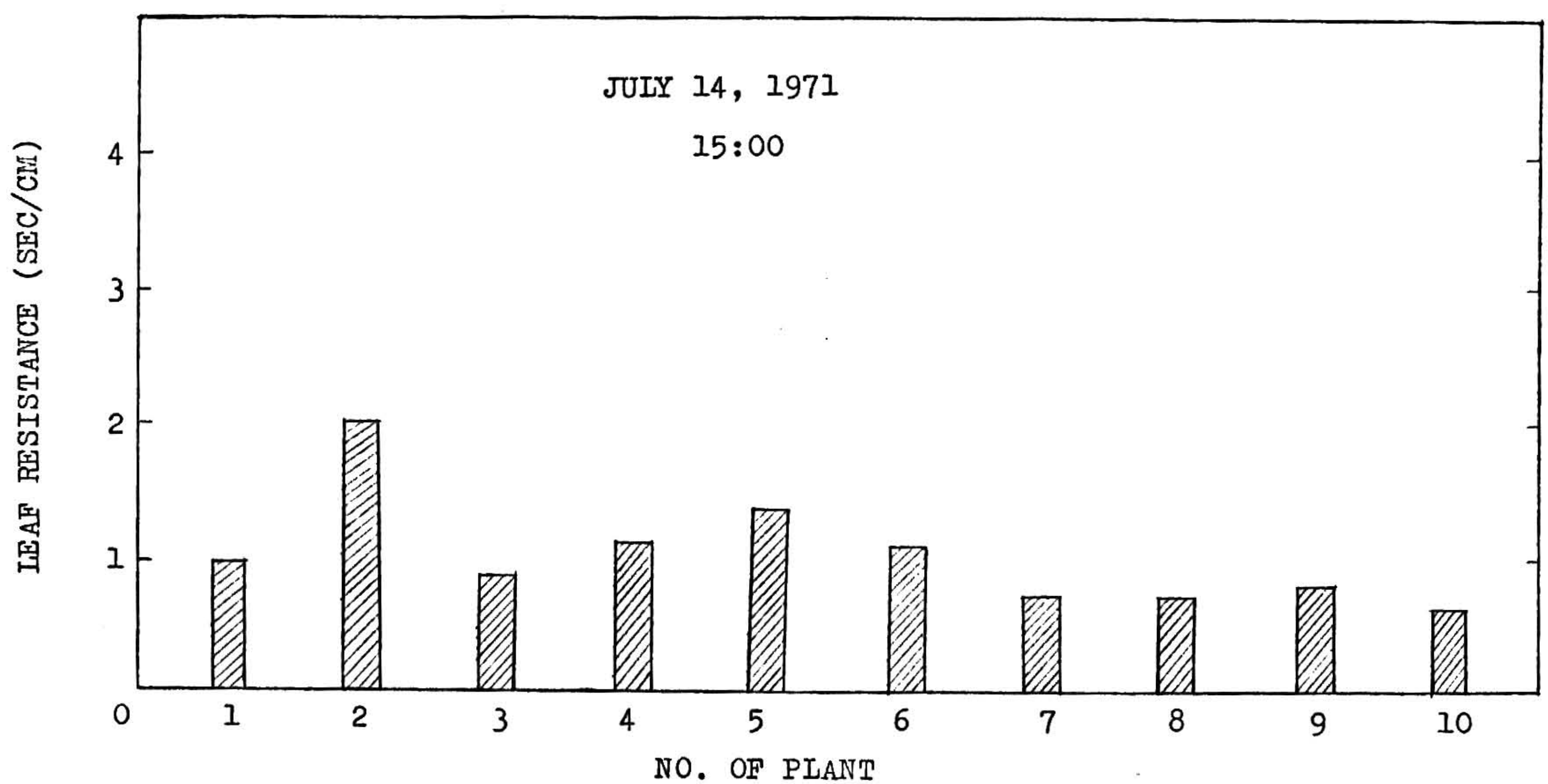

Figure 17. The Variation of Leaf Resistance on Different Sorghum Plants.

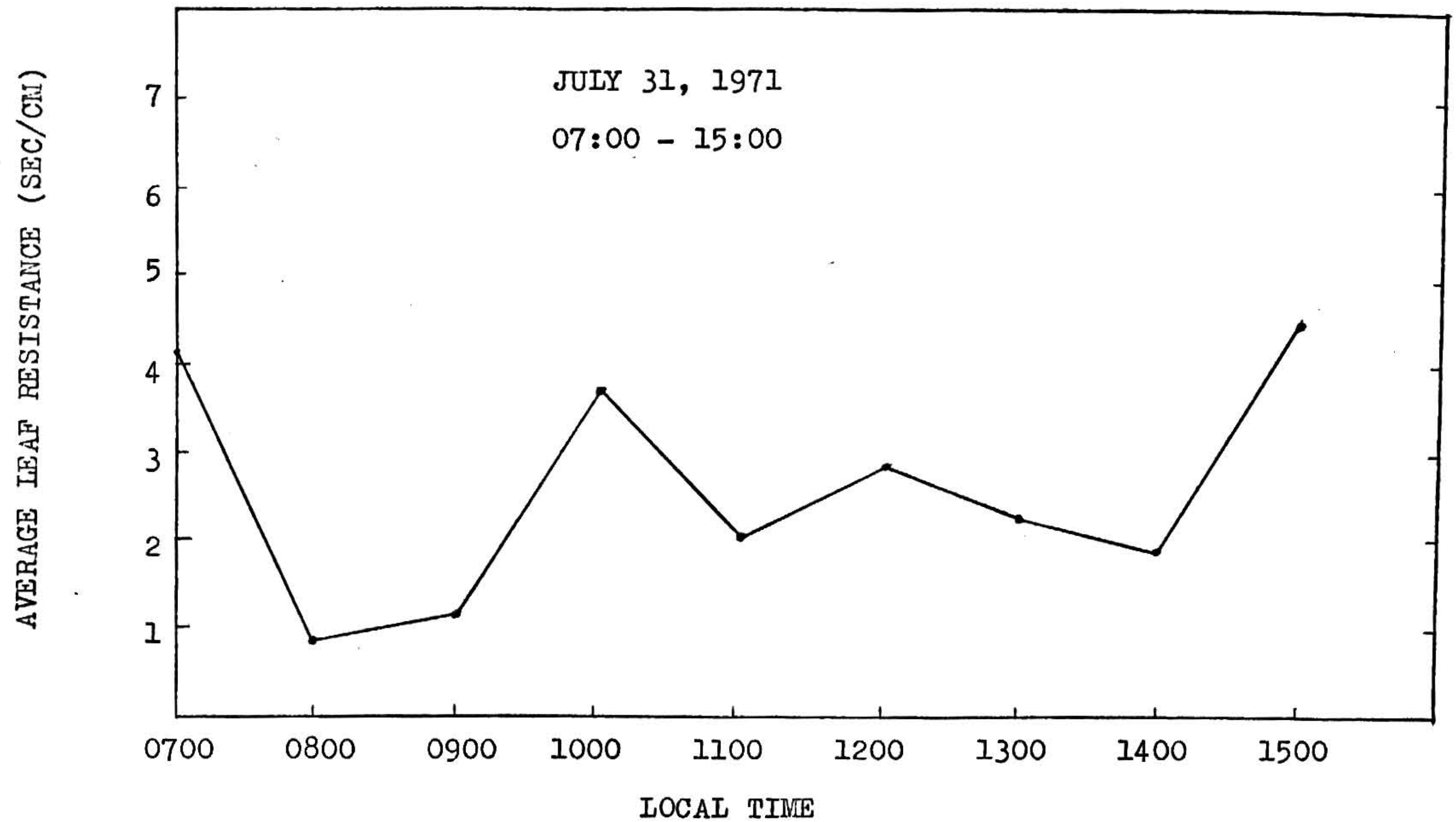

Figure 18. Hourly Trends of Average Leaf Resistance of Sorghum.

compared with soil water tension at 45 cm of depth, because during the growing season most roots were growing at approximately 45 cm of depth (unpublished research from Evapotranspiration Research Laboratory, Kansas State University). As shown in Figure 19 soil water tension and average leaf resistance tended to vary together.

Potted Plant Measurement

As mentioned earlier, the environmental factors can affect leaf resistance. Soil moisture is the major environmental condition in which we are concerned. In field measurements, one cannot find a constant soil moisture at different depths, thus, a comparison between soil moisture and leaf resistance becomes impracticable.

In order to obtain a beter soil moisture value to compare with leaf resistance, leaf resistances were measured on potted plants. It was assumed that the soil moisture had a uniform distribution inside the pot, because: (i) the rooting density of sorghum in August was high, (ii) a plastic cover was used to prevent evaporation from the soil surface, and (iii) there was no seepage from the pot. It was also assumed that changes in weight of the potted plants during the period August 9 to August 25 were small and could be neglected.

The pots were weighed on a balance frequently and soil moisture content was calculated. Leaf resistance of the potted plants was measured in August.

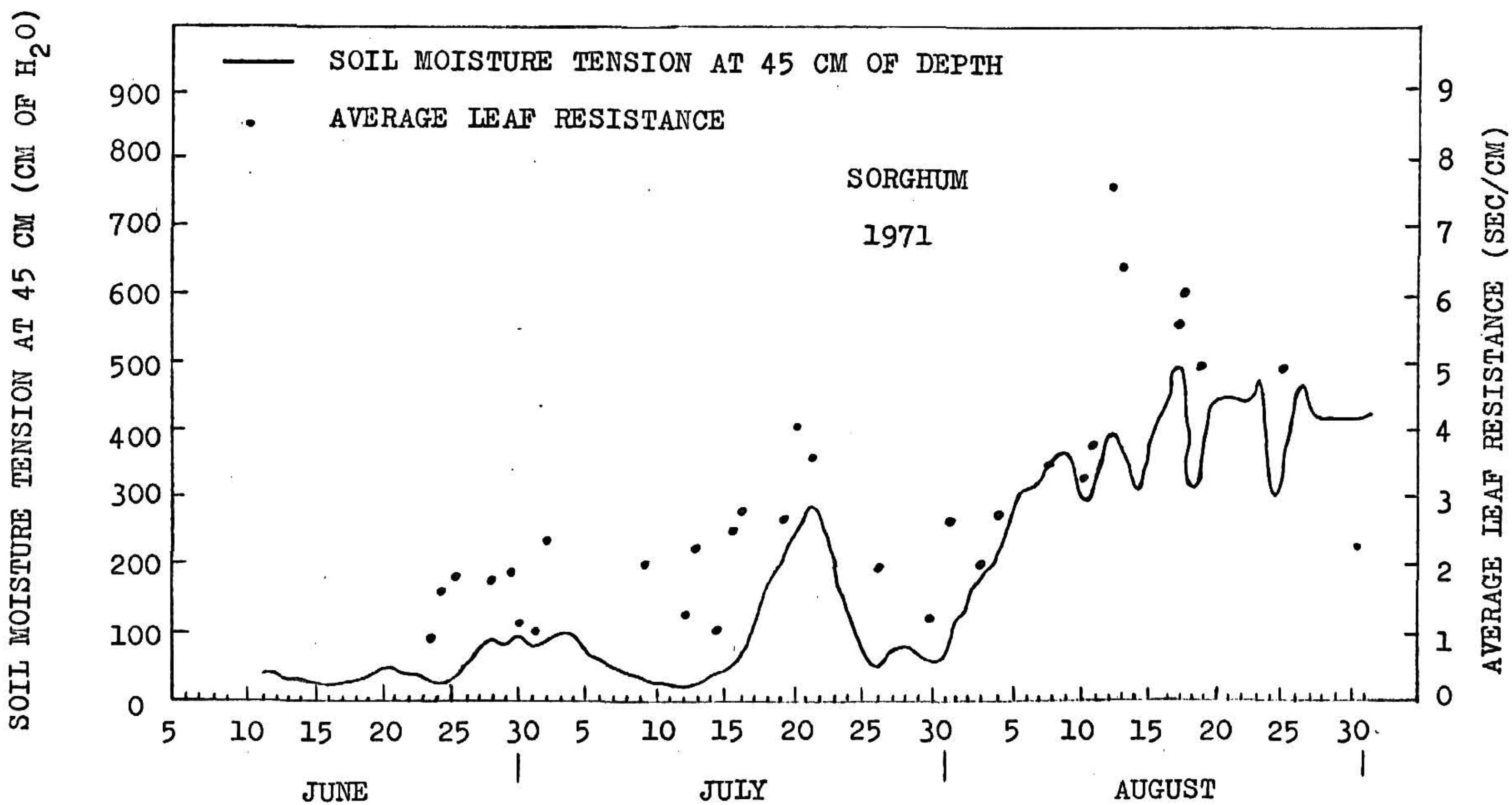

Figure 19. Seasonal Trends of Soil Moisture and Leaf Resistance.

Figure 20 shows the relationship between leaf resistance and soil water potential. Leaf resistance increased slowly as soil water potential increased in the range of low soil water potential. A transition zone occured as soil water potential rose from -5 bars to -6 bars during which range the leaf resistance increased rapdily.

Figure 21 shows the relationship between leaf resistance and percent of available soil water. As soil water becomes limiting, leaf stomata will close and the leaf resistance will increase in an attempt to prevent transpiration from the leaf. Past experience shows that irrigation should begin at 50 percent available soil water level (Soil Conservation Service, 1964); this corresponds to 3 sec/cm resistance.

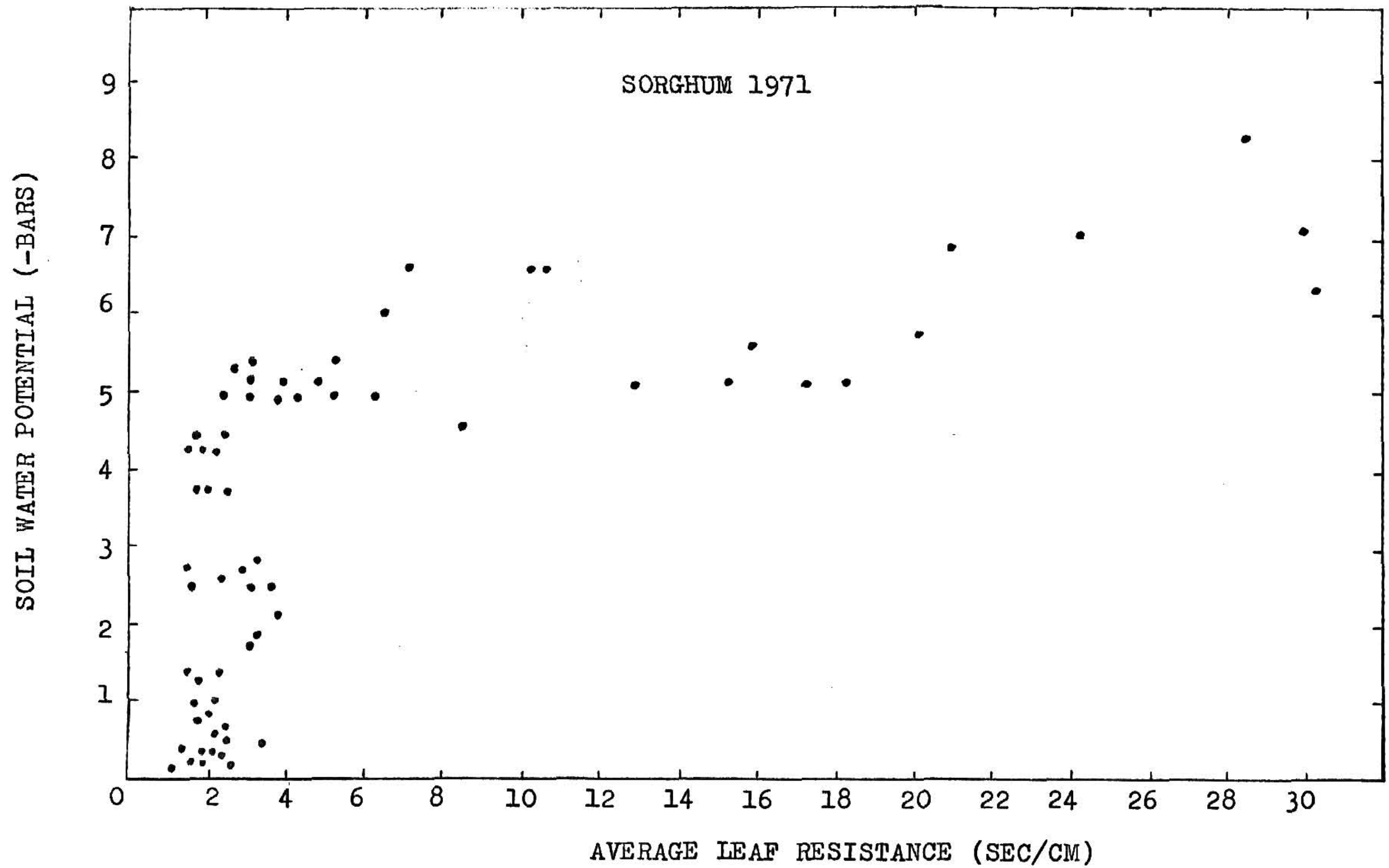

Figure 20. The Relation between Soil Water Potential and Average Leaf Resistance for Sorghum.

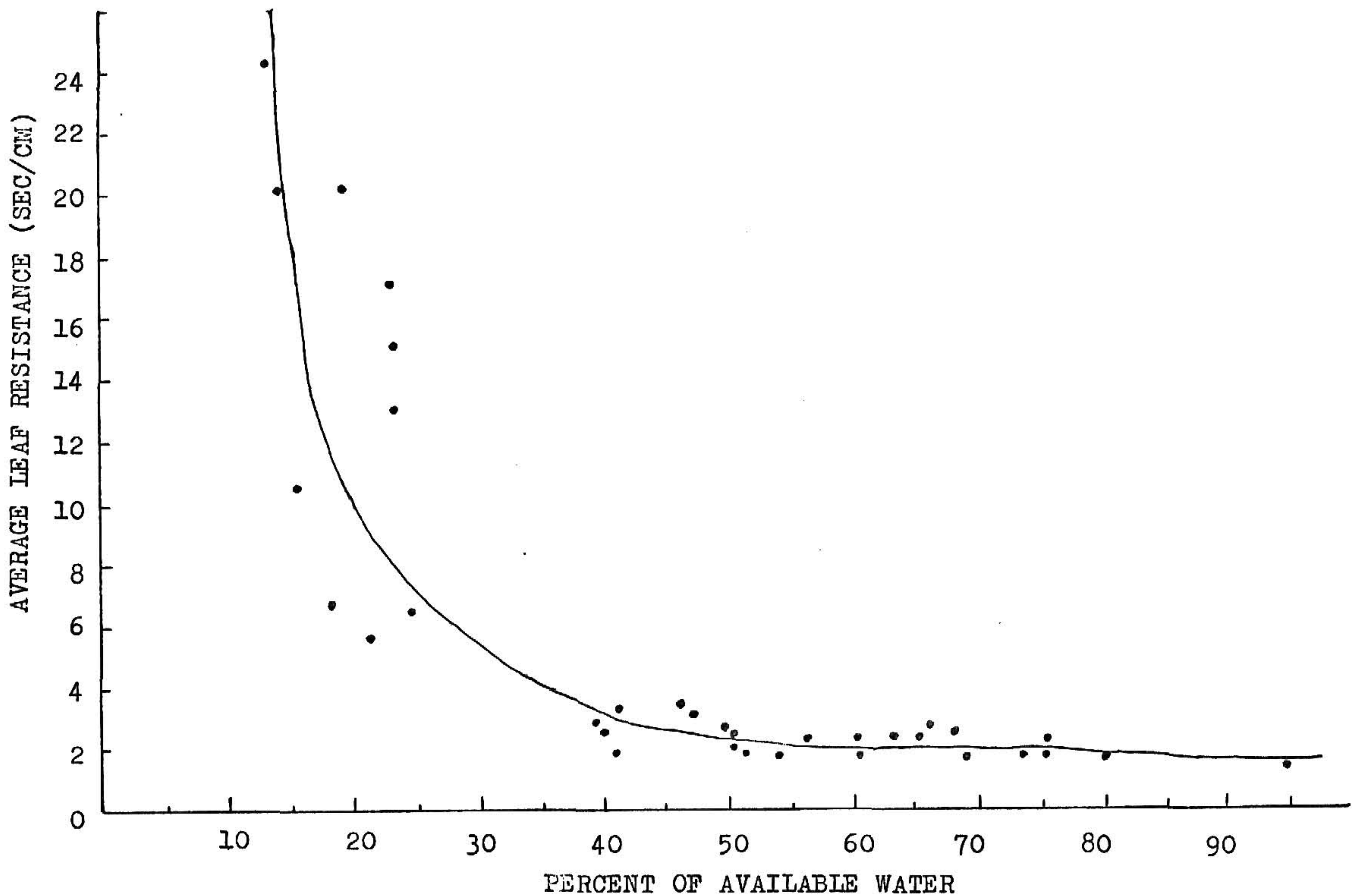

Figure 21. The Relationship between Average Leaf Resistance and Percent of Available Water for Sorghum.

CONCLUSIONS

The following conclusions are based on the analysis and interpretation of the experimental results.

1. Leaf resistance measurement on grain sorghum is recommended during the period 12 pm to 2 pm because it remains uniform during this period.
2. When average leaf resistance reaches 3 sec/cm, irrigation is needed for optimum grain sorghum growth.
3. It is recommended that leaf resistance measurements be made at the center of the leaf.

SUMMARY

A field experiment was conducted with grain sorghum (Sorghum bicolor L. cv. pioneer 846) from May 17 to September 15, 1971, at the Evapotranspiration Research Field, Manhattan, Kansas.

Leaf resistance was measured both on field and potted plants by a leaf diffusion porometer. During the growing season over 5000 individual leaf resistance measurements were made.

The objectives of this study were: (1) to find the characteristics of leaf resistance in sorghum plants, (2) to develop a relationship between soil water potential and leaf resistance, and (3) to evaluate the use of leaf resistance as a criterion for irrigation scheduling.

The leaf resistance was found to be high at the base of the leaf and low at the tip. The resistance at the adaxial leaf surface was always greater than that of the abaxial surface. Leaf resistance during the period 12 pm to 2 pm was found to be uniform.

The leaf resistance readings taken during the growing season were found to correspond closely with the soil water potential at 45 cm of depth. From potted plant measurements, a rapid increase in average leaf resistance occured at a soil water potential of -5 to -6 bars. This corresponds

to 50 percent of available soil water, the level at which irrigation should be initiated to provide adequate moisture for optimum grain sorghum growth.

SUGGESTIONS FOR FURTHER RESEARCH

For further research in leaf resistance measurements for predicting irrigation scheduling, the following areas of research are suggested:

1. Keep the leaf resistance below different levels during the growing season and compare crop yields. An economic analysis of water use and crop yields should be included.
2. Measure the effect of stage of growth on leaf resistance.
3. Develop a modern instrument which can measure the leaf resistance on both the adaxial and the abaxial surfaces at the same time.

ACKNOWLEDGMENTS

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Appendix A A Summary of Various Plant Measurements and Techniques Investigated to Schedule Irrigation for Various Crops. (after Hagan and Laborde, 1964)

Plant measurement and technique	Plant organ or constituent measured	Plants investigated	Literature reference
Visual indicators			
Color	Leaf	Cotton	Bilbro et al. (1960)
		Beans	Robins & Domingo (1956)
		Beans	Howe & Rhoades (1961)
		Cotton	Hoover & Booher (1952)
		Cotton	Bilbro et al. (1960)
		Cotton	Petinov (1961)
		Beans	Burman & Painter (1964)
Plant movements	Leaf angle	Sorghum	Henderson*
		Beans	Henderson*
Growth indices	Fruit, leaf, stem, trunk	Pears	Aldrich & Work (1934)
		Dates	Aldrich et al. (1946)
		Sugarcane	Mallick & Venkantaraman(1957)
		Sugarcane	Oppenheim & Elze (1937)
		Orchard	Verner (1962)
		Orchard	Verner et al. (1962)
		Apples	Magness et al. (1935)
		Oranges	Oppenheim & Elze (1937)
		Apples	Ladin (1959)
		Peaches	Uriu et al. (1964)
		Cotton	Stockton et al. (1955)
		Cotton	Stockton & Doneen (1957)
		Cotton	Stockton et al. (1961)
Water content			
Selected leaves or tissues		Sugarcane	Clements & Kubota (1942)
Absolute water content		Sugarcane	Clements et al. (1952)
		Sugarcane	Tanimoto (1961)
		Sugarcane	Chang et al. (1963)
Relative water content		Cotton	Namken (1965)
Transpiration	Leaf	Apples, plum, pear, quince, cherry, apricot	Gorin (1963)
Stomatal aperture (microscopy) (impressions) (infiltration)	Leaf	Coffee	Alvim and Havis (1954)
		Apple	Furr and Degman (1932)
		Citrus	Oppenheimer & Mendel (1939)
		Citrus	Oppenheimer & Elze (1941)
		Wheat	Maximov & Zernova (1936)
		Cotton	Ophir & Putter (1959)
		Corn	Ophir & Putter (1959)
		Banana	Schmueli (1953)
Osmotic potential (cryoscopic)	Cell sap concentration	Cabbages	Lobov (1951, 1957)
		Tomato	Lobov (1951, 1957)
		Potato	Lobov (1951, 1957)
		Alfalfa	Bauman (1955)†
		Wheat	Bauman (1955)†
		Barley	Bauman (1955)†
		Oats	Bauman (1955)†
		Sugar beets	Bauman (1955)†
		Potatoes	Bauman (1955)†
		Bananas	Schmueli (1953)
		Barley	Krech (1958)
		Barley	Slavik (1959)
		Cotton	Ophir & Putter (1959)
		Cotton	Filippov (1959a)
		Tomato	Belik (1960)
		Cucumber	Belik (1962)
		Apple	Filippov (1961)
		Corn	Rodionov (1962)
		Tomato	Babushkin (1959)
		Potato	Babushkin (1959)
		Sugar beets	Chomsova (1963)
		Cantaloupe	Davis (1963)
Water potential (Equilibria over solutions known osmotic concentrations, psychometric techniques)	Shoot or leaf	Cotton	Shardakov (1957)
		Cotton	Filippov (1951, 1959b)
		Cotton	Neshina (1955)
		Cotton	Krapivina (1963)
		Alfalfa	Kolesnikova (1957)
		Wheat	Petinov (1959)

Appendix B

GUIDE FOR JUDGING HOW MUCH OF THE AVAILABLE MOISTURE HAS BEEN REMOVED FROM THE SOIL

Soil Moisture Deficiency	Feel or Appearance of Soil and Moisture Deficiency in Inches of Water Per Foot of Soil			
	Coarse Texture	Moderately Coarse Texture	Medium Texture	Fine and Very Fine Texture
0% (Field capacity)	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand. 0.0	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand. 0.0	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand. 0.0	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand. 0.0
0–25%	Tends to stick together slightly, sometimes forms a very weak ball under pressure. 0.0 to 0.2	Forms weak ball, breaks easily, will not slick. 0.0 to 0.4	Forms a ball, is very pliable, slicks readily if relatively high in clay. 0.0 to 0.5	Easily ribbons out between fingers, has slick feeling. 0.0 to 0.6
25–50%	Appears to be dry, will not form a ball with pressure. 0.2 to 0.5	Tends to ball under pressure but seldom holds together. 0.4 to 0.8	Forms a ball somewhat plastic, will sometimes slick slightly with pressure. 0.5 to 1.0	Forms a ball, ribbons out between thumb and forefinger. 0.6 to 1.2
50–75%	Appears to be dry, will not form a ball with pressure.[1] 0.5 to 0.8	Appears to be dry, will not form a ball.[1] 0.8 to 1.2	Somewhat crumbly but holds together from pressure. 1.0 to 1.5	Somewhat pliable, will ball under pressure.[1] 1.2 to 1.9
75–100% (100% is permanent wilting)	Dry, loose, single-grained, flows through fingers. 0.8 to 1.0	Dry, loose, flows through fingers. 1.2 to 1.5	Powdery, dry, sometimes slightly crusted but easily broken down into powdery condition. 1.5 to 2.0	Hard, baked, cracked, sometimes has loose crumbs on surface. 1.9 to 2.5

[1] Ball is formed by squeezing a handful of soil very firmly.

Appendix C Plant Height and Number of Leaves of Sorghum Plant at Evapotranspiration Research Field, 1971.

Date	Number of leaves	Plant height (cm)
6/30	9	56
7/6	10	74
7/12	12	104
7/16	13	107
7/26	12	112
8/5	12	137
8/12	11	140
8/20	11	143

USE OF LEAF RESISTANCE FOR PREDICTING IRRIGATION SCHEDULING

by

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B.S., National Taiwan University, 1967

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

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Manhattan, Kansas

1972

ABSTRACT

Leaf resistance of grain sorghum (Sorghum biclor L. cv. Pioneer 846) was measured both in the field and on potted plants by a leaf diffusion porometer. During the growing season over 5000 individual leaf resistance measurements were made.

In field measurements, the leaf resistance was found to be high at the base of the leaf and low at the tip. The leaf resistance at the adaxial leaf surface was always greater than that of the abaxial. A temporal variation of leaf resistance was measured every 20 minutes on the same leaf. The leaf resistance was usually low during midday and was uniform. However, the leaf resistance in the early morning and late afternoon changed rapidly.

Field soil water potential was determined daily at different depths from tensiometer readings. The leaf resistance data, taken during the growing season, were found to follow closely with the soil water potential at 45 cm of depth.

In potted plant measurements, soil water potential was obtained from the average soil moisture in the pot and a soil water release curve determined in the laboratory. Leaf resistance measurements were made on the top four leaves of each plant. A relationship between average leaf resistance and

soil water potential was found. The average leaf resistance was not significantly affected at a soil water potential below -5 bars. However, with a further decrease in soil water potential the resistance increased sharply.

Average leaf resistance of 3 sec/cm is suggested as a criterion for scheduling irrigation of grain sorghum.