WATER STRESS OF TALLGRASS PRAIRIE PLANTS

IN CENTRAL OKLAHOMA

By

DANIEL R. HAKE

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Fort Hays State University

Hays, Kansas

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Thesis Adviser

Dean of Graduate College

PREFACE

Approximately 50 percent of the land surface of the United States is rangeland. A source of forage for free-ranging native and domestic animals as well as a source of wood products, water, and wildlife, these renewable natural resources must be maintained and managed on the basis of ecological principles to sustain their productivity. Only through understanding, support and education to proper range management can this objective be reached.

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This thesis was written in a format to facilitate immediate submission for a technical article in the Journal of Range Mangement. Approval for presenting the thesis in this manner is based on the Graduate College's policy of accepting theses written in manuscript form. This approval is subject to the Graduate College's acceptance of the major professor's request for a waiver of the standard format.

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CHAPTER I

INTRODUCTION

The soil water supply on central Oklahoma grasslands, and on the majority of all rangelands as well, is often inadequate for optimum plant growth throughout much of the growing season. When transpiration exceeds water absorption a decline in plant water potential results, inducing a state of water stress (Kramer, 1969; Slatyer, 1967). Hsiao et al. (1976) stated that cell metabolism is markedly affected by the removal of only 10 to 15 percent of the water held in plant tissues at full turgor. In an extensive literature review, Hsiao (1973) noted previous investigations found cell growth, wall synthesis and protein synthesis were the initial cell functions to be inhibited by water stress, and under prolonged stress, cell division was also affected. Kramer (1969) stated:

> the degree of water stress (in plants) is probably best expressed in terms of water potential, because this appears to be the most closely related to the physiological and biochemical processes which control growth (p. 390).

Leaves or shoots often show mid-day depressions in water potentials on sunny days when atmospheric water demands are high (Hsiao et al., 1976). If adequate soil moisture is available, internal gradients produced the previous day are usually diminished at night. At that time atmospheric demands for water are low and stomatal closure prohibits transpiration allowing leaf, shoot, and soil water potentials to reach an equilibrium (Ritchie and Hinckley, 1975). If soil water availability is low, plants do not regain the early morning equilibrium. When this occurs, daily water stress begins to form long-term stress patterns (Brown, 1977; Slaÿter, 1967), and these cause unfavorable physiological and morphological effects on the vegetation (Hsiao, 1973; Hsiao et al., 1976; Broyer, 1976). Ritchie and Hinckley (1975) tentatively stated that overnight equilibrium tends to be established in soils with high soil water potentials if transpiration is sufficiently retarded. Thus predawn xylem water potentials closely relate to the effective soil moisture. They further assert, as soils dry, predawn xylem water potentials become less indicative of soil moisture, but do indicate the level of water stress at which the plant begins the day and therefore remain useful as estimates of effective soil moisture.

Although the direct dependence of plant growth on plant water status is generally accepted, very few studies concerning tallgrass prairie plant species and plant water stress appear in the literature. Consequently, the main objective of this study was to determine levels and conditions of water stress in tallgrass prairie plant species during a dry growing season.

CHAPTER II

STUDY AREA

The study was conducted on an excellent condition, tallgrass prairie in Canadian County, Oklahoma (lat. 35° 30'N, long. 98° 00'W, elevation 600 m). Annual precipitation (Figure 1) averages 750 mm with nearly 80 percent occurring during the 208-day growing season from early April to early November (NOAA., 1980). Monthly precipitation is lowest in winter and highest in spring. The highest monthly average maximum temperature of 34 C occurs in August and the lowest monthly average minimum temperature of -3 C occurs in January. Mean monthly wind velocities vary from 18 km/hr in July to 24 km/hr in March. Monthly relative humidity at 0600 hours is approximately 80 percent throughout the year. Precipitation data were collected at the study site; all other weather data were collected at Oklahoma City (lat. 35° 24'N, long. 97° 36'W) by the National Weather Service.

The study area was on a three percent northwest-facing slope. Soils in the study area, as examined and described by a soil scientist, were transitional between a claypan prairie (Renfrow series) and a loamy prairie (Milan series) range site (Nance and Gray, 1977). The predom inante soil, Renfrow, was a member of the fine, mixed, thermic family of Vertic Argiustolls except the surface 0-34 cm had a loam texture. The secondary soil, Milan, was a member of the fine loamy, mixed, thermic family of Udic Paleustolls, with a 0-15 cm A1 horizon and a 15-30 cm B1

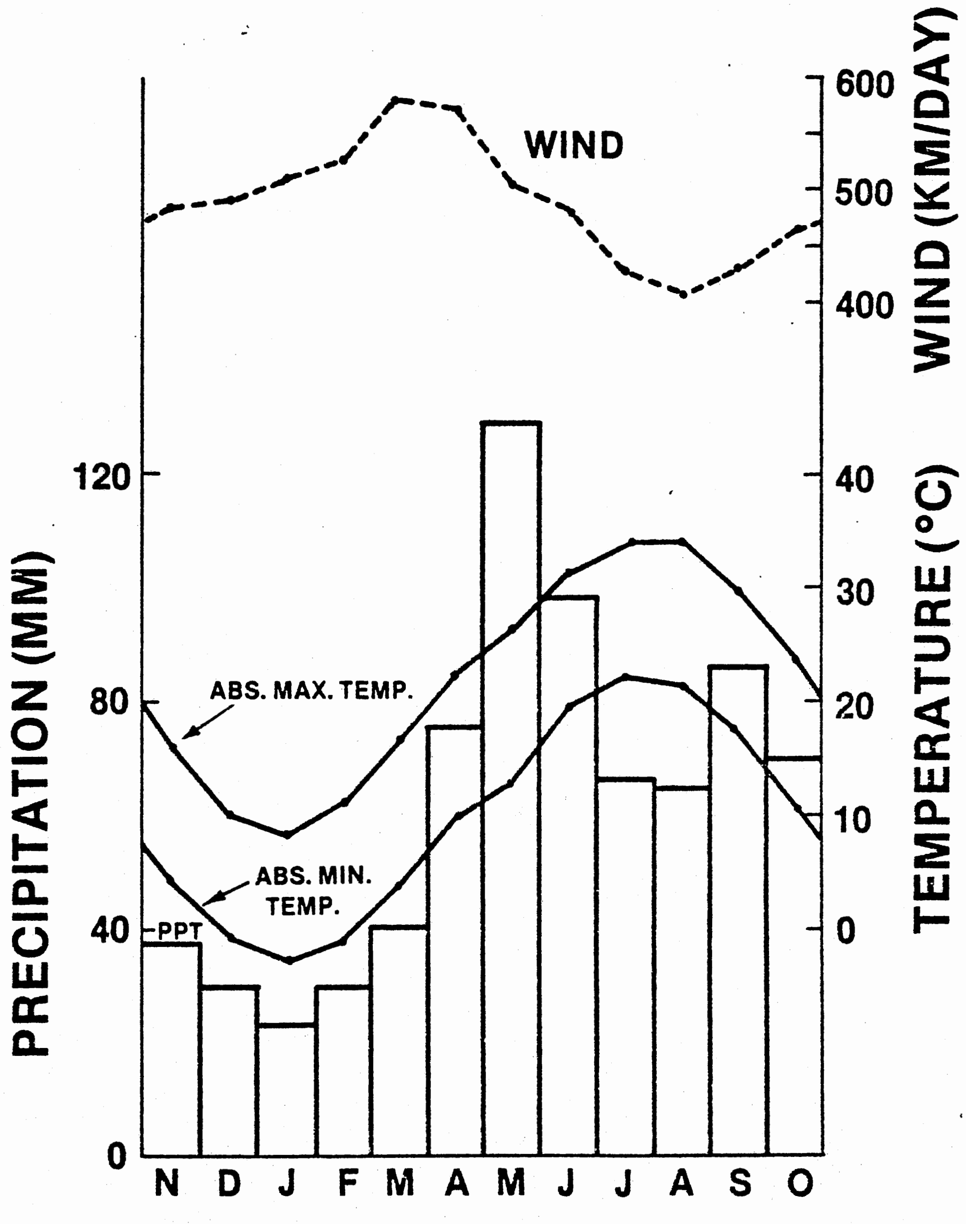

Figure 1. Long Term Average Monthly Precipitation (mm), Absolute Maximum and Minimum Temperatures (C) and Wind (km/day) for Study Area, in Canadian County, Oklahoma

horizon of loam texture. Both soil types are deep and well drained with slow permeability which developed from either shale or clayey and loamy sedimentary parent materials. The vegetation on these soils is dominated by *Andropogon gerardi*, *Schizachyrium scoparium*, *Panicum virgatum*, and *Sorghastrum nutans* when the range is in excellent condition (USDA, 1976). Common increaser and invader species include *Bouteloua curtipendula*, *B. gracilis*, *Buchloe dactyloides*, annual *Bromus* spp., *Ambrosia psilostachya*, and *Achillea lanulosa*. A detailed description of the site was given by Dunn and Powell (1979).

The study area has a rather long and varied history of grazing, but it was never plowed. For about 30 years prior to the study the area was part of a pasture grazed moderately (0.25 animal unit/ha) by a cow/calf beef herd. In the fall of 1977 the area was mowed, but the hay not removed. The area had been deferred from grazing since 1978.

CHAPTER III

METHODS

A pressure equilibration chamber (Scholander et al., 1965; Ritchie and Hinckley, 1975) was used to determine the predawn water potentials (ψ) of four grasses and three forbs. Grasses sampled were *Andropogon gerardi* (ANGE, big bluestem), *Schizachyrium scoparium* (SCSC, little bluestem), *Sporobolus asper* (SPAS, tall dropseed) and *Panicum oligosanthes* (PAOL, Scribner's panicum). The forbs sampled were *Ambrosia psilostachya* (AMPS, western ragweed), *Psoralea tenuiflora* (PSTE, slimflower scrufpea) and *Solanum eleaginfolium* (SOEL, silverleaf nightshade). Experimental plants were randomly selected from a 20 m x 20 m study area. Sampling began about two hours before sunrise and ended just before sunrise. A grass blade or a forb stem was removed from the sample plant and was sealed in a pressure chamber with the cut surface of the excised blade or stem protruding through a stopper located on the top. Pressure in the chamber was increased at a constant rate of approximately 0.7 bars/sec until water appeared at the cut end. The balancing pressure was then read and recorded. This procedure was replicated three times on three individual plants of each species every sampling day.

The vegetation in an area adjacent to the study plot was sampled throughout the 1980 growing season to coincide as closely as possible to pressure chamber sampling days. Aboveground live biomas (ALB) and composition of the vegetation were determined using a combination of the double sampling (Wilm et al., 1944) and weight-estimate (Pechanec and Pickford, 1937) methods.

The soil moisture content was determined in an adjacent area of similar soils and physical features using a neutron probe (Stone et al., 1955). The area where the probe was located was part on another ongoing study and was subjected to moderate grazing. Soil water values presented indicate probable soil water status and movement in the study area.

Data were analyzed with an analysis of variance for a completely randomized design. Regression equations were developed for interpretation of data. Water potential models were developed for each species for the sampling period. An aboveground live biomass model was also developed for the 1980 growing season. Water potential and ALB (kg/Ha) values were used as dependent variables. Independent variables for both models were days, which for calculation purposes were based upon a modified Julian year beginning November 1. Unless otherwise stated, all differences were significant at the 0.05 level of probability.

CHAPTER IV

RESULTS AND DISCUSSION

The summer of 1980 was hot and dry (Figure 2). After an unusally wet spring, only 120 mm of rainfall was recorded for the June through September period. Most (91 mm) of this rainfall occurred in late June. Average monthly temperatures were 33, 39, 38 and 31 C during June, July, August and September, respectively. The relative humidity at 0600 hours ranged from 59 percent in August to 77 percent in September.

Schizachyrium scoparium had the lowest daily mean Ψ, -48 bars, recorded 13 August (Figure 3). The highest daily mean value recorded for the grasses, -1.0 bar, occurred 24 June in *Andropogon gerardi*. Forb Ψ followed similar gradual decreasing trends, with pressures ranging from -1.2 bars to -12.0 bars. Significant differences ($p < .05$) among species occurred on 6 of 10 sampling days. Significant differences occurred on only two of the first six sample days. *Sporobolus asper* Ψ was greater than that of other species on 4 June, but differences were small and no reasonable explanation is available at this time. On 9 July, *Panicum oligosanthes* had the lowest Ψ value, -10.0 bars. This may have been the beginning of short term stresses in this species, possibly due to changing microenvironmental factors. Pressures on 23 July were not significantly different although all species had significantly lower pressures than previously recorded, indicating probable reduction of available soil moisture. After 23 July, large differences in mean pressures occurred,

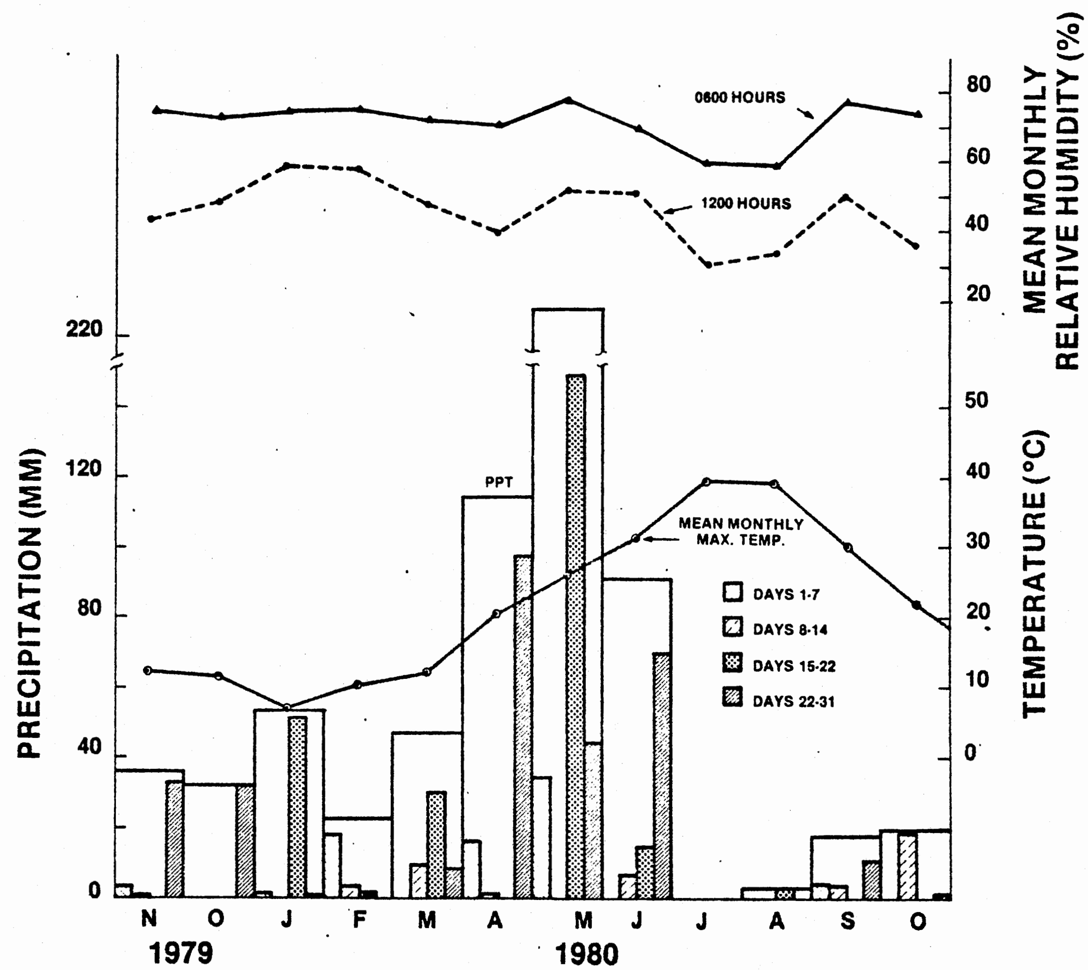

Figure 2. 1980 Monthly Precipitation (mm), Weekly Precipitation (mm, Inside Average Monthly Precipitation Bars), Mean Monthly Maximum Temperature (C) and 0600- and 1200-hour Relative Humidity Values (%) in Canadian County, Oklahoma

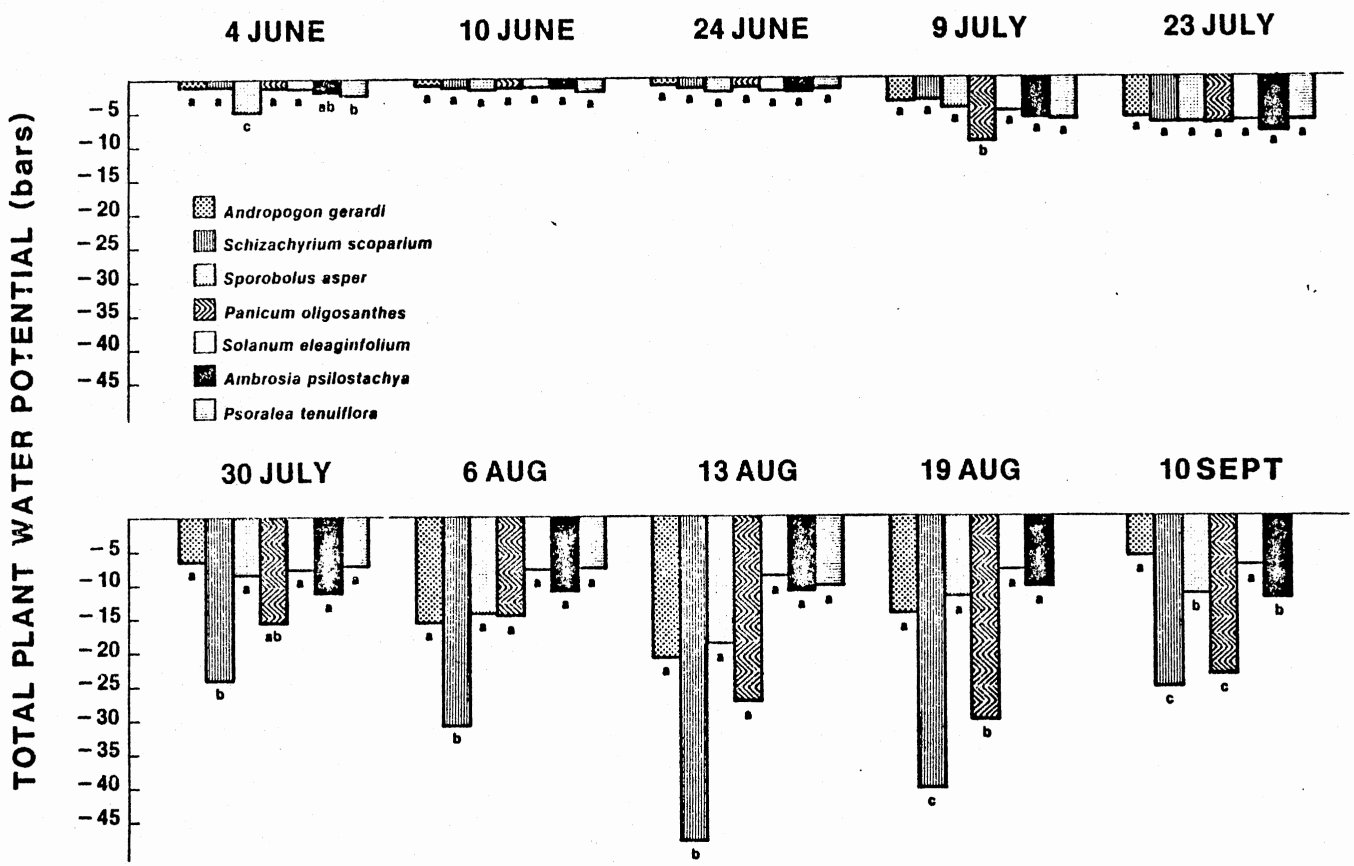

Figure 3. Tallgrass Prairie Plant Species Mean Water Potentials 4 June to 10 September, 1980, Canadian County, Oklahoma. All Values with the Same Lower Case Letter are not Significantly Different at the 0.05 Level

with Ψ SCSC and PAOL being greater than those for the other species. Psoralea tenuiflora plant began to die and abscise from their root crowns in late July. Dunn (1977) noted that critical Ψ values may be the cause of abcision in the majority of plants in a PSTE population. The lowest pressure for this plant, -11.5 bars, occurred 6 August. No PSTE plants were found after 13 August.

In a summary of permanent wilting points of plants as quoted from studies in the literature, permanent wilting points in leaves ranged from -13 to -45 bars, with values of -19, -17.7, -17.7 and -34 bars for tomato, smooth brome, intermediate wheatgrass and cotton, respectively (Brown, 1977). Brown also indicates that protoplast collapse was observed at -36.7 bars in Smooth brome and -37.8 bars for intermediate wheatgrass as measured under controlled environmental conditions.

All species had decreasing seasonal Ψ trends (Figure 4). Fluctuations early in the season seem to coincide with late June precipitation events. Only SCSC and PAOL had rapid declines in predicted Ψ values, both occurring in mid to late August. All other species followed a gradual decline until the 10 September sampling date when species sampled had increased pressure values. This increase late in the season may be due to several factors. Light rain showers occurred several days before and on the evening before the sampling day, possibly allowing the dehydrated plant cells to regain water. It is also possible the mid-season measurements did not represent an equilibrium condition with soil water potentials. Late in the season, all plants became dormant, and values increased slightly, possibly due to reduced water loss and passive absorption by tissue (Brown, 1977; Kramer, 1969). Decreased photosynthetic activity, stomatal closure, changes in solute potential and

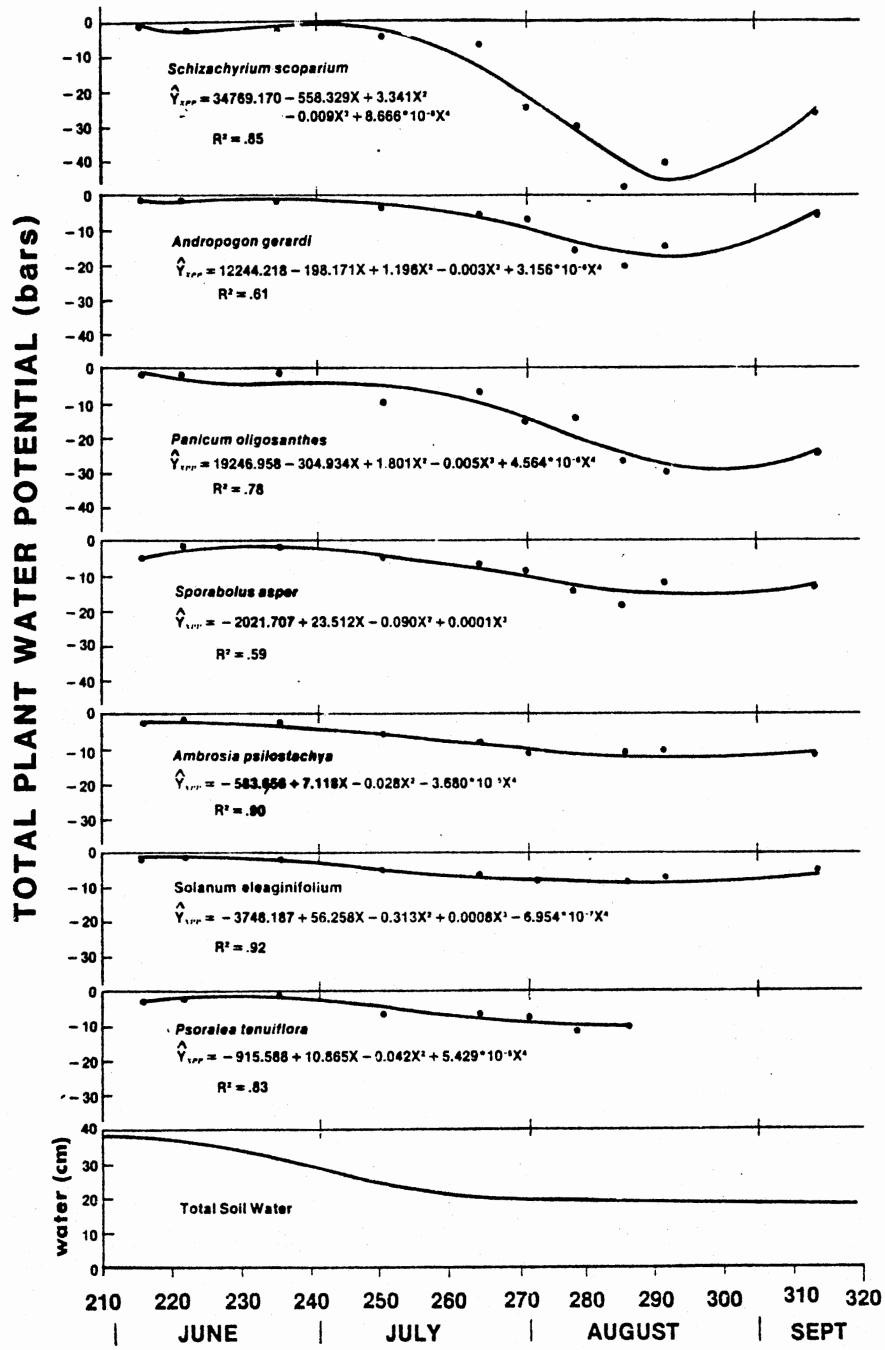

Figure 4. Water Potential (bars) Models for Seven Tallgrass Prairie Plant Species and Total Soil Water (0 - 122 cm depth), June - September, 1980, Canadian County, Oklahoma

absorption of atmospheric moisture are other factors which may have also contributed to pressure increases (Broyer, 1976; Hsiao et al., 1976; Slayter, 1967).

Soil moisture monitored with a neutron probe at 15 cm increments to a 122 cm depth indicated total soil water for the profile ranged from 38 cm in late May to 19 cm in mid-September (Figure 4). The upper 45 cm (37 percent of profile depth) of the profile held 40 to 45 percent of the total soil water until early June (Figure 5). In June, 91 mm of rain (91 mm rain; 0 mm runoff) entered the soil. However, during June, very great evapotranspiration losses caused a large reduction in soil moisture in the upper 45 cm of the profile. As soil water levels in the upper profile decreased, mean pressure potentials became less uniform indicating different levels of stress beginning among plant species.

Vegetation growth began in early April and reached peak production in early June. An above ground biomass (kg/ha) model developed from vegetation samples estimated the peak ALB to be approximately 3100 kg/ha (Figure 6). Low summer precipitation combined with record high temperatures induced rapid depletion of soil moisture slowing vegetation growth after late June. Growth patterns on grasslands dominated by warm season plants are greatly influenced by the spring and summer rainfall events (Sims and Singh, 1978). Peak ALB periods in the tallgrass prairie can vary from June through August (Conant and Risser, 1974; Dunn, 1981; Powell et al., 1978; Sims and Singh, 1978).

Sims and Singh (1971) in a comparison of net primary production of North American grasslands found a significant inverse curvilinear relation between the amount of below ground plant material and depth (decreasing biomass with increasing depth) on several grazed and ungrazed

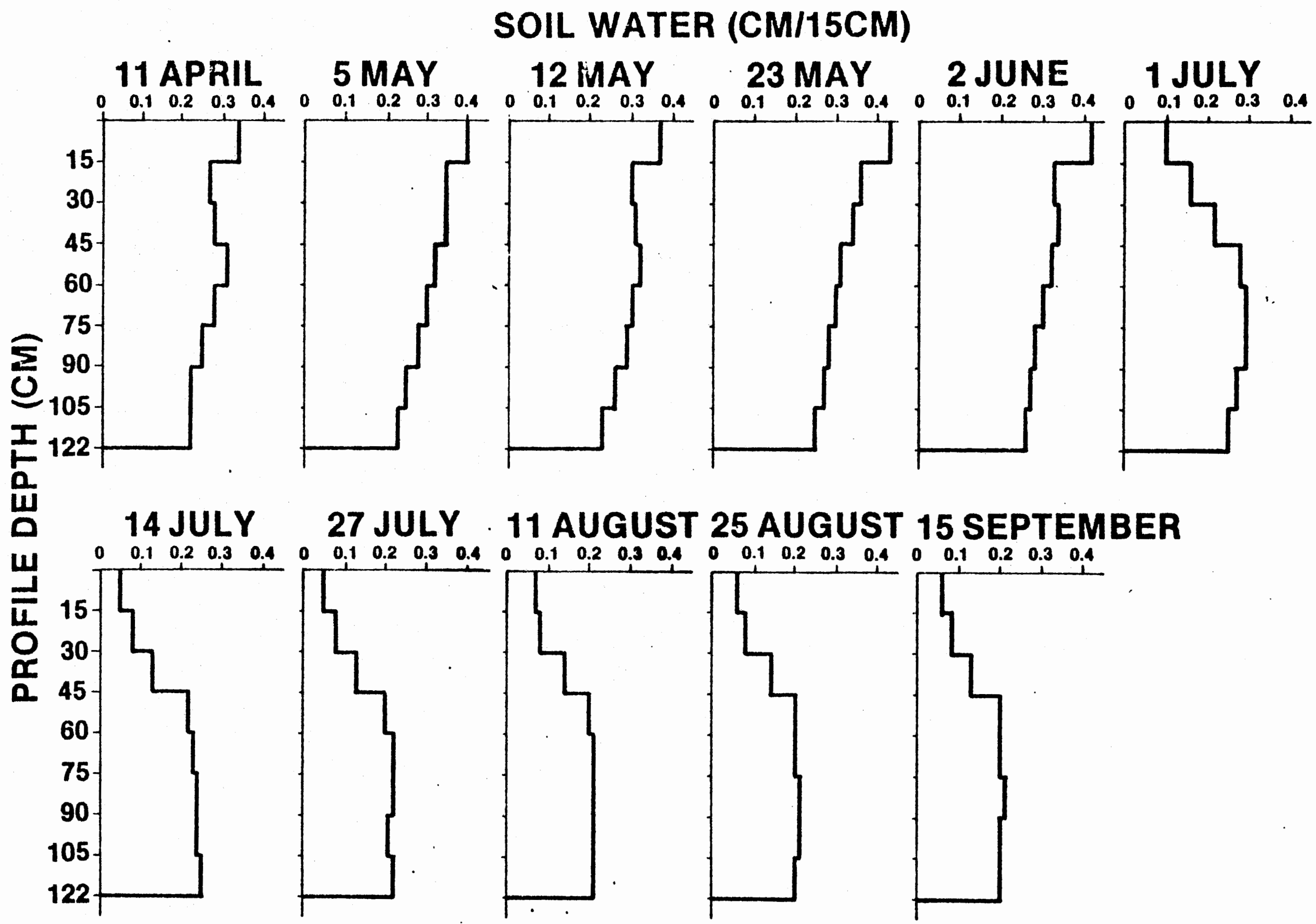

Figure 5. Soil Water Content (cm) at 15-cm Increments of a Vertic Argiustoll Soil Profile Between 11 April and 15 September 1980, Canadian County, Oklahoma

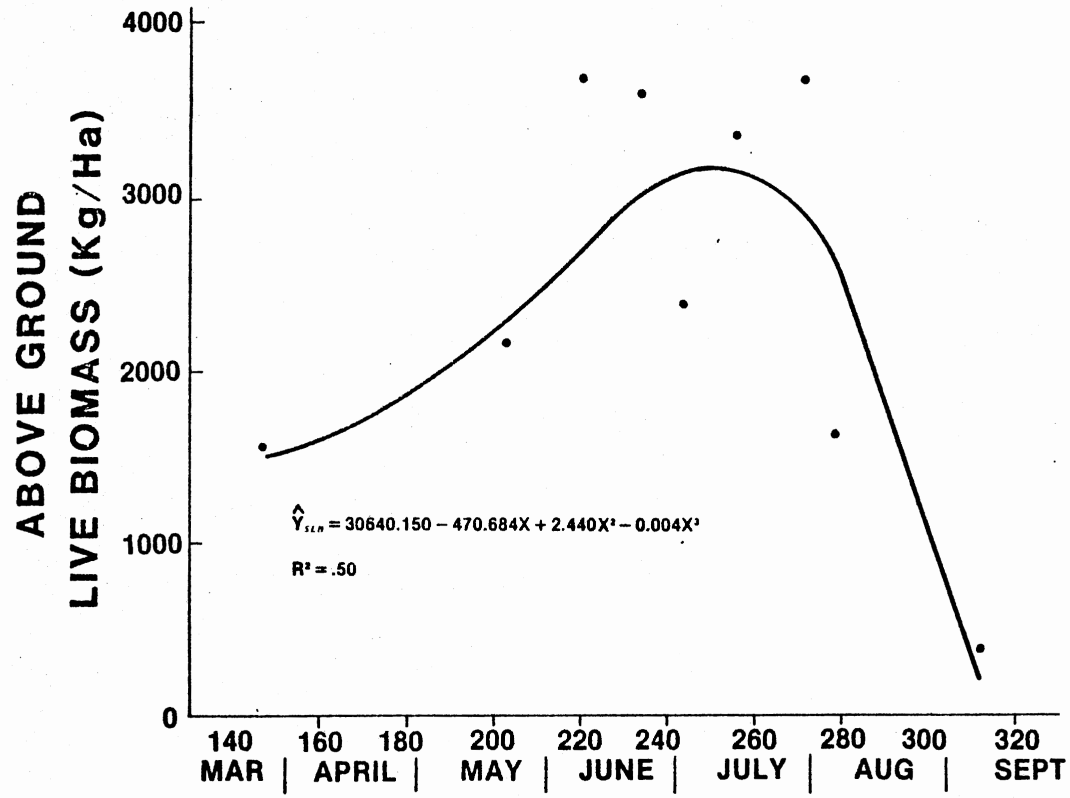

Figure 6. Model of Tallgrass Prairie Aboveground Live Biomass (kg/ha), March - September, 1980, Canadian County, Oklahoma

grasslands. The majority of grassland-root biomass is located in the upper 30 cm of the soil profile (Dahlman and Kucera, 1965; Sims and Singh, 1978; Weaver, 1968).

Root studies in a true prairie region near Lincoln, Nebraska (Weaver, 1968) noted that ANGE roots varied from 0.5 to 3 mm in diameter and were found at depths greater than 2 m, while SCSC varied from 0.1 to 0.8 mm in diameter and usually grew to a maximum depth of 1.5 m, with a possible lateral spread of 0.5 m. During a midseason drought period in southwest Kansas, maximum root depth attained by grasses, including SCSC, on shallow soils was only 1.5 m (Tomanek and Albertson, 1957). Many forb roots in both studies were measured at depths below 1.8 m. *Ambrosia psilostachya* roots and the tap roots of PSTE reach depths of 1.5 to 1.8 m and 2.2 to 4.3 m, respectively (Dunn, 1977; Weaver, 1958). Due to the high root biomass content in the upper layers of the soil, transpiration is high and soil moisture is rapidly depleted if not recharged. Deep root penetration and high root densities are important for water uptake (Kramer, 1969; Ritchie and Jordan, 1972).

Both SCSC and PAOL have shallow root systems. Thus as the upper soil dries, water availability decreases causing higher degrees of stress. *Andropogon gerardi* and SPAS have deeper root systems which may help these and other deep-rooted plants to maintain lower levels of water stress during dry periods (Cook, 1943). The forbs sampled are all deep-rooted and showed only moderate levels of stress.

Rooting patterns are only one of several factors which affect water stress resistance capabilities in plants. Brown (1977) stated

> plant drought resistance results from either (1) an ability to tolerate or endure stress because the protoplasm can sustain dehydration, or (2) structural and physiological adaptions that result in avoidance or postponement of the lethal effects of drought (p. 120).

Low Ψ values may not be uncommon for SCSC or other shallow-rooted prairie plants due to drought tolerance adaptions (Levit, 1972). This drought tolerance may be due to structural adjustments such as smaller cell size (Cutler et al., 1977), or other adaptations to prevent mechanical injury and development of desiccation resistant protoplasm (Brown, 1977). However, further study of these factors in SCSC and other tallgrass prairie species is needed to determine their role in plant survival and their relationships with plant water stress and growth.

CHAPTER V

SUMMARY AND CONCLUSIONS

Plant water stress expressed in terms of water potential appears to be closely related to the physiological and biochemical processes controlling growth. Water stress affects almost every aspect of plant growth, by modifying the anatomy, morphology, phsyiology and biochemistry. In this study conducted in central Oklahoma, seven tallgrass plant species were sampled to determine Ψ through a dry, hot growing season. Water potentials declined rapidly after June due to increasing temperatures and decreased soil water, causing increased levels of water stress in all species sampled. The decline in Ψ for SCSC, and to a lesser extent, PAOL, was much greater than that for the other five species. Data analyses indicated that ANGE was less affected by soil water depletion in the upper soil profile than was SCSC. Above ground live biomass declined sharply at about the same time plant water potential values decreased sharply. Water potential levels in these species indicate differing water relation strategies with their environment. Understanding these strategies may be important in determining appropriate plants for seeding different range sites, estimating optimum herbage production and grazing periods during a growing season and for other management decisions. The effect of stress on total herbage yield on grazed and ungrazed grasslands is still uncertain. Continued investigation of this subject is greatly needed.

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VITA

Daniel R. Hake

Candidate for the Degree of

Master of Science

Thesis: WATER STRESS OF TALLGRASS PRAIRIE PLANTS IN CENTRAL OKLAHOMA

Major Field: Agronomy

Biographical:

Personal Data: Born in Hays, Kansas, October 4, 1954, the son of Mr. and Mrs. Edward J. Hake.

Education: Graduated from Colby High School, Colby, Kansas in May, 1972; received Bachelor of Science degree in Botany from Fort Hays State University in December, 1979; completed requirements for Master of Science degree at Oklahoma State University in May, 1982.

Professional Experience: Teaching and research assistant, Department of Biological Sciences, Fort Hays State University 1978-1979; Kansas Fish and Game, January-May, 1980; graduate research assistant, Department of Agronomy, Oklahoma State University, May, 1980 - present.

Professional Organizations: Society of Range Management.