PLANT WATER RELATIONS OF SIX CULTIVARS OF WINTER WHEAT GROWN UNDER SOIL MOISTURE STRESS

By

GIDEON BOI-TONO ADJEI

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Texas A & I University

Kingsville, Texas

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MOISTURE STRESS

Thesis Approved:

M. B. Kirkham
Thesis Adviser

Lavoy I. Croy

James D Ownby

Norman N Durham
Dean of the Graduate College

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CHAPTER I

INTRODUCTION

It is important to identify cultivars of crop species which grow under drought conditions. Papers have been published which report drought resistance of different cultivars of corn and sorghum. Little or no work, however, has been reported on drought resistance of wheat cultivars. Yet wheat is the major crop in the world and much of it is grown in semi-arid regions such as the southern Great Plains.

A close look at yield data in the Great Plains clearly shows a reduction in yield from North to South in this region. The prevailing climatic conditions account for a major part of this yield reduction. Water is the most important limiting factor in wheat production in the southern Great Plains according to Smith (1976). This has been confirmed by other researchers (Sandhu and Laude 1957; Hurd 1974).

Rainfall tends to be erratic, and high intensity rains often occur. Because of rainfall patterns, soil types, and temperature regimes in the region, much water is lost through run-off and evaporation. Drought stress occurs in some part of this region nearly every year (Smith 1976). Stress can occur during the fall, winter, or spring, catching the wheat crop at various stages of growth. Kozlowski (1968) also reported that shortage of water is more limiting to crop production in the world than any other single factor.

Because of the lack of research concerning the response of wheat cultivars to drought, the present study was undertaken. The objective of this study was to determine which cultivars may be better adapted to dryland conditions than other cultivars based on measurements of the internal water status of the plant at different soil water potentials. The cultivars used in this study were chosen because they exhibit encouraging qualities such as good to fair amounts of straw strength, bread-making quality and disease resistance (The Wheat Digest - Hard Red Winter Varieties, 1971). The results should be valuable to plant breeders by serving to guide breeding programs in the development of cultivars which yield well when water is limited.

CHAPTER II

REVIEW OF LITERATURE

Published work on the various aspects of plant response to induced moisture stress is voluminous. However, the following references are those that seem to be pertinent to this particular study because they deal primarily with wheat.

Effects of Soil Moisture on Wheat Germination and Growth

Winter wheat frequently is sown in dry soil in the southern Great Plains, and under such conditions germination is delayed and irregular emergence may occur until rains come according to Hubbard (1941). Thus, the importance of soil moisture content in relation to wheat germination and emergence cannot be overemphasized. For example, Hanks and Thorp (1956) stated that seedling emergence of wheat, measured in three soils, was approximately the same when the soil moisture content was maintained between field capacity and permanent wilting point, provided other factors were optimum for seedling emergence. Hutchins (1926) reported that wheat germinates well when well supplied with water and with temperature near 22^{o}C, in a soil with an oxygen-supplying power of 3.0 milligrams or more per square meter per hour.

Fuller (1960) worked with three cultivars of wheat including "Concho" and "Triumph", and reported that a lower percent emergence was obtained with higher seeding rates as opposed to lower rate. Normally moisture as a limiting factor could be considered to explain these results according to Chang (1963). A more comprehensive and thorough treatment of various aspects of wheat germination has been reported by many workers (Everardo Aceves-N, et al. 1975a, 1975b; Kaack and Kristensen 1967).

However, Finnell (1929) showed that the initial moisture conditions in the soil are not of paramount importance to wheat except for establishment of a stand and wintering without drought damage. During the drought of 1927 in Oklahoma, it was noted that plots beginning with high initial moisture held a month or more longer than those starting with moisture shortage, but were unable to reach maturity on a four inch seasonal rainfall.

Soil Moisture Stress and Roots of Wheat

Soil moisture determinations are important in studies related to a plant's physiological response to moisture stress because according to Todd et al. (1962) they give indications of moisture tension within the plant, although under conditions in which water loss from transpiration exceeds water uptake by the roots, the plant may be under much more moisture stress than would be indicated by the soil moisture tension. Lehane and Staple (1962), working with wheat, observed that crops grown on heavy clay soils withstood drought better than those grown on lighter soils and attributed that to the greater water holding capacity of clays. Presumably, according to them, the wheat plant was capable of removing the stored moisture under a greater average stress or the results were due to reduced growth and transpiration in early stages of the crop, so that more moisture was left for heading and filling.

The effect of soil moisture stress on roots must be considered because after germination the seedling begins to depend on the roots for water and nutrient uptake from the soil.

Hurd (1974) worked with several cultivars of wheat and stressed that an extensive root system was associated with drought resistance in wheat and that selection for high yield under moisture stress conditions did select for larger root systems. He found that early rapid growth built up a reserve that would carry the plant through severe drought and contributed to yield even when that plant was not particularly resistant to desiccation.

Disagreements among researchers illustrate the limitation of knowledge of drought resistance in plants. One example of disagreement is the difference between Hurd (1974), who reported results indicating an association between extensive rooting and drought resistance, and Ray et al. (1974) who suggested that a small-rooted plant may use limited water more efficiently. Passiouri (1972) feels that plants should be bred for fewer roots so they will take up less water thereby conserving soil moisture.

In a personal communication with D. W. L. Reed, Hurd et al. (1973) reported that even in very dry years there was usually available moisture at depths from 60-120 cm in cropped land at harvest time. Hence, cultivars that had more extensive root systems below 60 cm, and expecially those that sent substantial roots below the 120 cm level, would have greater ability to avoid severe moisture stress.

The importance of the root system for the maintenance of water balance in the plant and as a character of drought hardy cultivars has been emphasized by several other workers (Weaver 1926; Misra 1956).

Some researchers (Briggle and Vogel 1968) have suggested that semi-dwarfs have fewer roots than normal-height wheat. Species and cultivar differences with respect to drought hardiness have been found in laboratory studies (Levitt 1956). Most researchers working with cereal crops have noted that the greater the depth of adequate moisture in the soil, the greater the root penetration and that drying of the upper soil layer increased growth of roots in deeper layers (Kmoch et al. 1957; Miller 1916).

Root habit of wheat varied with cultivar, according to Pinthus and Eshel (1962). Salim et al. (1965) studied root development of oats, wheat and barley, and inferred that root growth was always greatly reduced after the emergence of the first leaf through the soil surface. They also observed that shoot growth continued for some time after root growth had stopped in all cereals. Their study indicated that "Ponca" wheat continued shoot growth for a much longer time than "Cheyenne" wheat and produced a statistically significant greater shoot growth. They thought that excessive top growth of "Ponca" over root growth, and the concomitant increased water loss over uptake, explained its poor field performance under drought.

Their work also showed that there was little root penetration of the cereals into soil having a moisture content below the permanent wilting point. Drier soil treatments produced more branching in the upper soil layer in both oats and barley. Branching mostly occurred after the larger roots had penetrated to the bottom soil layers. Their results were in general agreement with those obtained by Weaver (1926). He found that the penetration of cereal roots was dependent on the depth to which the soil contains moisture above the permanent wilting point.

Movement of Water Within the Root Zone

Gardner and Ehlig (1962) showed that water movement within the root zone complicated the water uptake process. They divided the root zone roughly into two parts: an upper zone containing a high concentration of roots which tended to be depleted of water more or less uniformly with depth, and a lower zone containing fewer roots which tended to lose water at a relatively slow rate until much of the water had been removed from the upper region. Water was removed from the lower zone by two paths: uptake by the roots in the lower zone and upward movement of water into the upper zone, where it was subsequently taken up. Initially, much of the water loss from the lower region was due to upward movement. Gardner and Ehlig (1963) gave the approximate rate of upward movement in a homogeneous soil profile by the equation:

$$Q = \pi^2 DW/4L^2$$

where W was the amount of available water in the lower zone, L was the depth of this zone, and D was the soil-water diffusivity.

The rate of upward movement was then proportional to the product of the diffusivity and the water content. As the soil water content was reduced, the diffusivity decreased. That tended to cause an increasing proportion of the water to move upward through the roots relative to that moving through the soil. In effect, the root short-circuited the path of water movement through the soil. That compensated for the decrease in the soil-diffusivity. If the soil and the roots were considered together as a sort of composite porous medium, the apparent diffusivity of that combination tended to remain more nearly constant than the diffusivity of the soil alone. They concluded that the upward movement of water, which will determine the transpiration rate, should be proportional to the amount of available water. That has been observed by Knoerr (1961), Slatyer (1956), and Bierhuizen (1958).

Transpiration Patterns of Wheat

Transpiration patterns of wheat and other cereal crops have been reported by Shimshi and Ephrat (1975). They found that wheat cultivars do vary widely in their stomatal aperture under conditions of adequate moisture supply, and they indicated that more than one gene constituted the genetic background of the stomatal behavior in common wheat (*Triticum aestivum* L. em. Thell.) Ehlig and Gardner (1964) working with cotton, pepper and sunflower plants reported that the diffusion pressure deficit (DPD), (the DPD of water in a solution or biological system has been defined by Meyer (1945) as the amount by which its diffusion pressure is less than that of water at the same temperature and under atmospheric pressure), increased as the soil suction increased, but that there was little reduction in transpiration rate until the DPD reached an average value from 5 to 12 bars, depending upon the species. Thereafter, the transpiration rate decreased as the

DPD increased. The reduction in transpiration rate was greatest just after wilting, and all their curves tended to level off somewhat as the DPD continued to increase, due to the increasing soil suction. The transpiration rate tended to approach a constant value of about 20% of its inital value when the DPD reached about 20 bars.

Stomatal Behavior

Glover (1959) thought it was imperative to be aware of the previous growth conditions, at least for sorghum, in evaluation of stomatal response to water stress. Pallas et al. (1967) reported that the stomata of cotton close simultaneously on both surfaces, but Turner (1970) found the stomata on the lower surfaces of leaves of *Nicotiana tabacum* L. and *Sorghum bicolor* L. (Moench) to be more sensitive to light changes than the upper surface. According to Domes and Bertsch (1969), stomata on the lower surface of corn opened more quickly than those on the upper surface. Henzell et al. (1975) have also observed that the stomata on the adaxial surface were more sensitive to reduction in soil-water potential than those on the abaxial surface. Apparently, stomata react differently on leaves of different species, and also on leaves grown under different conditions. However, Sanchez-Diaz and Kramer (1971) concluded that it seemed that the resistance of the lower surface was the more reliable indicator in both corn and sorghum because it was less sensitive to varying environmental factors and controlled more of the water loss than the upper surface. A little bit of work has been done in this area for wheat by Rawson, Gifford and Bremner (1976). However, more work needs to be done.

Water Potential of Wheat

Although stomata are considered to be the major resistance regulating water loss from plants (Slatyer, 1967), Martin and Dougherty (1975) indicated that this regulatory mechanism does not prevent the development of very low water potentials in wheat. Soil moisture levels between 8 and 30% caused no significant changes in relative turgidity of wheat according to Todd et al. (1962). However, once the soil moisture dropped below 6% there was a rapid drop in moisture content in leaves with relatively small decreases in soil moisture content. They thought that the percent relative turgidity gave some indication as to whether or not the plant would survive upon rewatering. If the value did not fall below 25%, the plants would almost always recover. When the values were below 25%, the plant often did not recover after rewatering. Water retention was greatest in those known to be most drought hardy and least in the non-hardy cultivars. Sandhu and Laude (1957), and Boyles et al. (1937) have also suggested that a correlation exists between drought hardiness and plant water retention in both winter and spring wheat cultivars.

Simmelsgaard (1976) concluded that leaves grown under conditions of moderate water stress adapt themselves, so that the stomata remain open and the transpiration unchanged over a wide range of root water potential.

The literature review showed that apparently little or no information exists on the rate of germination, transpiration, stomatal resistance, and leaf water potential of wheat cultivars, commonly grown in the Southern Great Plains, and subjected to drought.

Consequently, these factors were measured in six different wheat cultivars adapted for growth in this region of the United States.

CHAPTER III

MATERIALS AND METHODS

Introduction

This study was conducted in a growth chamber at the Controlled Environmental Research Laboratory at Oklahoma State University. A standard germination test was performed separately in a growth chamber in Agriculture Hall, Oklahoma State University, after the Rules for Testing Seed (1965).

Certified seeds of six Hard Red Winter Wheat (*Triticum aestivum* L. em. Thell.) were obtained from the Texas Agricultural Extension Service (The Texas A&M University system) located at Amarillo, Texas. These cultivars were "Scout 66", "Concho", "Centurk", "Tascosa", "Osage", and "Improved Triumph". The seeds were stored in a refrigerator at about 10^{o}C for two weeks before the preliminary experiment commenced.

Plant Culture

Twenty-four seeds were selected from each cultivar based on equivalent size as judged by the eye, and were grown in 24 aluminum petri-dishes, six seeds per dish. The petri-dishes were six cm in diameter and one and a half cm deep and each contained 60 g of white silica sand. Twenty ml of tap water was added to each petri-dish on the first and third day after planting. Sprouting was observed on the fourth day after planting. Subsequently, the petri-dishes were transferred on a tray into a refrigerator at the Controlled Environmental Research Laboratory and vernalized for fifty days by a slightly modified method of Ahrens (1956), in that vernalization was done under continuous light instead of 18 hours. Inside temperature of the refrigerator was set at $6^{o}C \pm 1^{o}C$. During vernalization twenty ml of half strength Hoagland's nutrient solution (water potential about -0.4 bars) was added to each petri-dish weekly. Concentration of the major elements was based on Hoagland's solution (1933), and micro nutrients were provided according to the recommendation of Johnson et al. (1957). Iron was added as Fe EDTA.

After vernalization, the seedlings were transferred to a Sherer Controlled Environmental Growth Chamber Model CEL 37-14 and allowed to acclimatize to the new environment for one week. The growth chamber was maintained at $25^{o}C$ day and $22^{o}C$ night, with a 12 hour photoperiod from 0700 to 1900. Fluorescent and incandescent bulbs in the chamber furnished light at an intensity of 635 microeinsteins M^{-2} Sec^{-1}, as measured by Lambda Instrument L1-185 Quantum, Radiometer, Photometer, in the region of exposed leaves. The relative humidity inside the growth chamber varied between 42 and 68%. No attempt was made to control the relative humidity. Twenty-two kilograms of Kirkland silty loam soil (Oklahoma Agricultural Experiment Station Bull. Series P-315, 1959), classified as a Paleustoll by Gray and Roozitalab (1976), were collected from the upper 18-20 cm of topsoil. This soil was autoclaved in a Scanlan - Morris sterilizer #A420 at $100^{o}C$ and 3.18 kg of pressure for two and one half hours at the Controlled Environmental Research Laboratory. After sterilization the soil was passed through a U.S. standard size #10 mesh-sieve with 2000 micron openings and thoroughly mixed by hand. Each of the 26 10-cm plastic pots used in the experiment was lined with 0.5 cm (10 g) of vermiculite and then another layer of one cm (20 g) of white silica sand was added. After this, 540 g of the sterilized soil was added to each of the pots. Subsequently, the pots were inverted (see Figure 1).

Seedling selection was based on stage of growth, health, and equivalent size. Stage of growth was based on the proposal of Feekes (1941).

Seedlings were transplanted after one week in the growth chamber, into the pots through four 1-cm equally spaced holes at the top of each pot. Therefore, there were four seedlings per pot (see Figure 1). Each pot received 180 ml of half strength Hoagland's nutrient solution and seedlings were allowed to grow for two weeks before data collection began. The plants were 71 days old when measurements began on January 23, 1978, and continued through February 10, 1978.

Treatments

A split-plot arrangement in a randomized design block was used for this study (see Figure 2). There were two replications and two treatments. Half the plants were watered daily with 80 ml of tap water (Daily Watered Plants), and half with 120 ml once a week (Weekly Watered Plants). Saucers were placed under each pot into which water was added and allowed to rise into the inverted pots by capillarity. All pots in the growth chamber were rotated each day in a clockwise direction.

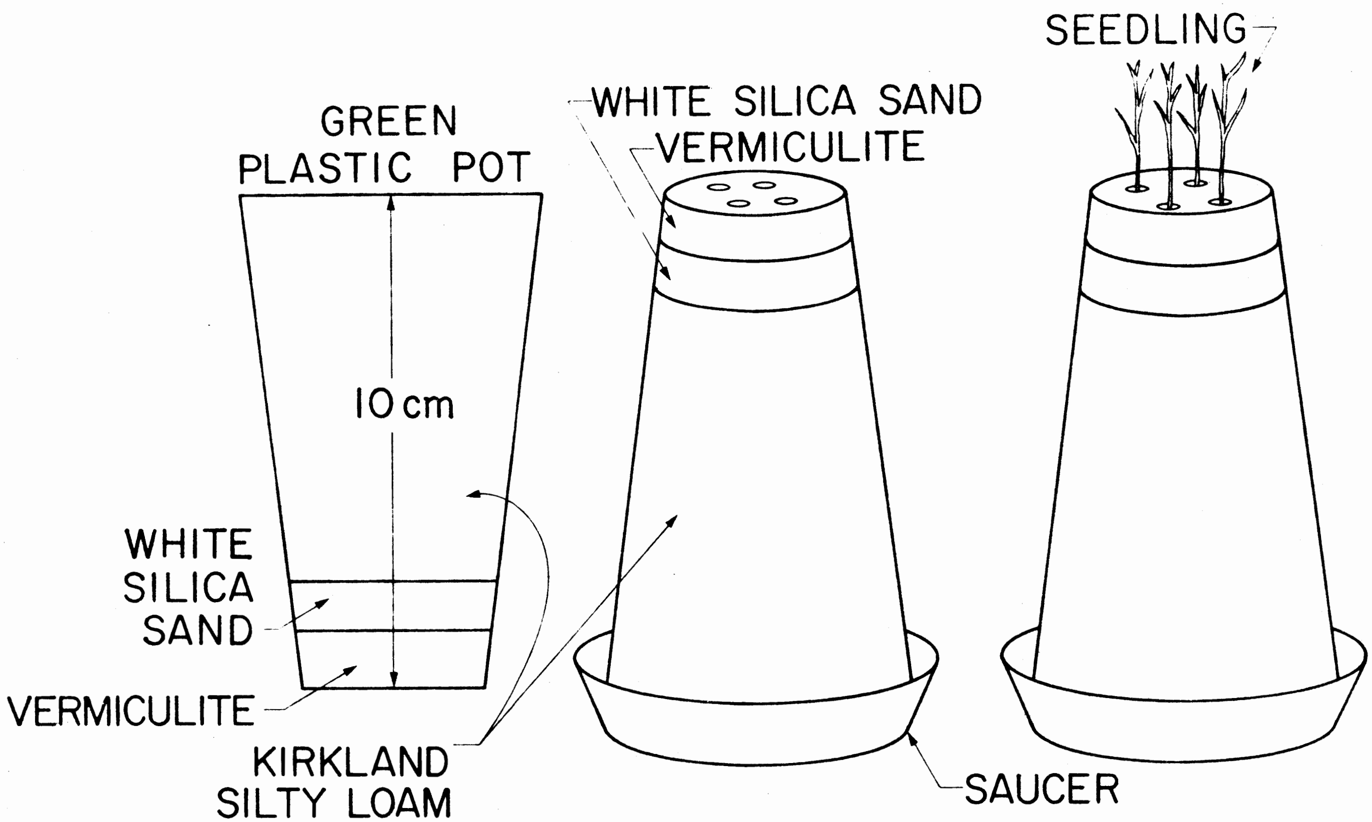


Figure 1. A Method of Reducing Surface Evaporation

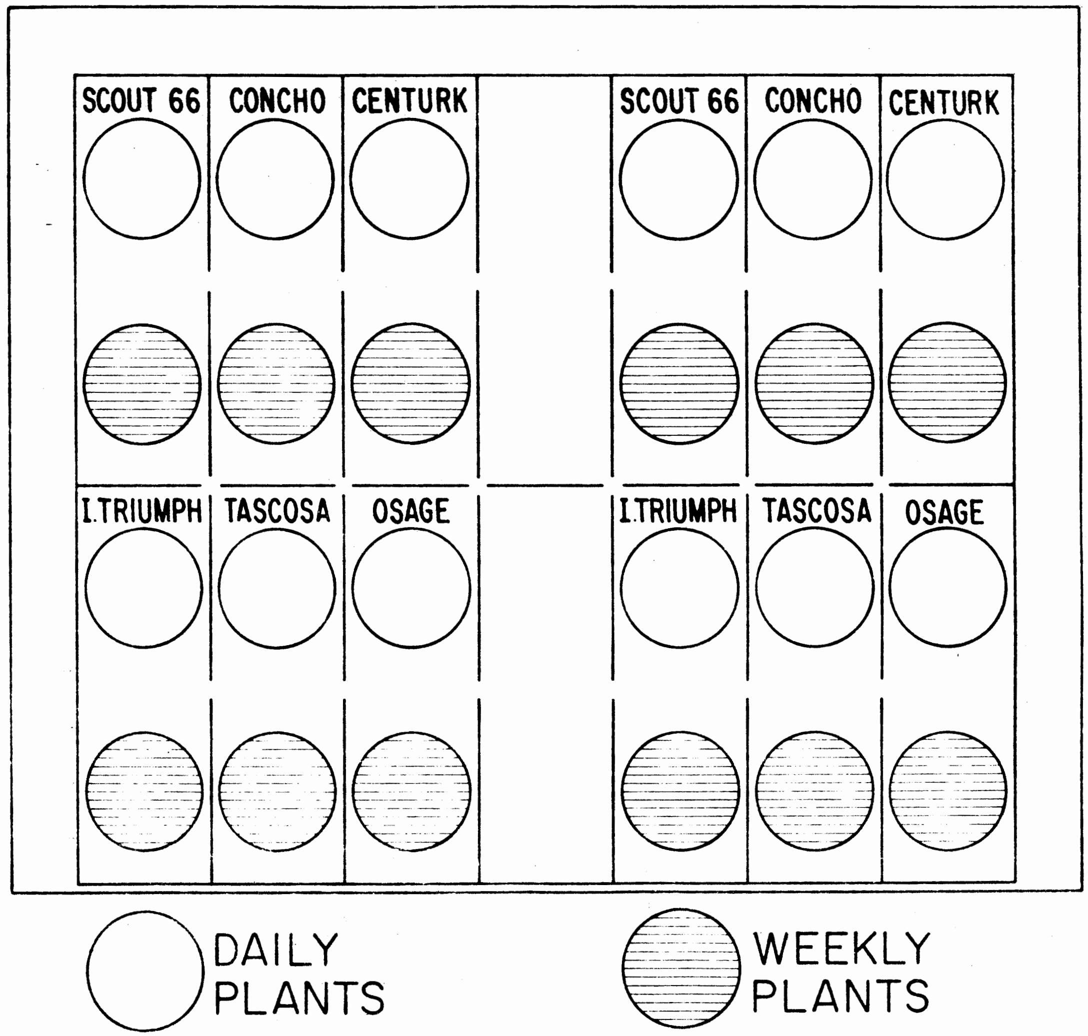


Figure 2. Experimental Design

Measurements and Instrumentation

Only exposed second leaves from the bottom of the plants were sampled.

Leaf area measurements were taken every four days with L1-COR Area Meter, Model L1-3000 (Lambda Inst. Corp., Lincoln, Nebraska 68504, USA). Leaf water potential readings were taken every three days "in situ" with a Wescor Sensor L-51A which was connected to a Wescor HR-33T Dew Point Microvoltmeter (Wescor, Inc., Logan, Utah, USA).

Transpiration rate was determined daily on a per-pot basis by weighing each pot before watering, using a Sartorius 2351 scale with a maximum load of 7000 g. Accuracy of the scale was $\pm$ 1 g.

Stomatal resistance readings were taken daily from the lower surface of the leaves by a diffusion porometer (Lambda Instruments Corporation, Lincoln, Nebraska, USA) of the type described by Kanemasu et al. (1969). The porometer registers the vapor diffusion from the leaf surface. Thus, the resistance measured is a combination of the stomatal and cuticular resistances.

Soil water potentials were taken daily with soil psychrometers connected to a microvoltmeter (Wescor Inc, Logan, Utah, USA, model MJ55) after the method of Keisling (1972). The psychrometer output was 0.47 microvolt/bar $\pm$ 5% at 25^{o}C.

Plant height measurements were taken every three days.

Root mass in the soil was determined by the method of Al-Khafaf et al. (1977).

CHAPTER IV

RESULTS AND DISCUSSION

Table I shows results of several agronomic characters recorded for the cultivars used in this study. Results of the germination test are averages of four replicates, with 50 seeds of each cultivar per replicate. Therefore, there were 200 seeds per cultivar. Centurk had the highest germination rate (100%) on the first day that counts were taken on February 7. It is the belief of the present writer that this high germination rate might enable Centurk to build up food reserves at early stages of growth to draw on during adverse conditions. Tascosa had the lowest germination rate of all the cultivars (84%), while the rest of the other cultivars had comparable germination rates. Scout 66 was the tallest of all the cultivars after vernalization, and Tascosa the shortest. This might be an indication that Scout 66 is the most cold tolerant and Tascosa the least cold tolerant. The results of the plant height measurements are averages of twelve tallest plants per cultivar immediately after vernalization. Number of tillers per plant are those of daily watered plants only, and are averages of eight plants per cultivar. Root mass entries are for one replicate only. Osage had the highest root mass in the daily watered plants while Tascosa had the least in the weekly watered plants.

Table II gives additional plant heights taken during the course of the experiment. The entries made are averages of four measurements

TABLE I

AGRONOMIC CHARACTERS OF SIX CULTIVARS
OF HARD RED WINTER WHEAT

Cultivar	Germ. %	Ht. After Vernal. cm	Number of tillers per plant	Root Mass (aired dried wt. g.) Daily Wat. Plants	Wkly. Wat. Plants	Maturity
Scout 66	94.00	7.62	7.00	0.70	0.30	Midearly
Concho	90.00	2.79	5.00	0.50	0.49	Midseason
Centurk	100.00	2.29	7.00	1.40	0.50	Midseason to late
Osage	96.00	2.54	7.00	2.90	0.40	Medium late
Tascosa	84.50	1.98	8.00	0.50	0.20	Early to Midseason
Improved Triumph	92.00	2.24	5.00	0.35	0.30	Early

TABLE II

PLANT HEIGHT OF SIX CULTIVARS OF HARD RED WINTER WHEAT

Date	Daily Watered Plants						Date	Weekly Watered Plants					
	Scout 66	Concho	Centurk	Osage	Tascosa	Improved Triumph		Scout 66	Concho	Centruk	Osage	Tascosa	Improved Triumph
						cm.							cm.
1/25	25.37	21.75	23.00	21.65	17.30	14.75	1/25	22.25	19.00	21.75	20.60		14.00
1/28	25.55	21.95	23.65	26.40	17.25	15.15	1/28	19.85	21.65	22.00	20.80	13.10	14.50
1/31	27.10	22.25	23.50	26.75	18.00	15.50	1/31	20.50	20.80	21.75	20.25	13.10	16.25
2/3	27.10	21.85	23.60	27.25	18.25	16.25	2/3	21.00	21.35	21.50	20.75	15.50	16.50
2/7	27.12	21.50	25.35	27.20	19.25	17.25	2/7	21.50	19.90	22.00	20.10	15.90	16.50

per cultivar for each date indicated. In general, for both daily watered and weekly watered plants, noticeable increases in growth, as indicated by plant height in this study, were observed on the 31st of January. At the time of the last measurement on February 7, 1978, Osage and Scout 66 were the tallest and Improved Triumph the shortest for the daily watered plants. Centurk, Osage and Scout 66 were the tallest in the weekly watered plants, and Tascosa the shortest in this respect also. Plant height was reduced in weekly watered plants relative to those receiving water every day. Evidently, a decrease in soil water potential over time appears to affect growth of the cultivars as evidenced by the reduction in height.

Visual observations made of the foliar parts of the cultivars under stress have been tabulated in Table III. The interesting thing to note here is the observed yellowish spots recorded only for Scout 66, which progressed from basal leaves and faded near top-most leaves, and which were visible under fluorescent light. These spots were scattered at irregular intervals and appeared to be due to inherent genetic factors within the cultivar, rather than nutrient deficiency symptoms. The observations herein recorded were clearly visible as the soil water potential approached -7.0 bars.

Tables IV and V give values for transpiration rates of the cultivars. These are means of two readings per cultivar for each day indicated. They are included here because these values were divided by leaf area of the respective cultivars and results obtained were thus used in plotting Figure 6. Since leaf area measurements were not taken at the beginning and end of the study, values from January 23 to 24, and after February 7 are

TABLE III

OBSERVED RESPONSES OF LEAVES OF SIX CULTIVARS OF HARD RED WINTER WHEAT TO SOIL MOISTURE STRESS

Cultivar	Spiralling Leaves	Leaf Folding	Glaucous Deposit On Leaves	Floppy Lower Leaves	Yellow Spots	Dark Chlorophyll Coloration
Scout 66	X	X	X		X	
Concho	X	X	X			X
Centurk	X	X				X
Osage	X	X		X		
Tascosa	X	X				
Improved Triumph	X		X	X		X

TABLE IV

TRANSPIRATION RATE OF SIX CULTIVARS OF HARD RED WINTER WHEAT - DAILY WATERED PLANTS

Date	Scout 66	Concho	Centurk	Osage	Tascosa	Improved Triumph
			$g/dm^2/day$			
1/23	30.50	29.35	25.05	31.15	27.50	29.25
1/24	28.15	26.27	24.61	26.17	27.65	28.00
1/25	25.10	28.35	27.75	29.12	28.35	29.05
1/26	17.50	18.60	17.01	14.25	18.59	21.02
1/27	26.07	21.85	23.30	15.10	29.50	26.85
1/29	24.25	25.75	32.20	33.10	23.95	22.25
1/30	24.30	20.34	23.47	25.95	27.60	27.60
1/31	25.14	24.20	29.46	24.50	27.60	24.88
2/1	20.80	17.88	24.60	29.60	26.20	25.95
2/2	15.35	13.31	20.50	19.75	18.60	26.00
2/3	19.31	14.21	31.82	21.25	18.30	25.70
2/4	25.85	13.10	30.30	15.80	17.36	20.65
2/6	28.65	21.30	35.10	27.50	13.90	28.45
2/7	32.31	16.50	31.81	21.50	24.55	19.50
2/8	32.90	17.70	35.00	20.35	25.55	30.10
2/9	31.50	22.10	16.10	16.40	23.62	23.90
2/10	25.55	19.35	12.40	22.90	24.95	21.35

TABLE V

TRANSPIRATION RATE OF SIX CULTIVARS OF HARD RED WINTER WHEAT - WEEKLY WATERED PLANTS

Date	Scout 66	Concho	Centurk	Osage	Tascosa	Improved Triumph
			$g/dm^2/day$			
1/23	12.30	13.37	15.99	15.55	-----	15.39
1/24	10.65	10.60	13.15	11.75	-----	7.85
1/25	9.50	10.15	12.65	10.10	-----	8.65
1/26	8.92	10.59	11.35	11.30	-----	11.65
1/27	8.35	8.90	8.15	11.21	-----	11.74
1/29	13.52	13.80	15.90	15.81	11.42	15.10
1/30	13.10	13.09	13.69	12.71	12.52	15.10
1/31	11.91	12.49	12.20	11.81	11.70	10.75
2/1	8.11	11.10	11.30	9.21	11.80	9.90
2/2	7.70	9.59	10.80	9.10	7.40	11.30
2/3	5.75	7.30	7.50	5.80	10.30	9.70
2/4	5.75	7.30	7.50	5.80	10.29	9.70
2/6	15.65	14.77	15.75	12.50	14.16	15.40
2/7	11.85	11.98	12.40	10.90	13.11	13.80
2/8	9.50	8.39	9.10	8.69	11.81	12.05
2/9	8.39	6.28	6.30	6.40	10.20	10.90
2/10	7.68	4.65	5.05	5.05	8.75	9.75

omitted from that figure. Thus this table serves to furnish an idea about what the values were for the omitted dates.

Table VI shows results of leaf area for the various cultivars. Entries made are means of two measurements per cultivar. The results indicate that leaf area is reduced as soil moisture decreases. However, the extent to which leaf area was reduced differed with each cultivar. For example, Scout 66 reduced leaf area by 55% (eg. 6.24/13.76) at the end of the study; Osage and Tascosa individually reduced leaf area by 46%. Concho and Centurk reduced leaf area by 41% and 40%, respectively. Improved Triumph reduced leaf area by only 16%. The ability to reduce leaf area is an important mechanism plants may develop in response to soil moisture stress.

Average soil water potential has been plotted on a per-pot basis for both treatments (Figures 3 & 4). Days on which readings were taken have been indicated by thick black dots. Days on which readings were omitted were those on which the soil was too saturated for the psychrometer to register a clear cut-reading. Arrows have been used to indicate days on which water was added to the weekly watered plants. On these days the amount of water added to the daily watered plants was increased by 20 ml. Results shown are averages of twelve readings (one reading per pot) per day for daily watered plants and an additional twelve readings for pots receiving water once per week. Therefore, there were twenty-four readings per day. Soil water potential was higher (less negative) for pots receiving water each day relative to those receiving water once per week. However, upon rewatering, all pots had similar soil water potential. Figure 5 shows that there seems to be an inverse relationship between stomatal resistance and soil water

TABLE VI

LEAF AREA OF SIX CULTIVARS OF
HARD RED WINTER WHEAT

Date	Scout 66		Concho		Centurk		Osage		Tascosa		Imp. Triumph	
	Daily Water-plants	Weekly Water-plants	Daily Water-plants	Weekly Water-plants	Daily Water-plants	Weekly Water-plants	Daily Water-plants	Weekly Water-plants	Daily Water-plants	Weekly Water-plants	Daily Water-plants	Weekly Water-plants
						cm^2						
1/27	6.00	4.89	4.80	4.30	5.87	5.23	8.66	4.47	4.51		3.24	2.52
1/31	7.32	4.72	6.04	4.80	5.65	5.43	8.41	4.39	5.29	2.49	4.33	2.76
2/4	10.87	4.44	6.80	5.61	5.97	5.52	10.99	6.66	4.73	3.20	4.90	4.00
2/8	13.76	6.24	7.94	4.67	8.80	5.28	11.71	6.35	7.48	4.04	5.62	4.70

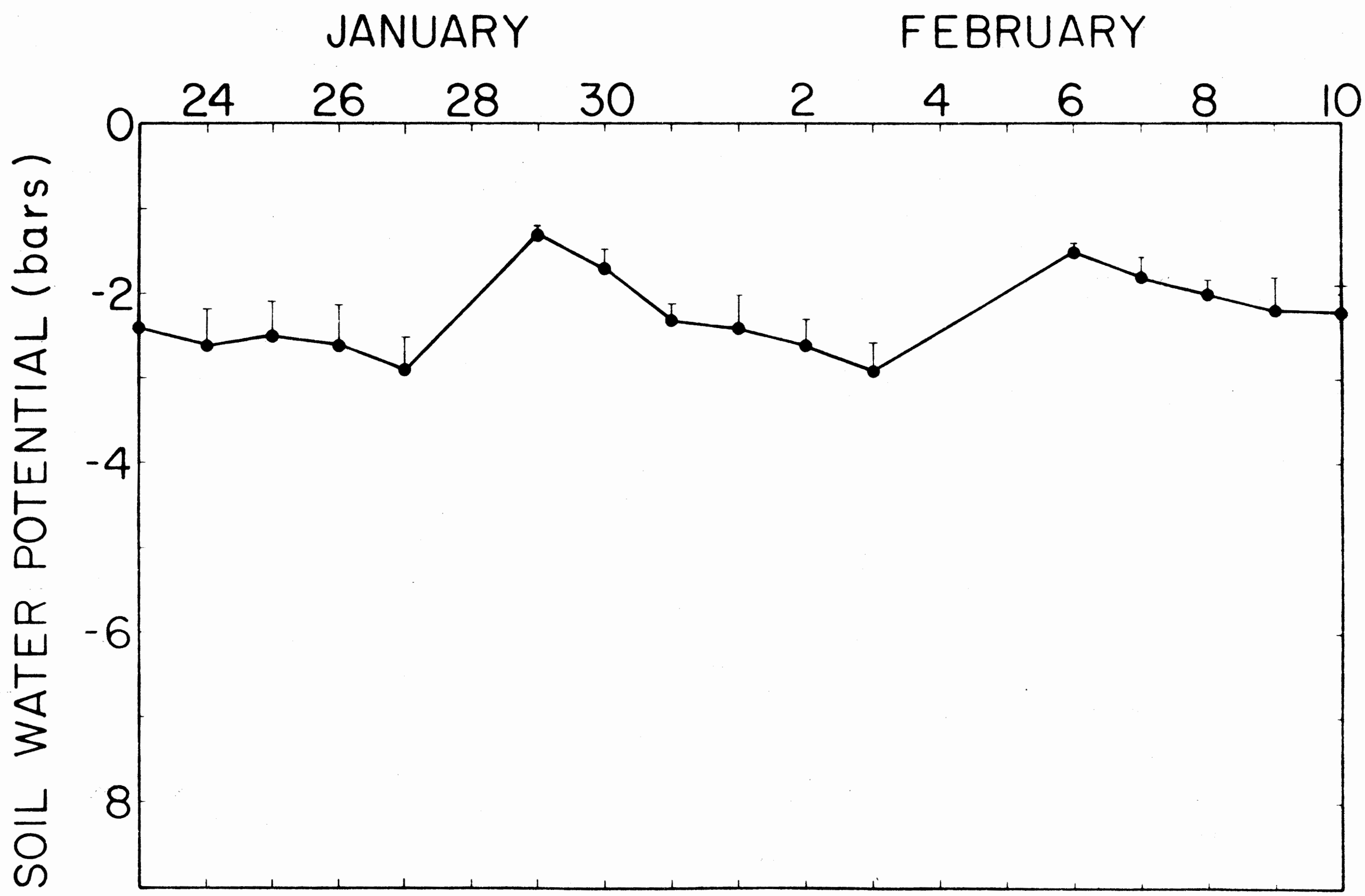


Figure 3. Average Soil Water Potential - Daily Water Plants

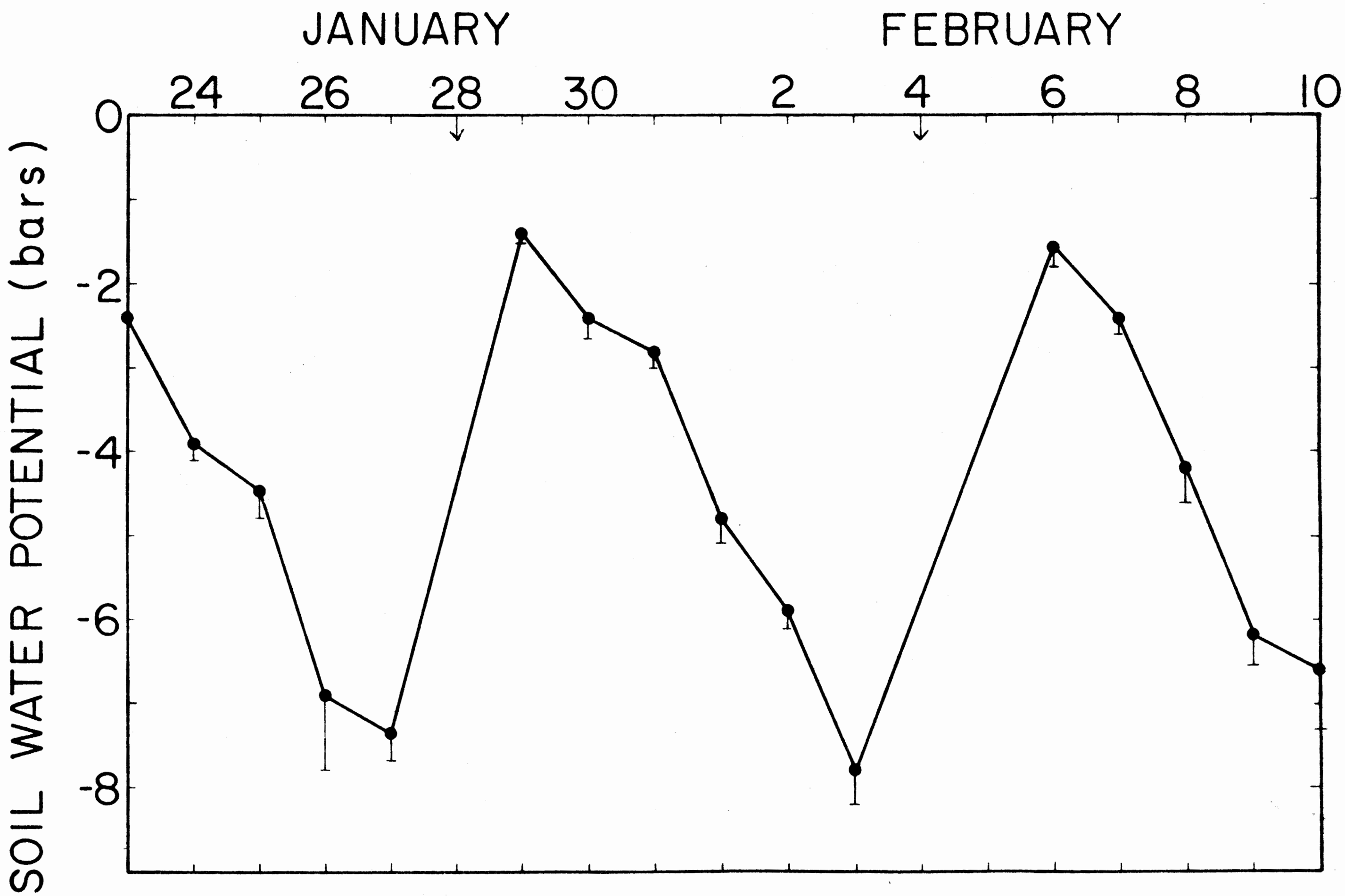


Figure 4. Average Soil Water Potential - Weekly Watered Plants

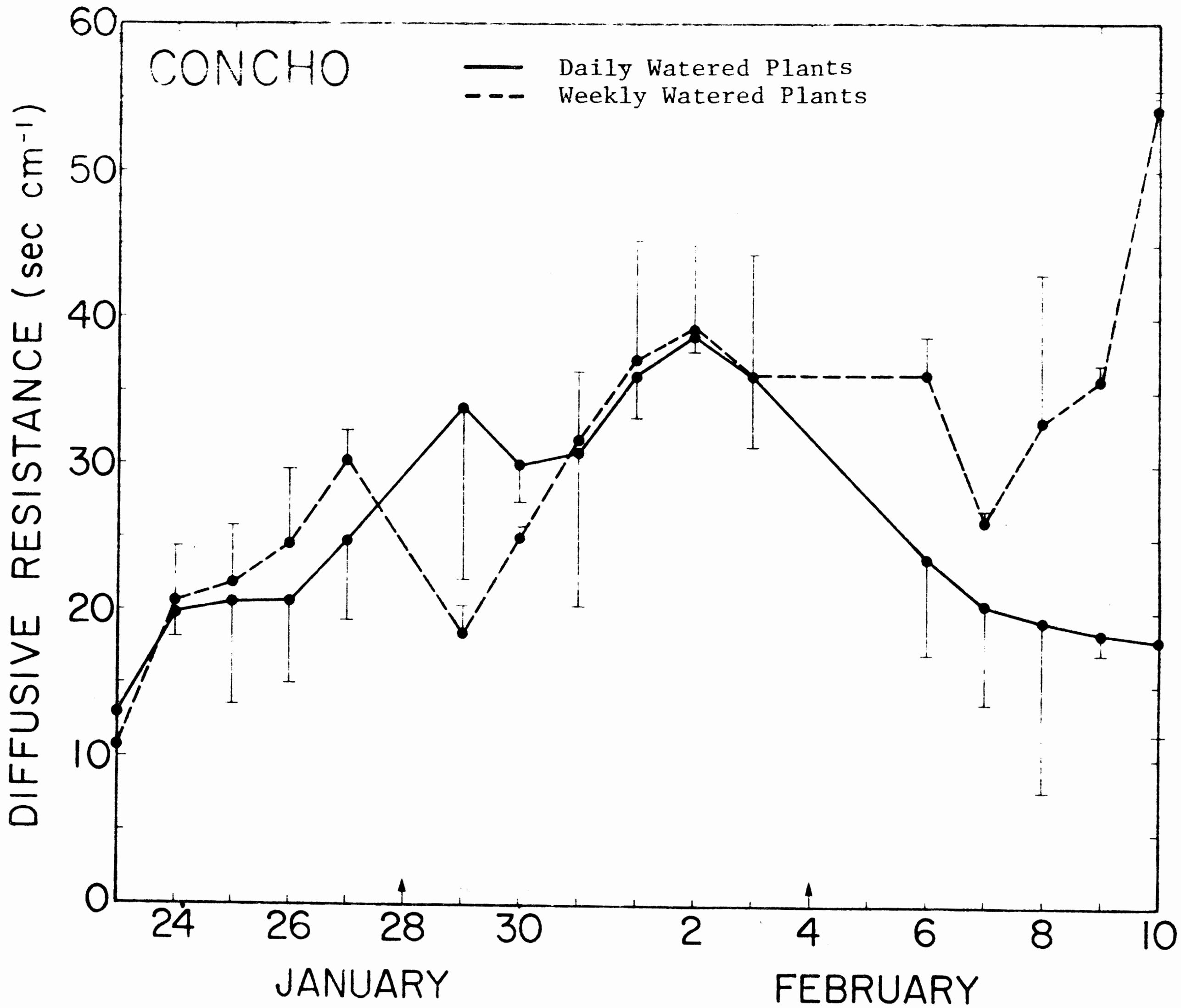
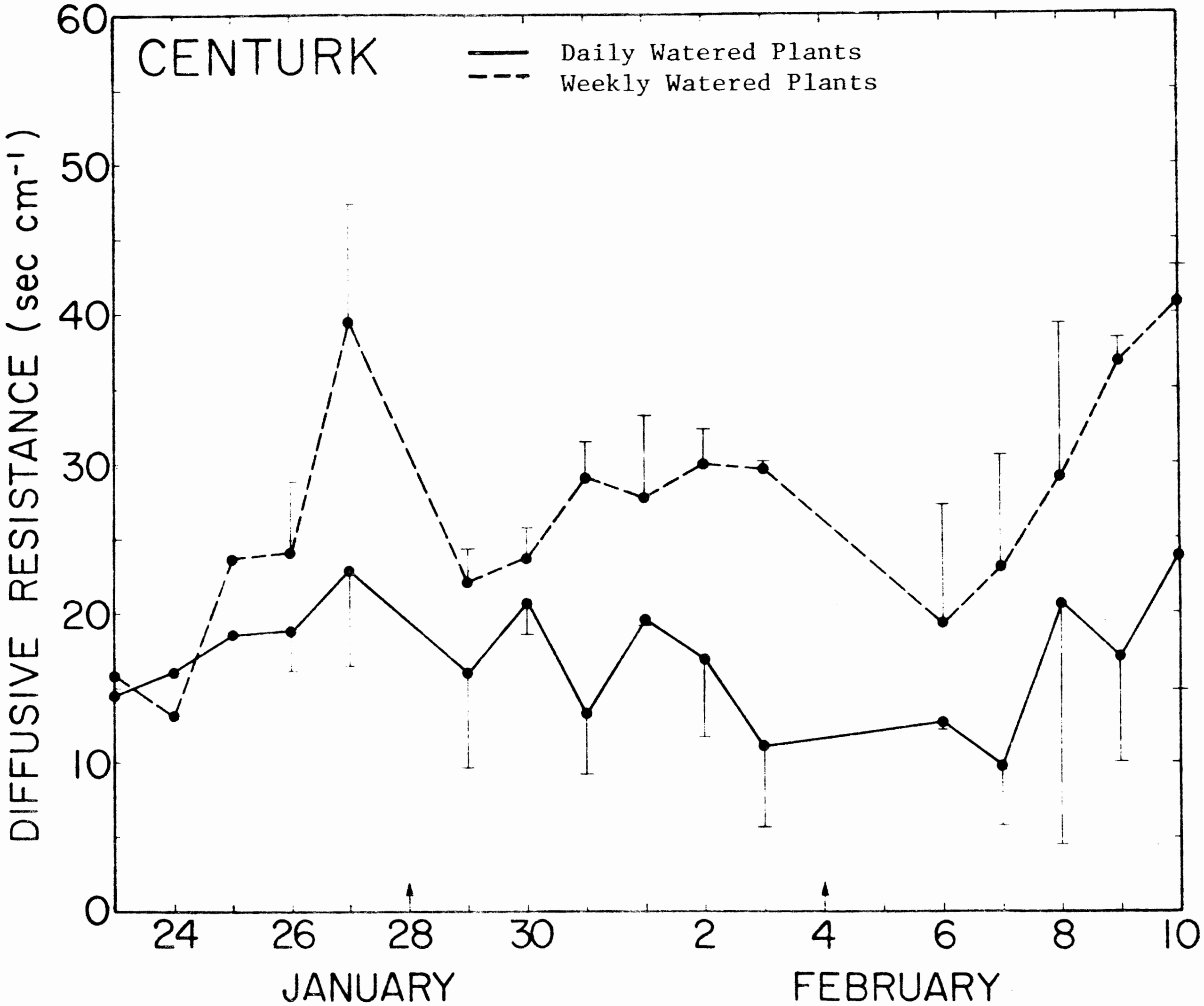


Figure 5. Stomatal Resistance of Six Cultivars of Hard Red Winter Wheat



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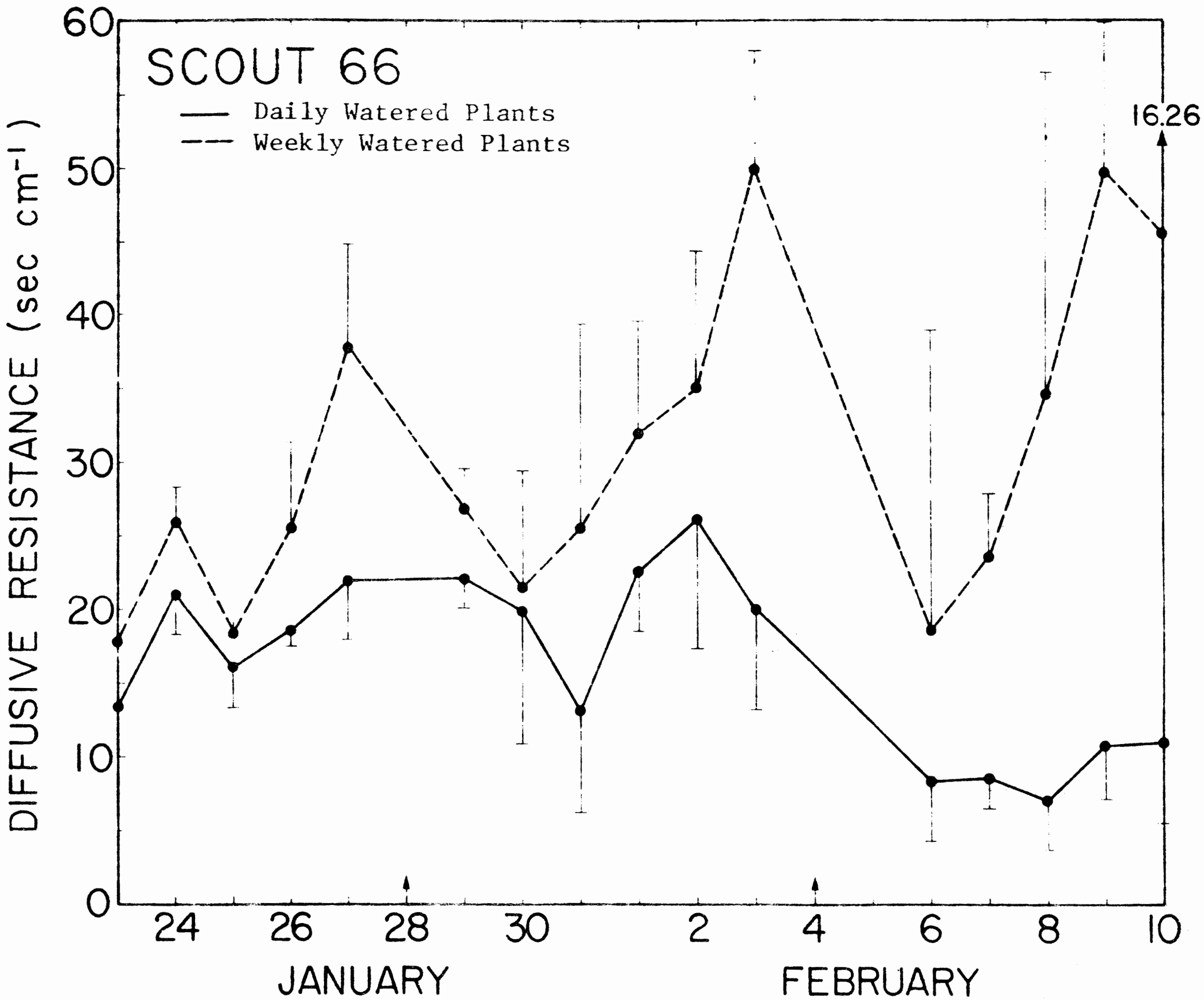

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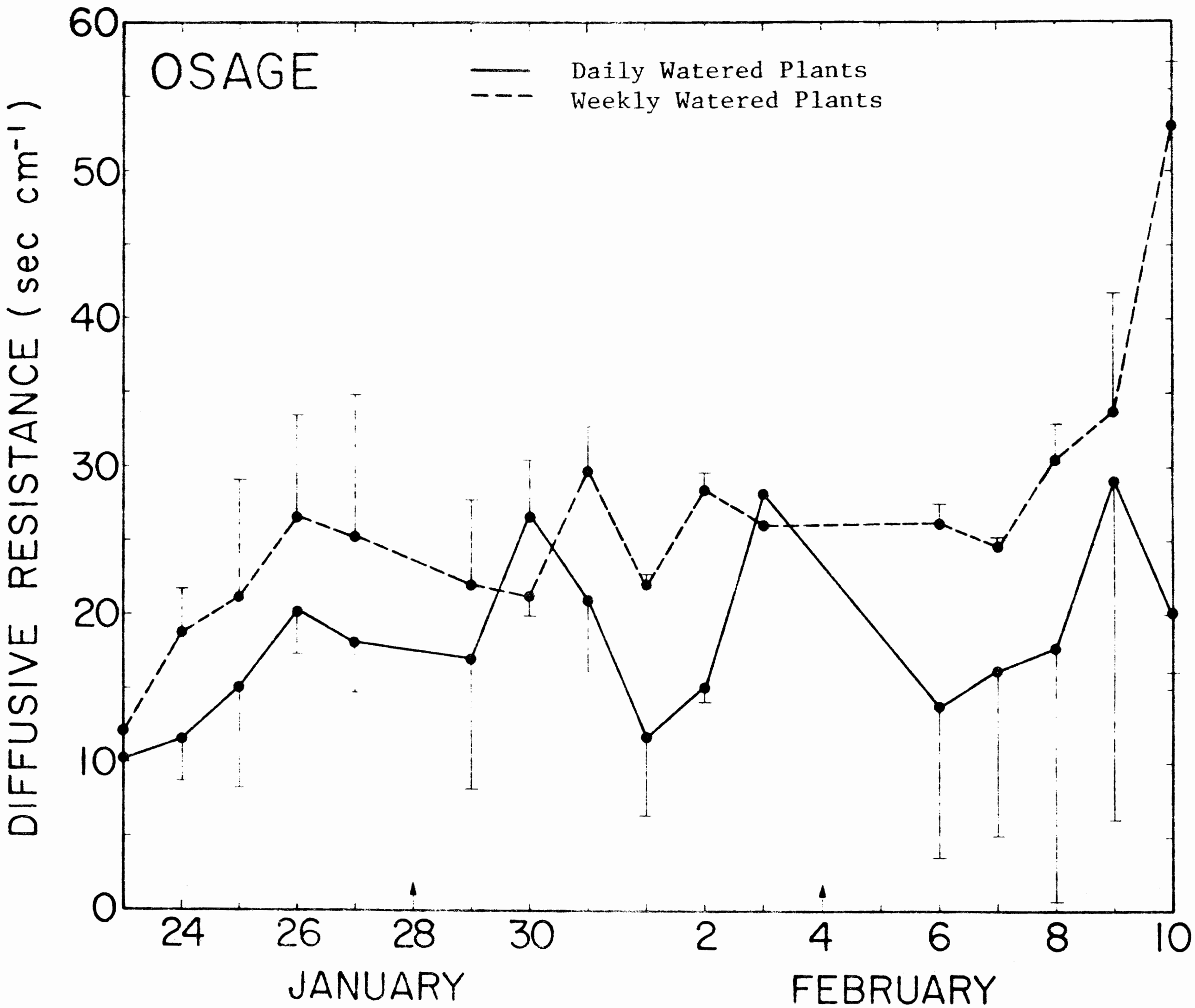

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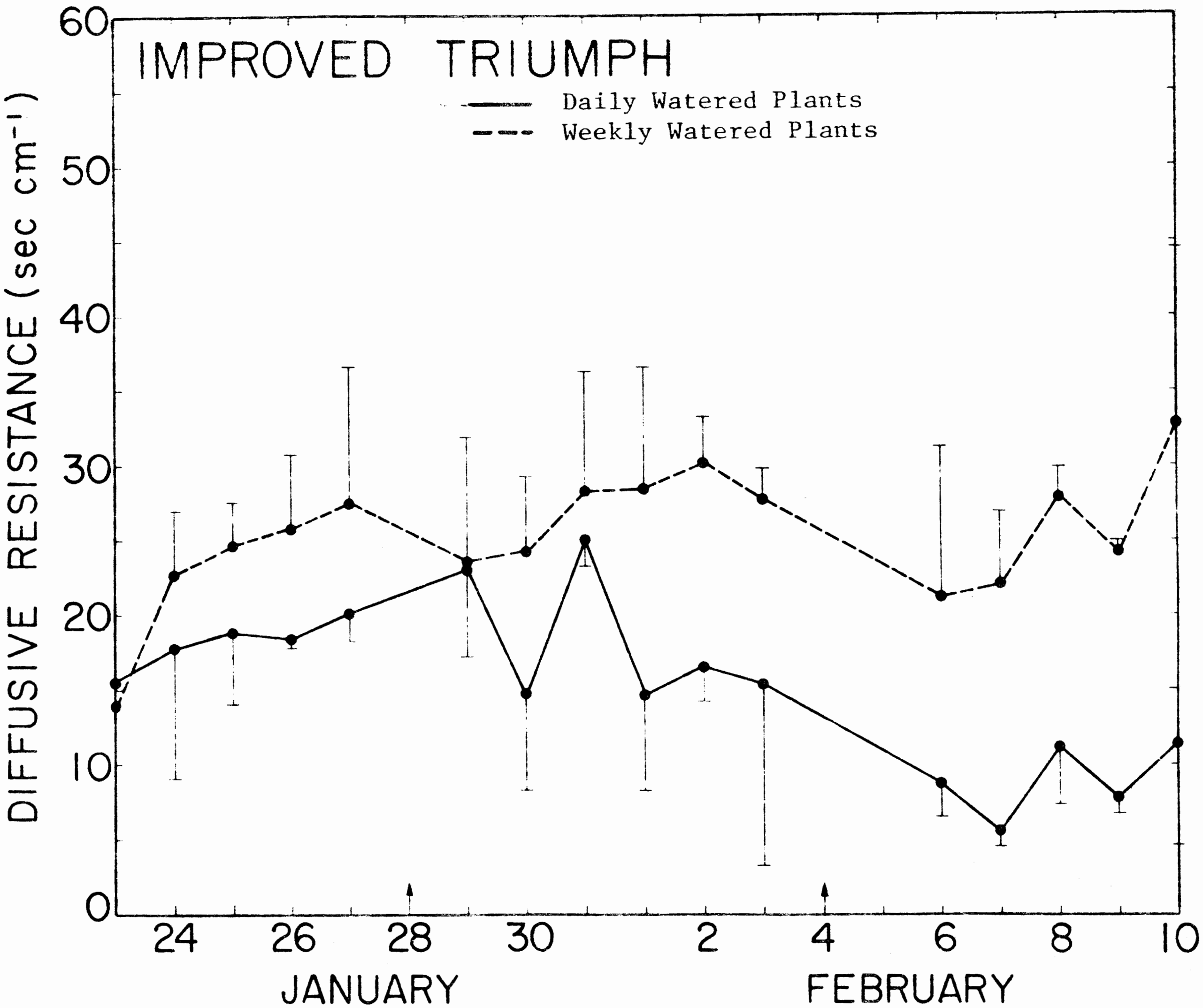

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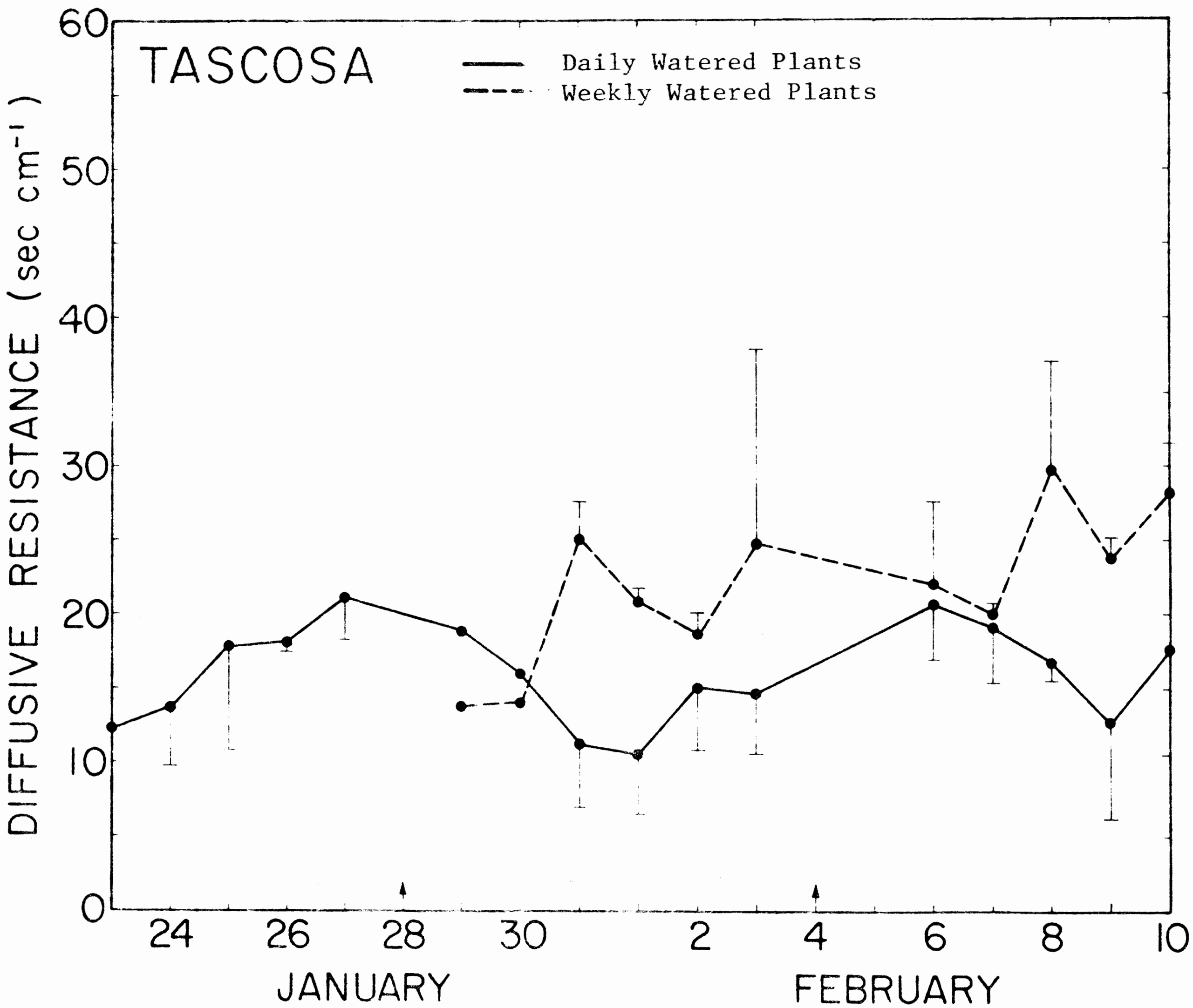


Figure 5 (Continued)

potential (Figure 3). In general for all the cultivars, the weekly watered plants had a higher stomatal resistance relative to those watered daily. The cultivars responded differently to rewatering at the end of each drying cycle. No noticeable change in stomatal resistance was recorded for Osage after the first and second drying cycles. Tascosa, Centurk, Concho and Improved Triumph showed decreases in stomatal resistance to rewatering at the end of the second drying cycle. With regard to Scout 66, dramatic increase in response to rewatering by reducing stomatal resistance was observed. After the first drying cycle, Concho consistently maintained a higher stomatal resistance, and there was essentially no marked difference in stomatal resistance whether it was watered daily or weekly, from the thirtieth of January through the third of February. The cultivars appeared to be following a drying cycle relative to the soil water potential. That is to say, stomatal resistance increased as soil water potential decreased. However, the amount of increase differed with type and age of cultivar. At the end of the study, Tascosa had the lowest stomatal resistance while Concho had the highest stomatal resistance. Within the precision of data presented, it would appear that the highest diffusive resistance to be developed in response to decreasing soil water potential should occur between -6.6 and -7.7 bars soil water potential, since these were the lowest (more negative) soil water potential recorded in this study. Means of stomatal resistance for all the daily watered plants (D) and weekly watered plants (W) are given in Table VII; also given are the corresponding means of soil water potential for the daily and weekly watered plants. Thus, taking a stomatal resistance of 30 sec. cm^{-1} (Table VII, lines 10

TABLE VII

DAILY MEANS OF STOMATAL RESISTANCE AND SOIL WATER POTENTIAL OF SIX CULTIVARS OF HARD RED WINTER WHEAT

Day	Water	N	Sto. Resistance	Soil W. Potential
23	D	12	13.1	2.4
23	W	10	13.4	2.4
24	D	12	16.7	2.6
24	W	10	20.3	3.9
25	D	12	17.8	2.4
25	W	10	22.0	4.4
26	D	12	19.1	2.5
26	W	10	25.3	6.9
27	D	12	21.5	2.9
27	W	10	32.1	7.3
29	D	12	21.8	1.3
29	W	12	21.2	1.4
30	D	12	21.4	1.6
30	W	12	21.9	2.4
31	D	12	19.3	2.3
31	W	12	28.2	3.3
32	D	12	19.2	2.3
32	W	12	28.1	4.8
33	D	12	21.5	2.6
33	W	12	30.3	5.8
34	D	12	21.1	2.9
34	W	12	32.4	7.7
37	D	12	14.6	1.5
37	W	12	24.0	1.5
38	D	12	13.2	1.8
38	W	12	23.3	2.4
39	D	12	15.5	2.0
39	W	12	31.0	4.2
40	D	12	15.9	2.2
40	W	12	34.1	6.1
41	D	12	17.0	2.3
41	W	12	42.4	6.6

and 22) to be the value at which stomata have closed, since most of the cultivars had values near this amount at the indicated soil water potential, it can be concluded that stomata of the cultivars close at -7.3 and -7.7 bars soil water potential for the first and second drying cycles, respectively. However, stomata may close at a higher soil water potential upon subsequent drying cycle (Table VII, line 28). It would appear, then, that the cultivars Concho and Centurk close their stomata earlier than the rest of the cultivars used in this study. Only Concho had a stomatal resistance of 30 sec. cm^{-1} among the daily watered plants.

Results of transpiration rate are shown in Figure 6. These are average values of two readings per day for each cultivar. These values have taken into account leaf area for the respective cultivars. Transpiration rate was lower for weekly watered plants than daily watered plants. Within the limits of this study, transpiration rate for most of the cultivars diminished linearly with decreasing soil water potential between -2.3 to about -8.0 bars, and leveled off somewhat for most of the cultivars. Linear relations between soil moisture and transpiration rate have been obtained by Bierhuizen (1958) and Slatyer (1956). These results also agree with reductions in transpiration rate after a period of stress reported by Salim et al. (1965). Centurk had a transpiration rate similar to Tascosa and Improved Triumph among the daily watered plants, but was able to reduce transpiration as soil moisture declined, relative to the named cultivars. Tascosa and Improved Triumph transpired most of all the cultivars in both daily and weekly watered plants while Concho, Osage and Scout 66 consistently maintained lower transpiration rates

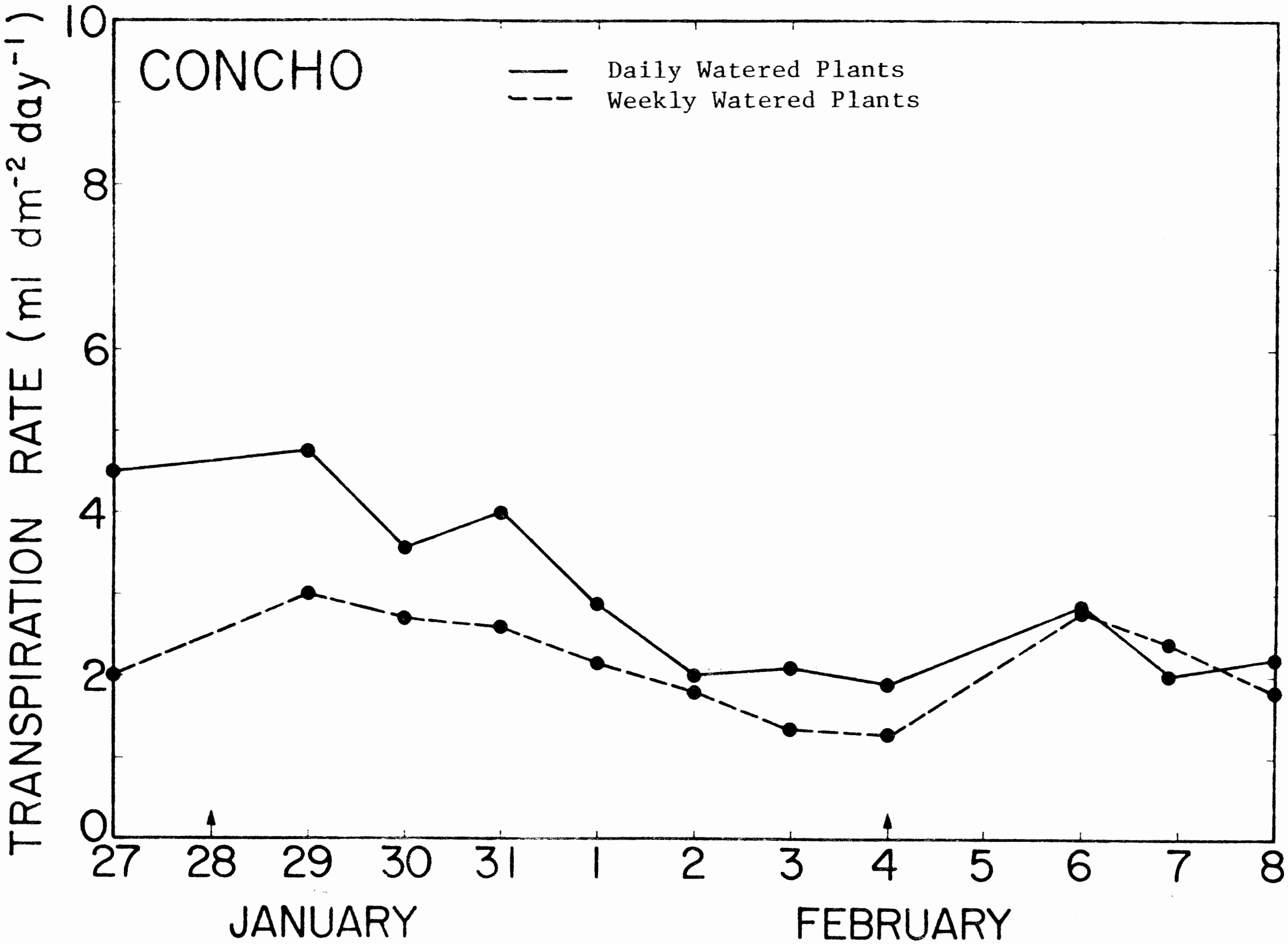
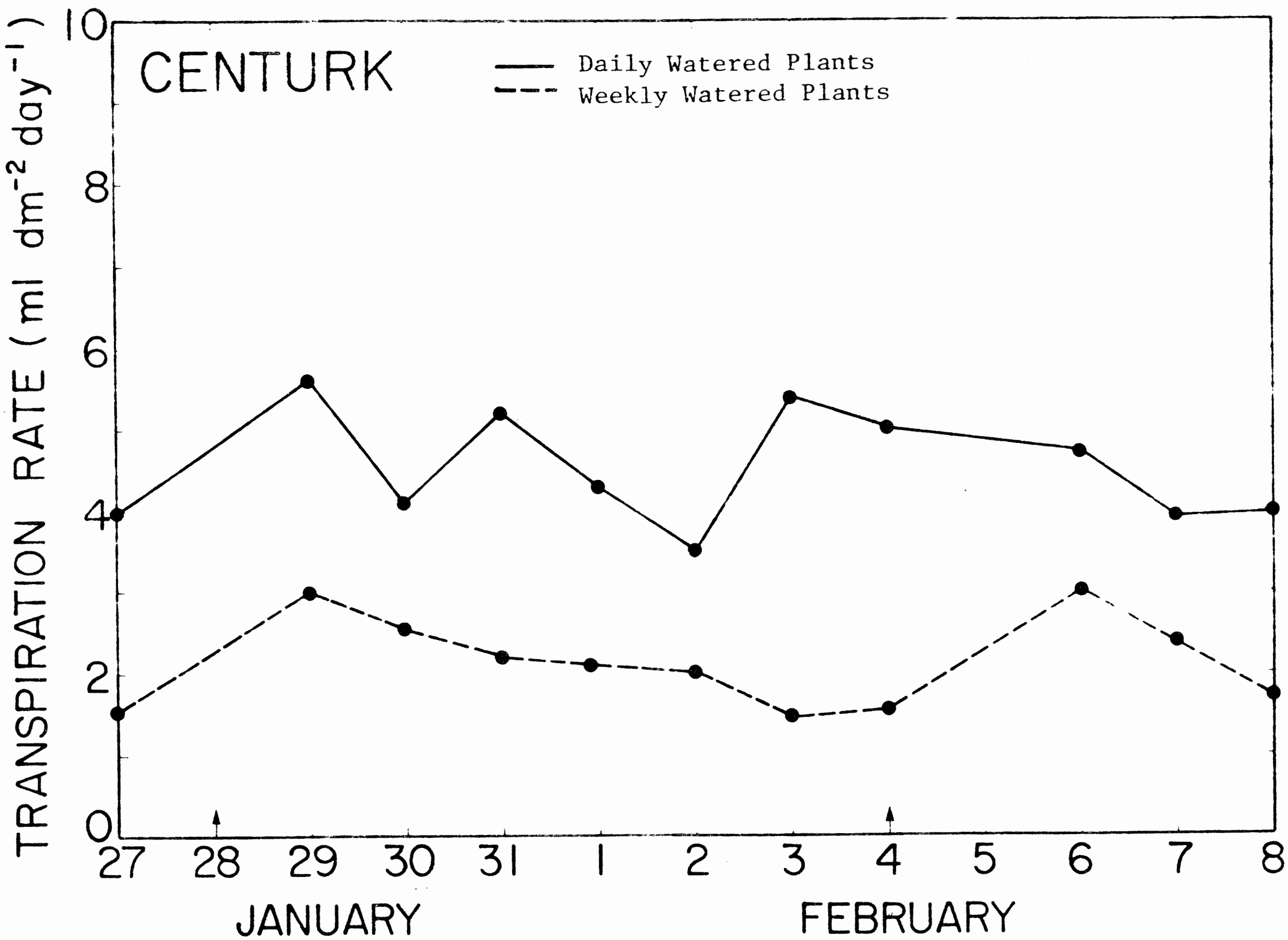


Figure 6. Transpiration Rate of Six Cultivars of Hard Red Winter Wheat



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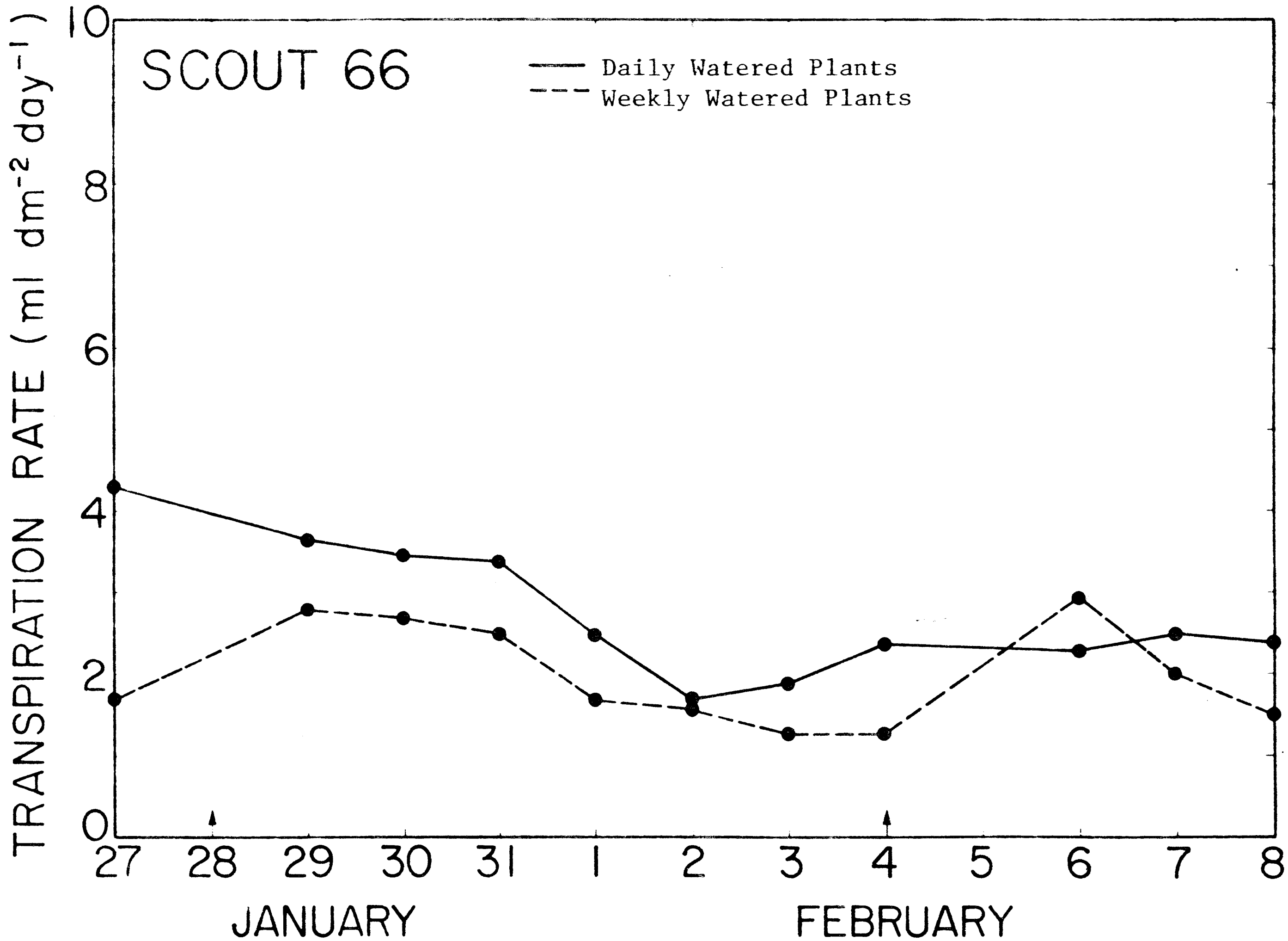

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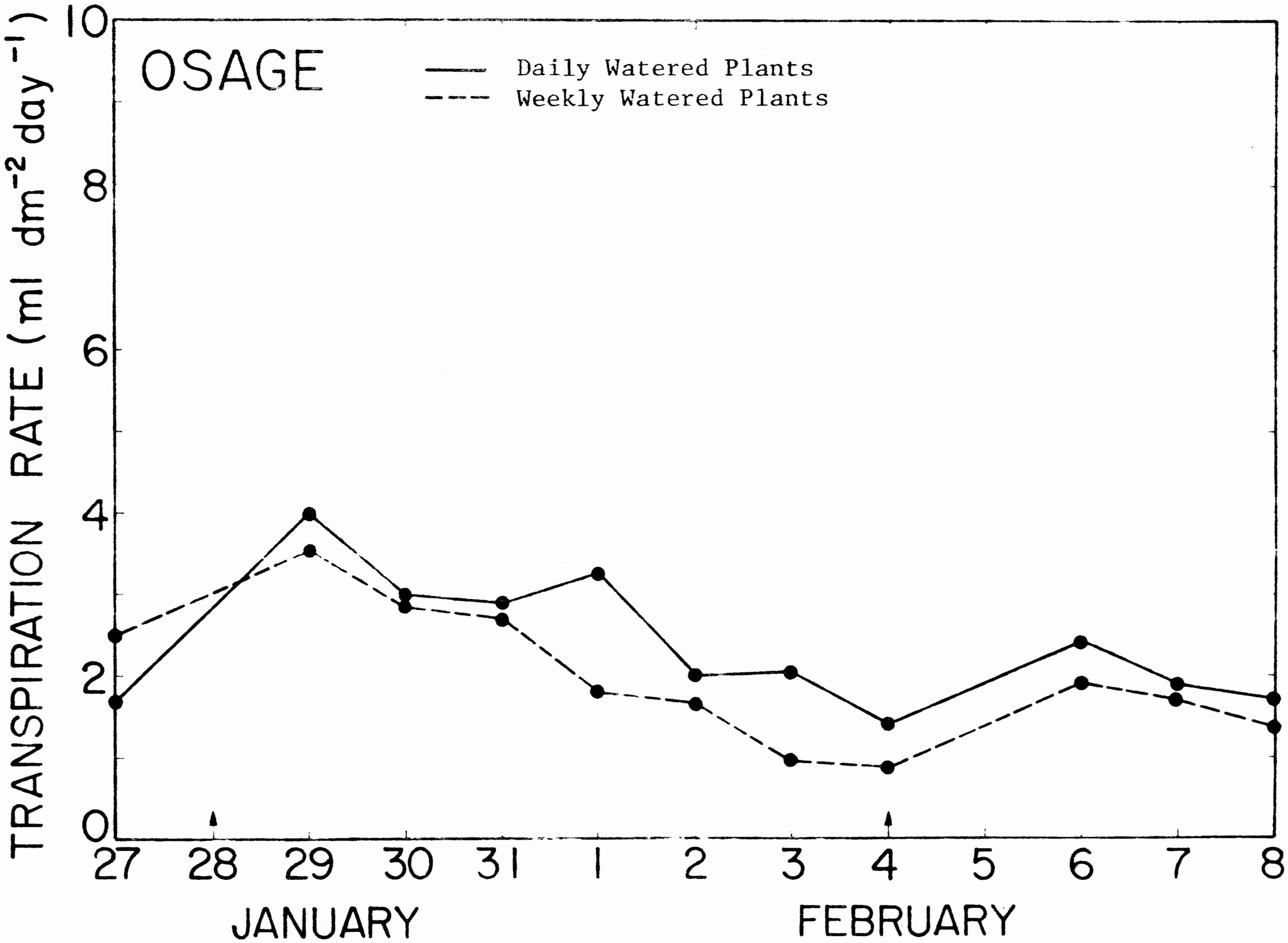

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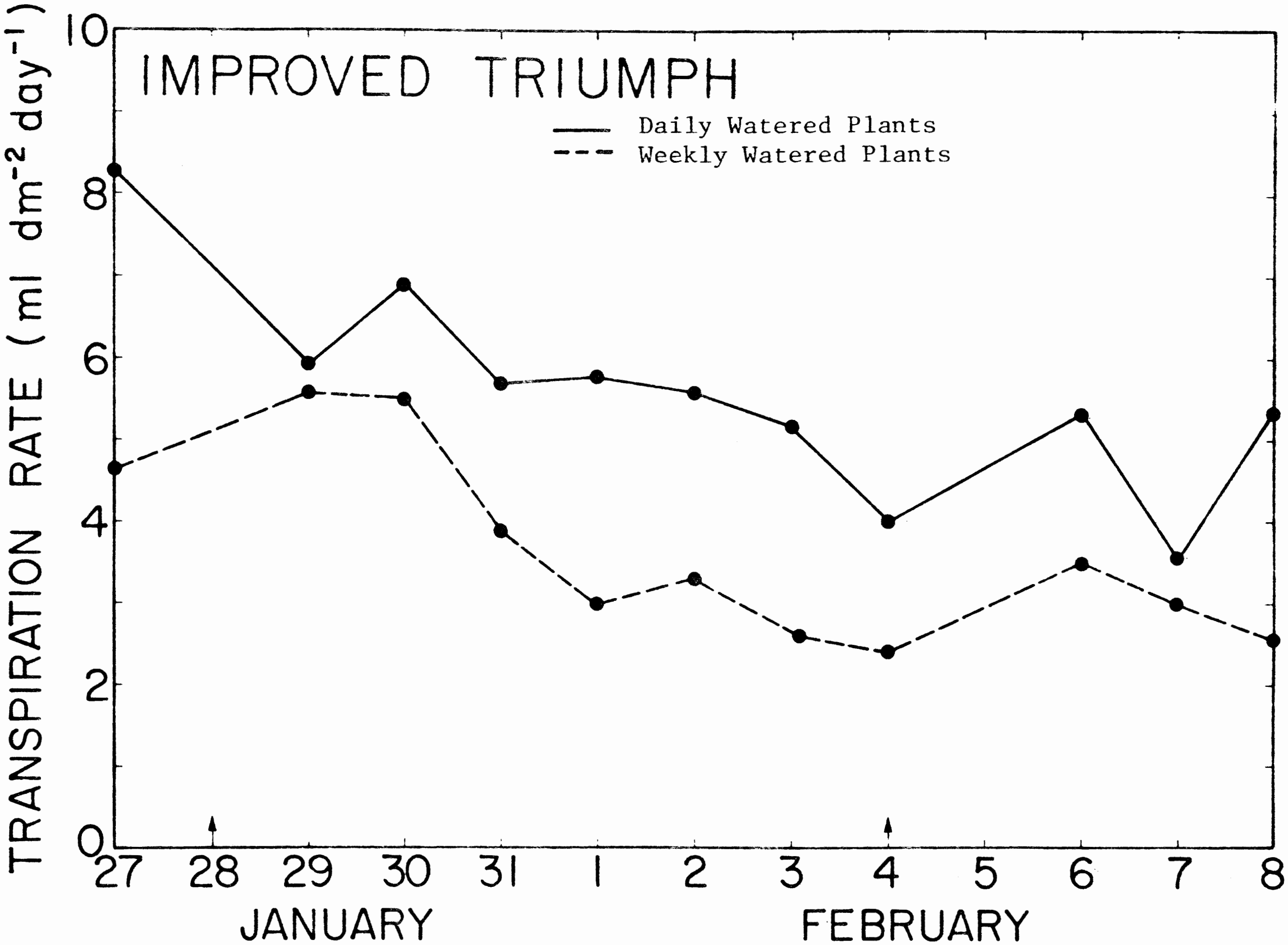

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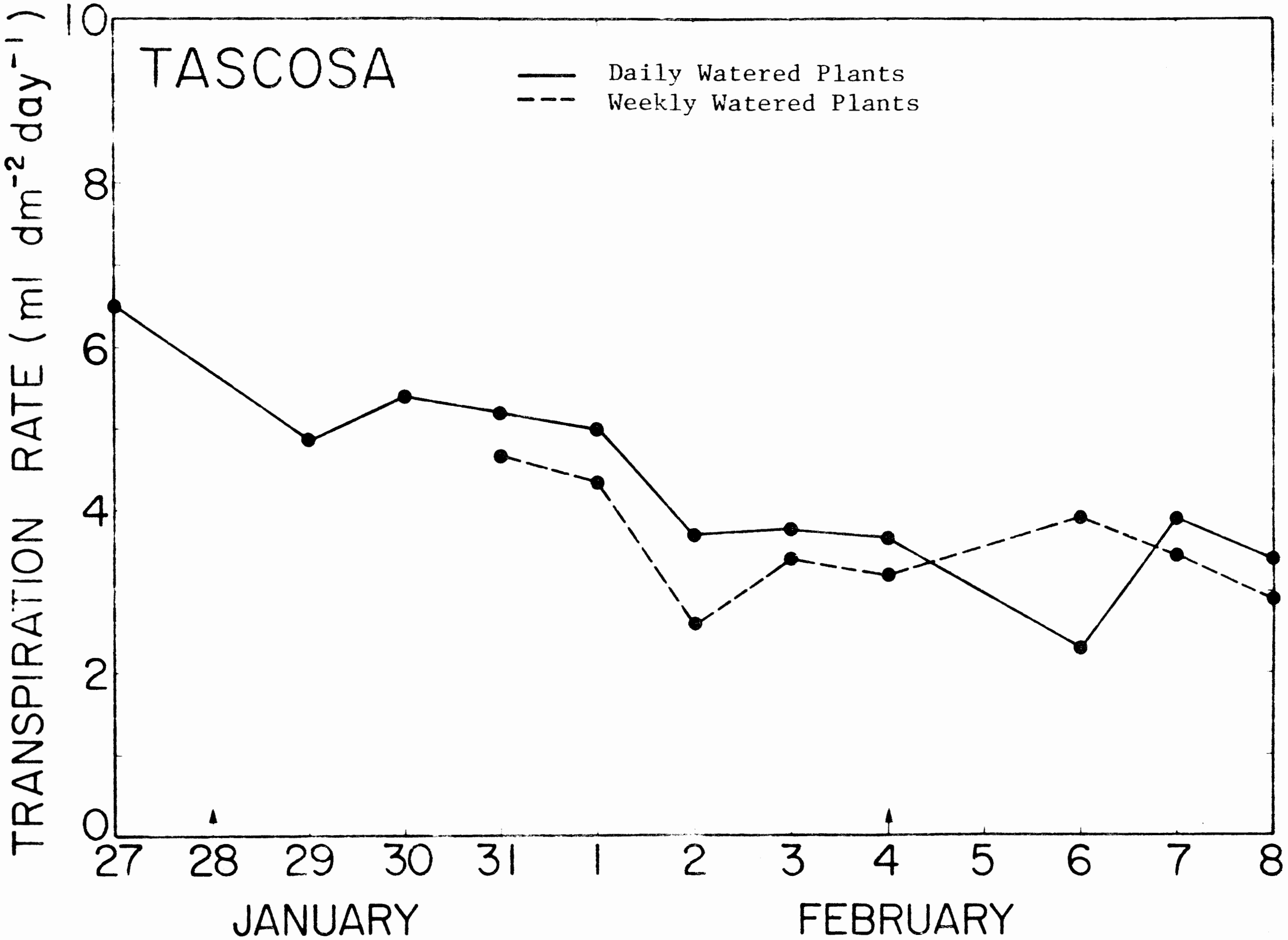


Figure 6 (Continued)

for both treatments. After rewatering, however, recovery of transpiration was recorded within 48 hours. This finding is also in agreement with Todd et al. (1962) who reported maximum recovery of wheat two days after rewatering when plants were subjected to soil moisture stress. The reductions in transpiration rate might be due primarily to the increased diffusive resistance developed by the cultivars, under stress, or to the deposition of cuticular lipid layer (Table III) on the surface of the leaves.

Figure 7 shows results of total plant water potential for the various cultivars. Values are averages of two readings per cultivar for each day indicated. At the bottom of each graph average soil water potential values have been given. Those above the abscissa are for the daily watered plants and those below are for the weekly watered plants. The figure indicates that total plant water potential decreases (becomes more negative) as soil water potential decreases (becomes more negative). Total plant water potential for Improved Triumph was consistently lower for the weekly watered plants in comparison to values obtained when it was watered daily. Total plant water potential below -20 bars appears to cause reduced transpiration rate with age of the cultivars. It is interesting to note that Scout 66 had one of the highest total plant water potential among the daily watered plants at the end of the study, but it also had the lowest total plant water potential among the weekly watered plants for the same period.

A close look at total plant water potential for Scout 66 around the 27th and 28th of January (Table VIII, which gives values of total plant water potential for the cultivar Scout 66 on days that total plant water potentials were taken for both daily (D) and weekly (W) watered plants)

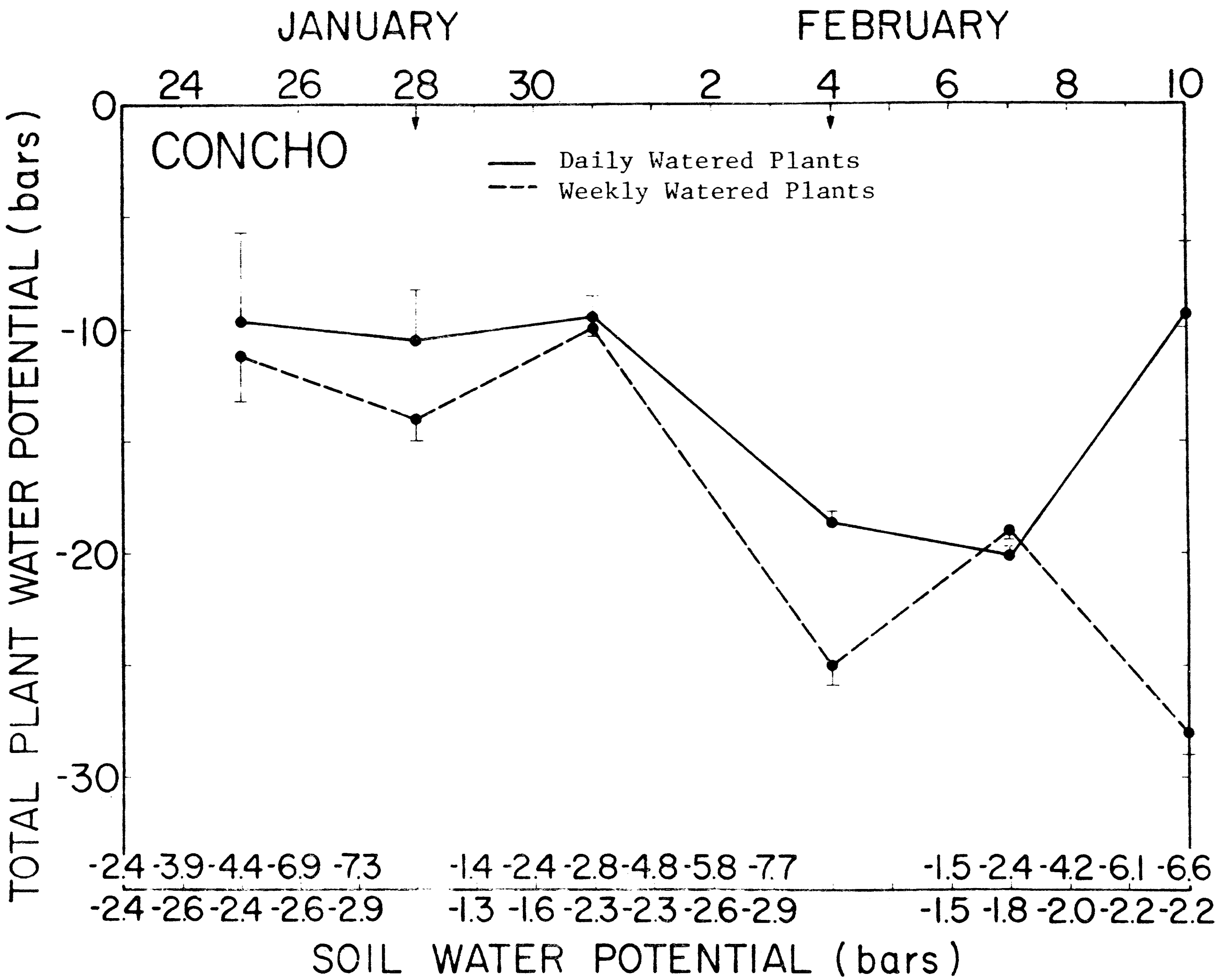
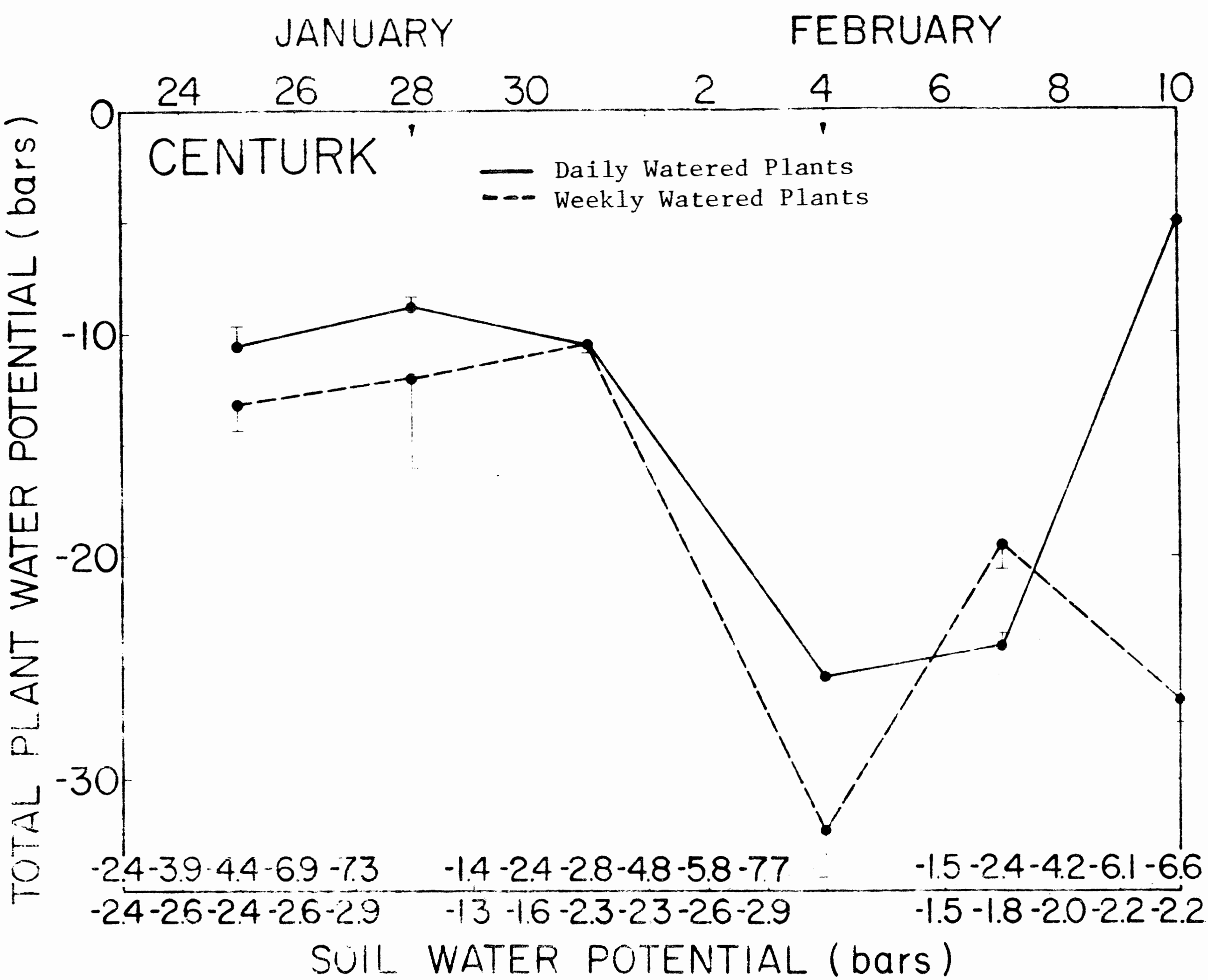


Figure 7. Total Plant Water Potential of Six Cultivars of Hard Red Winter Wheat



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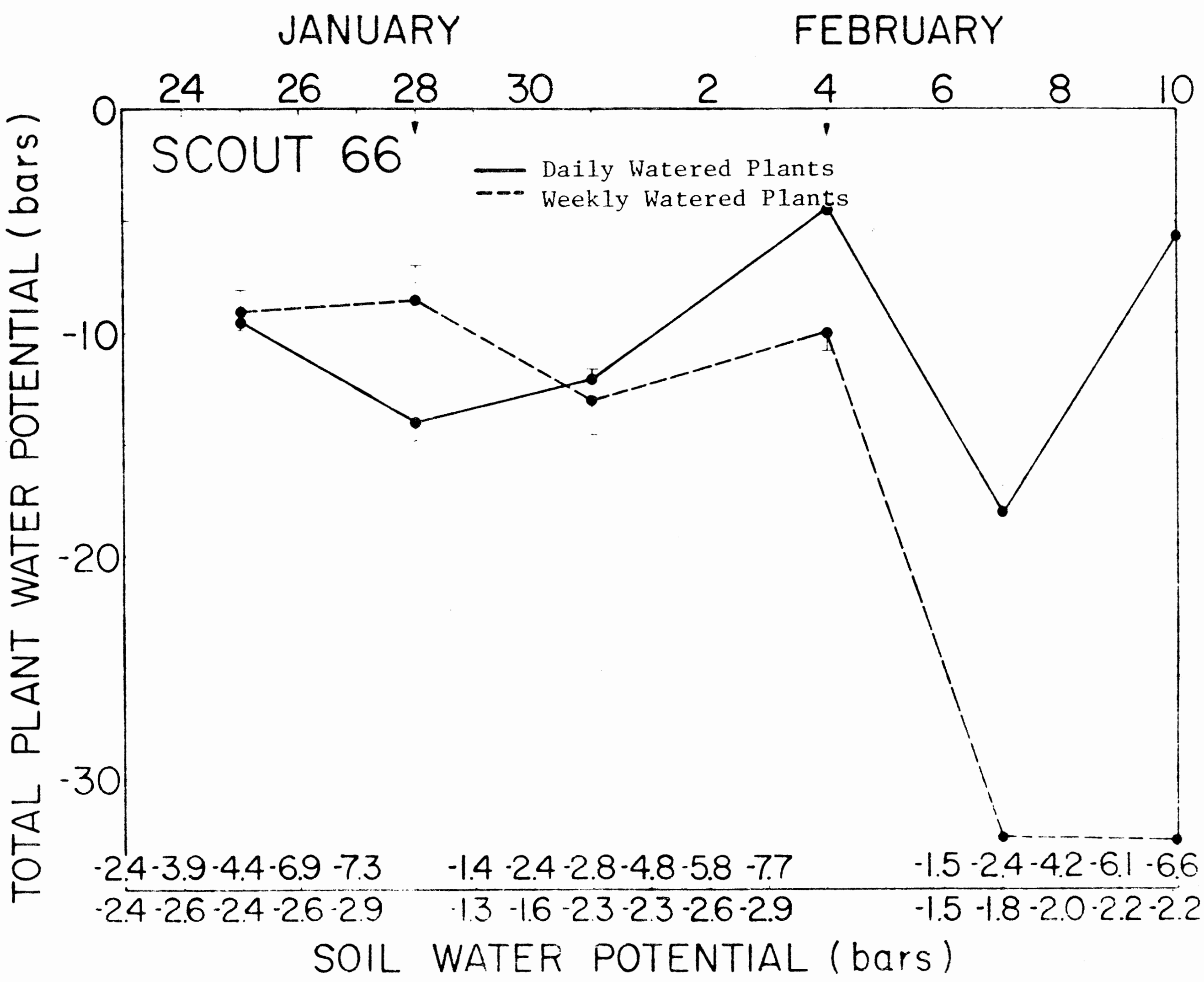

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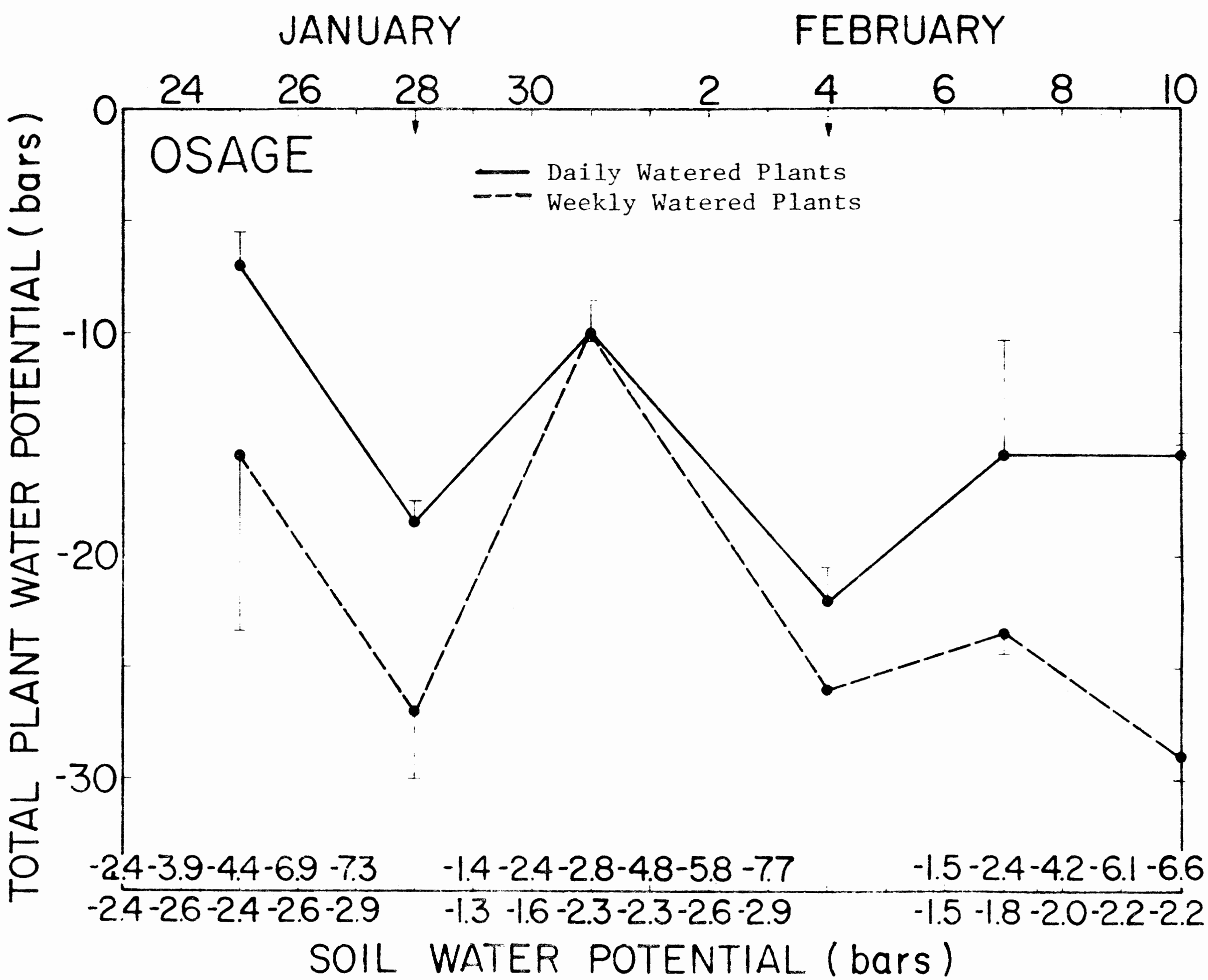

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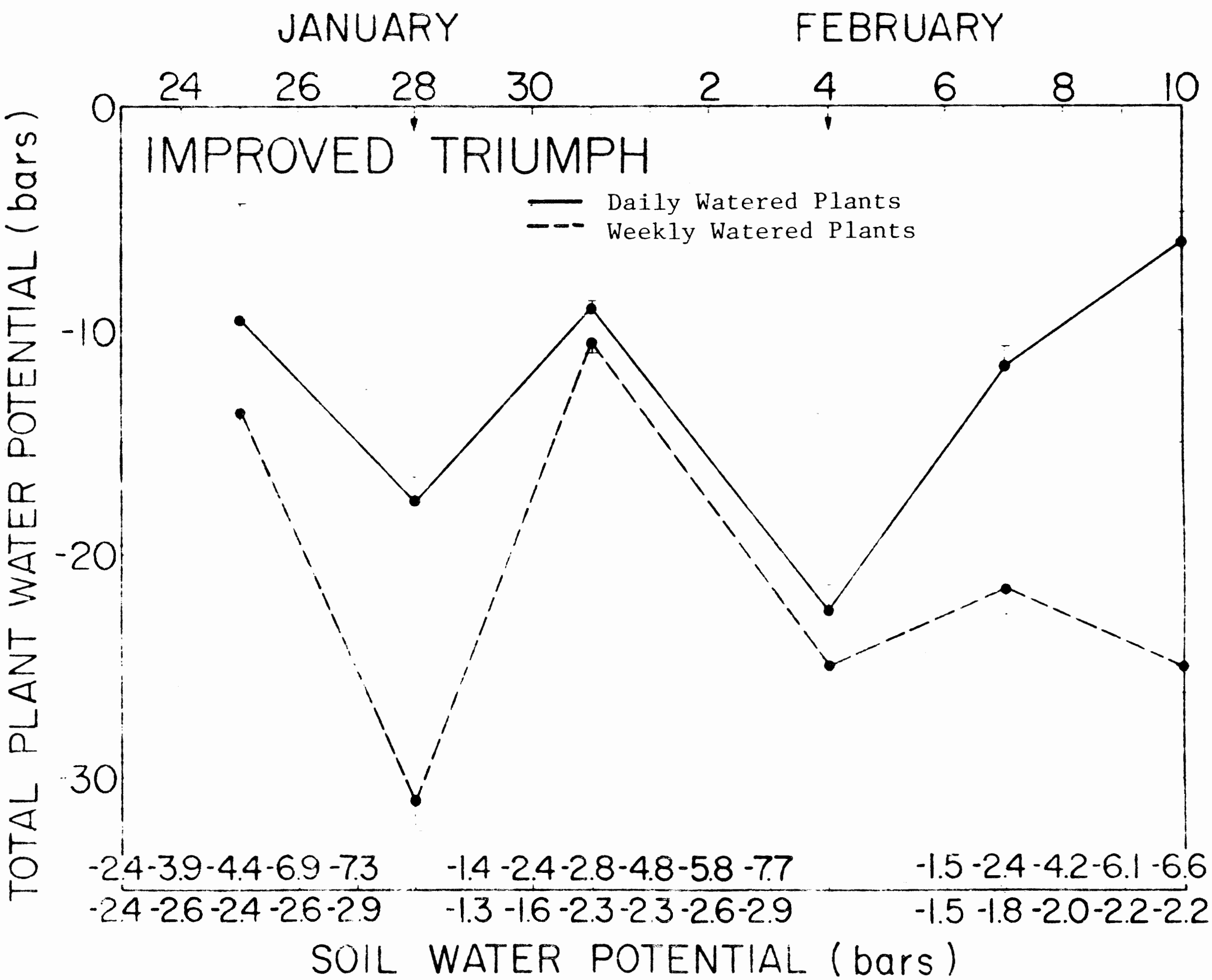

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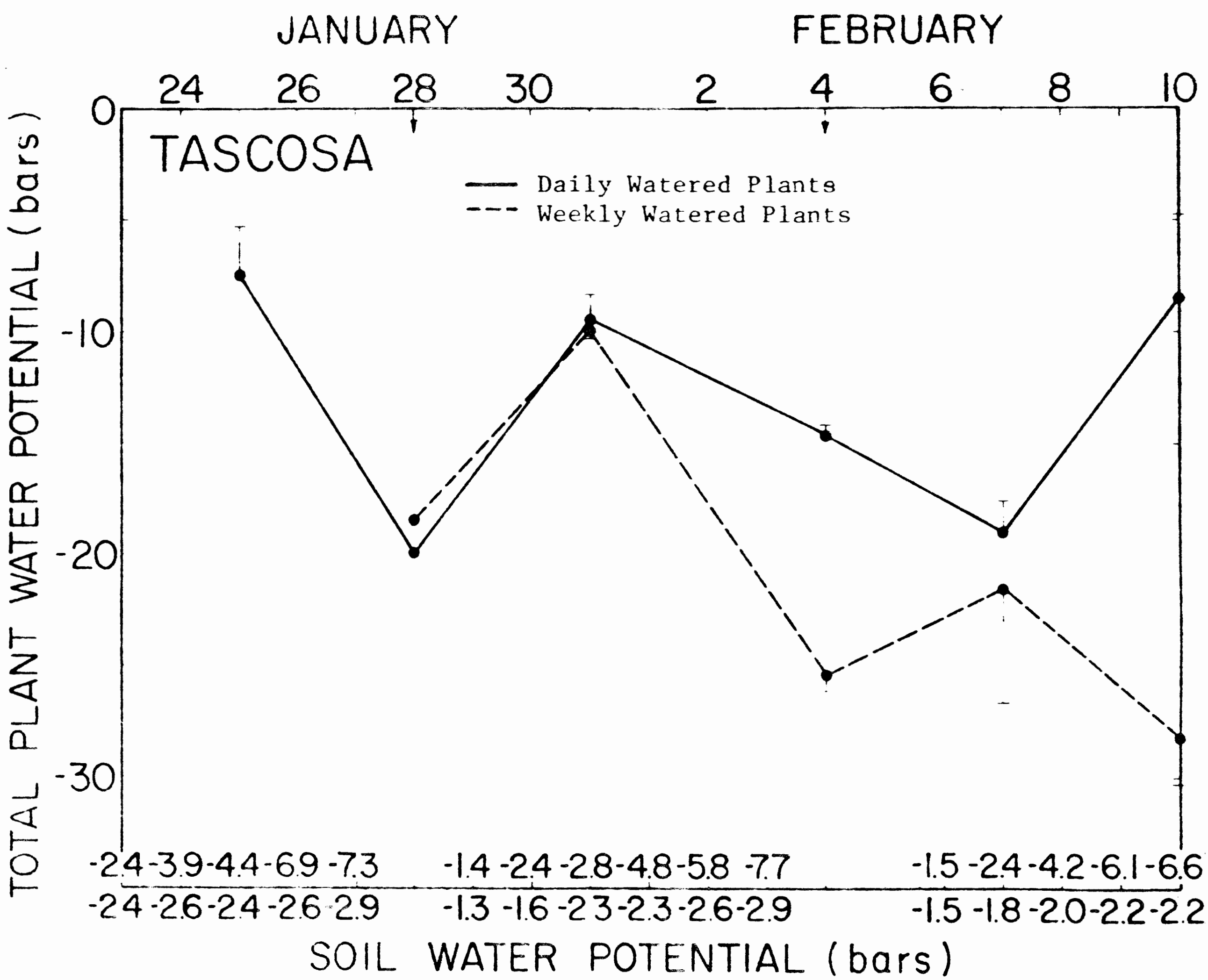

Figure 7 (Continued)

TABLE VIII

TOTAL PLANT WATER POTENTIAL - SCOUT 66

Variety	Day	Water	No. Obs.	TWP
SCO	25	D	2	9.5
SCO	25	W	2	9.2
SCO	28	D	2	14.0
SCO	28	W	2	8.5
SCO	31	D	2	12.2
SCO	31	W	2	13.1
SCO	35	D	2	4.5
SCO	35	W	2	9.8
SCO	38	D	2	18.2
SCO	38	W	2	31.0
SCO	41	D	2	5.7
SCO	41	W	2	31.5

SCO = Scout 66
D = Daily Watered Plants
W = Weekly Watered Plants

and the corresponding soil water potential for the same period (Table IX, which gives soil water potential for the cultivar Scout 66 on a daily basis for both daily (D) and weekly (W) watered plants) shows the total plant water potential for Scout 66 during this period to be very close to that of the soil water potential. Shortly thereafter, its total plant water potential began to show a decrease, then increased somewhat, and thereafter decreased sharply and leveled off. It might be that sufficient tissue damage was caused or that Scout 66 is unable to take up enough water after short periods of soil moisture stress. Low water potential developed in these cultivars in drying soil near -7.0 to -8.0 bars soil water potential. Evidently, high stomatal resistance developed by most of the cultivars did not prevent the development of low total plant water potential.

TABLE IX

SOIL WATER POTENTIAL - SCOUT 66

Variety	Day	Water	No. Obs.	SWP
SCO	25	D	2	2.4
SCO	25	W	2	4.3
SCO	26	D	2	2.9
SCO	26	W	2	7.0
SCO	27	D	2	3.1
SCO	27	W	2	7.7
SCO	29	D	2	1.3
SCO	29	W	2	1.5
SCO	30	D	2	1.6
SCO	30	W	2	2.6
SCO	31	D	2	2.1
SCO	31	W	2	3.6
SCO	32	D	2	2.0
SCO	32	W	2	4.8
SCO	33	D	2	2.5
SCO	33	W	2	6.0
SCO	34	D	2	3.0
SCO	34	W	2	7.9
SCO	37	D	2	1.5
SCO	37	W	2	1.8
SCO	38	D	2	1.9
SCO	38	W	2	2.6
SCO	39	D	2	1.9
SCO	39	W	2	3.8
SCO	40	D	2	2.0
SCO	40	W	2	6.9
SCO	41	D	2	2.1
SCO	41	W	2	7.9

SCO = Scout 66
D = Daily Watered Plants
W = Weekly Watered Plants

CHAPTER V

SUMMARY AND CONCLUSION

The cultivars of Hard Red Winter Wheat used in this study were found to differ with respect to the soil water potential at which stomata closed. Stomata may close at a higher soil water potential upon subsequent drying cycles.

Centurk and Concho were found to exhibit several qualities which might make them more adaptive to dryland areas. For example, they closed their stomata earlier than the rest of the cultivars; soil moisture stress did not appear to affect root mass of Concho, while Centurk reduced transpiration rate as soil moisture decreased relative to the rate at which it transpired when sufficient water was available.

An inverse relation was found to exist between soil water potential and stomatal resistance. Stomatal resistance may increase with type and age of cultivar. For example, stomatal resistance recorded for Concho continued to increase over time, while those recorded for Tascosa or Improved Triumph did not show noticeable increase.

Transpiration rate decreased linearly for most of the cultivars as soil moisture decreased.

All cultivars reduced leaf area as well as plant height in response to soil moisture stress.

Total plant water potential below -20.0 bars caused reduced transpiration rate with age of the cultivars.

The development of high stomatal resistance did not prevent the development of low total plant water potential.

Cultivars must be developed which have stomatal behavior and total plant water potential at which stomata close similar to that of Concho but with a root mass like that of Centurk or Concho.

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VITA

Gideon Boi-Tono Adjei

Candidate for the Degree of

Master of Science

Thesis: PLANT WATER RELATIONS OF SIX CULTIVARS OF WINTER WHEAT GROWN UNDER SOIL MOISTURE STRESS

Major Field: Agronomy

Biographical:

Personal Data: Born in Accra, Ghana, April 13, 1949, the son of Theodore E. N. and Mary O. Adjei.

Education: Received G. C. E. 'A' Level from University of London, June 1969; received a Bachelor of Science in Agriculture degree with a major in Agronomy from Texas A & I University, Kingsville, Texas, December, 1975; completed requirements for the Master of Science degree at Oklahoma State University, May, 1978, with a major in Agronomy.

Professional Organizations: Member of ASA, CSSA, Alpha Tau Alpha, Alpha Chi, Smithsonian Associate and Vice President of African Student Organization, Oklahoma State University.

Honors: Received Grant-in-Aid of Research for Sigma Xi, The Scientific Research Society of North America, in Spring, 1978.