THESIS

VARIETY TOLERANCE TO DROUGHT IN KENTUCKY BLUEGRASS

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY PETER HAMILTON DERNOEDEN ENTITLED VARIETY TOLERANCE TO DROUGHT IN KENTUCKY BLUEGRASS BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

Committee on Graduate Work

Adviser

ABSTRACT OF THESIS

VARIETY TOLERANCE TO DROUGHT

IN KENTUCKY BLUEGRASS

The relative drought tolerance of 25 Kentucky bluegrasses were studied by examining seedlings and mature plants in the field and greenhouse. The anatomy and morphology of representative varieties were studied relative to drought tolerance.

The varieties were tested under field conditions and the "common types" were shown to be the more drought tolerant. Code 95, a common type, and Merion exhibited excellent drought tolerance and produced turf with good color, texture and density. Turf mowed at $1\frac{1}{2}$ inches was more tolerant to drought than turf maintained at 3/4 inch.

Seedlings of ten varieties were subjected to drought stress. The primary purpose of this study was to determine the length of time seedlings could survive between irrigations. The study indicated that drought tolerance for mature turfgrass could not be adequately determined from seedlings. Maturity and rhizome development of Kentucky bluegrass were correlated with drought tolerance.

To obtain supportive data for field findings, drought work was repeated under greenhouse conditions. Contradictive data was

obtained due to environmental differences in the greenhouse. Several varieties, however, responded similarly in both field and greenhouse. It was concluded that Code 95, Merion and Geary, a common type, required less water to produce quality turf. Windsor and Pennstar did not satisfactorily tolerate drought stress in either the greenhouse or field.

The morphology and anatomy, as related to drought, was investigated. The purpose was to determine what structural adaptations, if any, may be responsible for postponing internal moisture stress. Drought tolerant varieties were shown to be relatively more rapid growing, to have many, small stomata on the upper leaf surface and fewer and relatively larger stomata on the lower leaf surface, bulliform cells of greater length, closely oriented vascular bundles, smaller metaxylem vessels, and an absence of thick walled sclerenchyma fiber development.

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INTRODUCTION

Efficient utilization and management of water is becoming more important in agriculture, particularly for landscape use where no food is produced. The reduction in water availability is directly related to the rise in the world's population and the subsequent need for more food production. Today, as in the past, man must rely upon natural precipitation. In the arid United States irrigation, not precipitation, remains the primary source of water for all crop use. While precipitation remains relatively constant, the need for irrigation water increases. The largest dependable fresh water supply anticipated for the United States is about 650 billion gallons per day (Lunin, 1967). Presently, approximately 400 billion gallons of water are used daily. By the year 2000 the projected daily water requirements will be at 1000 billion gallons. Because of this increased water demand, sanitary engineers estimate that by 1980 all water will be used at least twice before release to the environment.

More water is needed not only for agriculture, but also for numerous other industrial and urban demands. One of these demands is for Kentucky bluegrass (Poa pratensis L.) turf, perhaps the largest acreage cultured in North America (Hanson and Juska, 1969). In the arid regions of the United States large quantities of supplemental irrigation water is used to maintain Kentucky bluegrass. Various

studies indicate that Kentucky bluegrass requires approximately one inch of water per week during the growing season. Although this estimation may be high, there is little doubt that more water is needed to maintain turf in the arid west than is supplied by natural precipitation. Therefore, perhaps as much as 18 to 20 inches of additional water may be needed to produce quality turfgrass in the arid United States. Woodward (1972) noted that nearly 42 percent of the total municipal and industrial water supply in Denver, Colorado is used for lawn irrigation. A recent study conducted in New Mexico indicated that approximately 70 to 75 percent of private metered water is applied to the landscape (Chavez, 1972). Homes in New Mexico with 90 to 100 percent of the yard in plant materials apply 88 percent more water per home than landscapes where plants were grown on only 50 to 70 percent of the yard. Tovey et al. (1969) has noted that water accounts for 14.5 percent of the maintenance budget for turf. This expense is only exceeded by the cost of labor. Water costs are expected to increase 6 to 7 percent annually during the coming years. Hence, large sums of money and great quantities of water are being allocated to the maintenance of Kentucky bluegrass turf in Colorado and New Mexico.

With water resources remaining relatively constant, and demands increasing rapidly it is realistic to assume that water allocated to landscape purposes will be drastically reduced in the near future.

For this reason, it is imperative that ornamental and turfgrass selection and breeding programs be directed towards developing varieties that require less water. In addition to the need for more drought-tolerant species, more knowledge is needed on how to grow existing varieties with less water. Other sources of water, such as sewage and industrial effluents, should be considered. Also needed is in depth consideration of anti-transpiration chemicals for use on irrigated turf.

An extensive review of the literature revealed that very little research has been devoted to the study and development of turfgrasses that are tolerant of drought. This factor, more than any, has caused a need for the beginning investigation into the varietal tolerance to drought of Kentucky bluegrass, the most widely used turfgrass in the northern regions of the United States. It is the intention of this study to establish relevant information to serve as a basis for future study; also to provide information on varieties of Kentucky bluegrass which can be utilized to conserve water today. The scope of this inquiry is limited to a study of morphological, anatomical and physiological relationships that might influence drought tolerance. A large portion of the study is devoted to the determination of the relative drought tolerance of 25 varieties of Kentucky bluegrass. A study of the gross morphology and anatomy of several varieties was initiated with the intent of providing basic information to explain (in part) differences in drought tolerance among varieties.

A prolonged water deficit that induces stress, thus limiting or preventing growth is termed drought. Drought is a relative term which may be readily defined in a descriptive sense. However, the precise meaning of drought is quantitative and not easily defined (Herbell et al., 1972). Water deficits that induce drought are caused by numerous environmental conditions and the reaction of plants in response to these conditions during their various stages of development should be considered. Consequently, the definition of drought must be elaborated to include the ecological factors of soil and atmosphere as well as plant physiology.

Soil drought is correlated with a decrease of available soil moisture to a point where plants are unable to absorb water rapidly enough to replace that transpired. Atmospheric drought arises when water deficits cause wilting and desiccation due to transpiration exceeding absorption, although available soil moisture levels would normally be considered to be adequate. Physiological drought develops when water deficits are caused by cold soils or a high osmotic pressure of the soil solution which interferes with water absorption.

Severity of drought depends upon the duration of periods without effective precipitation, on the evaporative power of the air, on air and soil temperature, on wind movement and on soil type. Characteristics of soil type of importance include its mechanical analysis,

its organic matter, its water holding capacity, its total salt content and its field capacity.

LITERATURE REVIEW

Soil Factor

Drought is most commonly correlated with soil moisture, and occurs when available soil moisture is lowered to the point where the plant is unable to extract water rapidly enough to replace that lost to the air by transpiration and evaporation.

To understand drought entirely one must understand the route of water from the soil, through the plant and into the atmosphere. The edaphic role of drought has been efficiently explained by Schmidt (1973) and warrants consideration.

When soil moisture decreases, soil water tension will increase. If the plant water suction (water potential) is less than the suction of the soil the roots are unable to take up water and desiccation will result. As the soil adjacent to the root system dries a soil water suction gradient develops and water will move from a wet to dry area. As in the soil, water within plants will move along a gradient of decreasing water potential within the intercellular air spaces of leaves and evaporation occurs. Thus, the water vapor diffuses through the stomatal cavity to the air boundary above the leaf and finally the external atmosphere.

Within the fully turgid leaf the air spaces are saturated with water vapor. The temperature of the leaf will be lower than the

ambient air temperature. As the temperature of air increases the leaf temperature will increase. If the temperature of the turgid leaf exceeds air temperature, water will transpire from the leaf. Transpiration also occurs when the relative humidity of the air is lower than the humidity in the leaf.

Transpiration rate is influenced by dissolved substances within the cell. These substances may influence water retention by plants.

It is of interest to note that the wilting point of the plant does not delimit the lower limit of soil moisture availability to plants, but rather the approximate lower limit available for growth (Furr, 1945).

Physiology of Drought Injury

In response to internal water deficits stomates close and transpirational losses are significantly reduced. As drought continues, plants become wilted as a result of their inability to remove sufficient quantities of water from the soil to maintain turgor. Prolonged drought results in injury due to desiccation, finally death occurs.

Early views of drought resistance maintained that those plants able to resist drought had a low rate of water loss. This hypothesis was disproven when xeromorphic species were shown to rapidly transpire when supplied with water. Consequently, emphasis was shifted from structural characteristics which enabled plants to reduce water loss to other ideas. Currently, the most widely accepted factor contributing to drought resistance is the ability of the protoplasm to

endure dehydration. A mechanism of drought injury was proposed by Iljin (1957). According to Iljin it is not the loss of water that kills cells, but the mechanical injury to cells resulting from the drying and remoistening processes. When plant tissue dries, cells will collapse. The outward diffusion of water causes the vacuole to shrink and the protoplasm is pulled inward. The cell wall will resist collapse and exert an outward pull on the protoplasm which adheres to the cell wall. Hence, the stress is produced by this inward pull by the shrinking vacuole and outward pull by the cell wall. This disruption results in death to the cells. Cells surviving drying are also subject to mechanical stress upon remoistening. Rupture of the protoplasm during remoistening results in death by dispersion of the cell sap. When tissues have not lost a great deal of moisture and the protoplasm remains semiliquid, vigor may be restored without rupturing the protoplasm.

Levitt (1951) opposes Iljin's mechanical disruption hypothesis. Levitt felt that injury occurred in the cytoplasm due to an unfolding and denaturation of protoplasmic proteins. According to Levitt water loss causes enzymes to alter shape so that active sites become disturbed and enzymatic activity is lost. High water stress, according to Levitt's hypothesis, affect the sulfhydral groups of protein by removing layers of water from around protein molecules. This causes the sulfhydral groups to contact one another in adjacent

proteins. Hydrogen is removed by oxidation and results in the formation of disulfide linkages. Remoistening will strain and distort these molecules and enzymatic activity is lost.

Other factors which influence drought resistance includes those which postpone dehydration and those which enable plants to endure dehydration.

A Classification of Drought Resistance

Kearney and Shantz (1911) classified plants which grow in droughty regions as drought escaping, drought evading, drought enduring and drought resisting. Drought escaping plants grow during periods when there is no drought. They are capable of escaping drought by a short, rapid growth period during which they produce seed. Drought evading plants are characterized by their ability to economically use limited soil moisture supplies. Water conservation by these plants is accomplished by wide spacings, maintaining small size with a small leaf surface, limited amount of annual growth and extensive root systems. Drought resistant plants include the succulents which store large quantities of water and are able to expand their root systems into dry soil. Drought enduring plants become drought dormant during periods of moisture stress. During dormancy they do not grow but live until water is again available to their roots.

A more elaborate classification pertaining to turfgrasses is offered by Beard (1973). According to Beard turfgrasses are able to survive drought by escape, dormancy, an increased water absorption capacity, xeromorphic features or a physiological capability to endure dehydration. Escape and dormancy are specialized mechanisms enabling turf to avoid soil drought. Increased water absorption capacity and xeromorphic features aid the plant in delaying the onset of dehydration. The physiological ability of the protoplasm to endure drought stress is probably the ultimate adaptation which enables a plant to survive desiccation.

Escape

Poa annua is a grass which escapes drought by producing seed during the favorable moisture periods of each spring and fall. This plant dies during drought periods and survives as seed.

Dormancy

During periods of severe soil drought or exposure to prolonged temperatures above 90°F, shoots will discontinue growth and eventually the aboveground leaves die (Madison, 1971). Buds in the crowns and rhizomes of Kentucky bluegrass are able to survive drought in a state of arrested development. New growth is initiated when soil moisture and temperature are favorable. These buds are extremely drought hardy due to their small cell size which are devoid

of vacuoles (Beard, 1973). Abscissic acid initiates dormancy of tree buds, perhaps a hormone is also responsible for the phenomenon of drought dormancy in turf.

Dormancy may alternate with growth several times in a season. With adequate irrigation Kentucky bluegrass is capable of breaking dormancy with recovery evident within one to two weeks.

The dead, straw colored leaves of dormant turf provides a mulch which contributes to moisture conservation and temperature modification.

Water Absorption Capability

Xeromorphic features which enable turfgrass to increase absorption capability include deep rooting, an increase of root mass, extensive root branching, an extended root hair zone, and vigorous root growth. It should be noted that those turf species which produce a deep, extensive root system are not necessarily drought hardy. A deep root system will, however, possess an increased capacity for absorption as it will normally be in contact with a larger volume of soil and will be exploring deeper soils where more water may be available. The extensive root system merely prolongs the eventual desiccation of grass plants during intensive drought. This increased capability is, however, only proportional to the amount of moisture that is present at lower depths.

The root system of Kentucky bluegrass may penetrate approximately 30 to 36 inches. This is considered only intermediate in depth when compared with other turf species. The short grasses indigenous or naturalized to the high plains are typically low growing and shallow rooted due to the limited rainfall of the region. The shallow root system of grasses such as buffalograss (Buchloe dactyloides) and blue grama (Bouteloua gracilis) is an adaption which enables these grasses to benefit from brief rains which typically occur during summer in Colorado. These summer rains rarely penetrate greater than 2 feet before the moisture is exhausted. Deep rooted species, therefore, benefit very little from an extensive root system if no water is available from deeper in the soil.

Studies have shown that during drought some grasses increase rooting depth; however, as drought continues available moisture is limited to current rainfall and plants become dependent upon moisture near the surface and deep roots are of no advantage (Copeland, 1958).

Root systems are usually established prior to the period of rapid moisture utilization and periods of most probable moisture stress (Barkley et al., 1965). A species capable of rapid root penetration has a valuable characteristic for semi-arid regions where subsoils may be moist. Deep roots allow ample transpiration to occur during drought. It is considered by Julander (1945) that carbohydrate reserves are essential for drought resistance.

During moisture stress the free energy of the roots exceeds that of shoots. Also, during moisture stress large portions of carbohydrates are transported to roots where they are used to enhance root growth. A limited water stress may be artificially induced to increase drought hardiness through encouraging root development (Schmidt, 1973).

Water losses may occur from the roots to the soil in response to a soil moisture gradient and also as vapor into soil air spaces when the soil is dry (Parker, 1968).

Drought resistant grasses generally possess a large root to shoot ratio.

Xeromorphic Features

Certain turfgrasses possess structural modifications which decrease the rate of water loss and thereby postpone the development of critical internal water deficits. Among the structural modifications which reduces transpirational losses are: decreased leaf surface area, alteration of stomatal size, spacing, number and location, increased cuticle thickness, presence of surface hairs, less intercellular space, small conductive tissue, and the ability of leaves to roll or fold (Beard, 1973).

Beard (1973) states that narrow leaves contribute to a small leaf area index, a reduction in transpiration rate, a lower demand for

the available soil moisture and, consequently, a greater potential for drought survival.

Perhaps the most significant morphological adaptation for drought resistance is the ability of a species to close its stomates early in the development of moisture stress. Sunken stomates, an increased number of stomates per unit area of leaf surface, small stomatal openings, and presence of hairs covering stomates also decrease transpirational losses.

Proper growth and development is related to stomatal opening and closing. For photosynthesis to occur there must be an internal-external exchange of gases. This exchange occurs primarily through stomates. Since the leaf must function in absorbing CO_2 it cannot prevent the loss of water vapor to the air. When drought occurs, moisture deficits will result in decreased transpiration and stomates close. A water loss of 10 percent (fresh tissue basis) generally induces stomatal closure (Iljin, 1957). With closed stomates, photosynthesis is slowed down and plant vigor declines. During prolonged drought and high temperature, plants will die when the thermal death point is attained.

Stomatal closure results in a dramatic reduction, but not necessarily a complete cessation of transpiration. With photosynthate decline the plant's ability to survive is reduced. Those varieties which are able to maintain open stomates longer may be more drought

hardy as they are able to fix more carbon and increase vigor. The restrictive action of stomatal closure seems to be less important in turf than food crops as dry matter production is not as critical (Hanson and Juska, 1969).

Stomatal opening and closing results from turgor differences between guard cells and surrounding subsidiary or epidermal cells. Turgor buildup and opening of stomates results from an accumulation of potassium in guard cells triggered by sunlight (Salisbury and Ross, 1969).

A dramatic accumulation of abscissic acid (growth inhibitor) accompanies water stress. This phenomena, however, has not been documented for turfgrasses. Abscissic acid (ABA) inhibits stomatal opening (Hsiao, 1973). It is proposed that water stress affects stomates by way of its affects upon ABA levels or on plant hormone balance, specifically, the balance between ABA and the cytokinins (Hsiao, 1973).

A thick, dense cuticle composed of materials impermeable to water will reduce cuticular transpiration. It is somewhat questionable if cuticular thickness alone is proportional to the delay in water loss, as the cuticle is complex and varies among species both in chemical composition and structure (Parker, 1968). There is no doubt, however, that water losses are greatly retarded by the cuticle.

As the cuticle dries submicroscopic channels which pass through the cuticle eventually constrict and increased retardation of water loss occurs (Parker, 1968).

The water vapor boundry layer of a leaf is increased by the presence of hairs. These hairs lengthen the diffusion pathway and increases the resistance to water vapor diffusion. This will reduce the rate of transpiration. The transpirational reduction due to pubescence is not as significant as other xeromorphic features.

Hairs also scatter incoming radiation, break up soil reflected radiation and aid in preventing insect attack.

The ability of Kentucky bluegrass leaves to fold during periods of water stress reduces exposed leaf area to the atmosphere and decreases the water loss rate. The structural mechanism responsible for this phenomenon is attributed to bulliform cells. These cells are triangular shaped with the greater depth being opposite the leaf surface. They are considerably larger than normal epidermal cells and occur in rows that extend the length of the upper leaf. Because the bulliform cells have a much thinner cell wall and cuticle they have a more rapid rate of transpirational water loss. Collapse of these bulliform cells during water stress causes the leaves of Kentucky bluegrass to fold. To facilitate folding, some species have two parallel groups of bulliform cells with one located on each side and immediately adjacent to the midrib (Black, 1968). The arrangement of stomata, of certain grasses, along the sides of the bulliform channels enables leaves to fold so that stomata are not as exposed.

The advantage of leaf rolling and folding is controversial as some investigations were unable to confirm the usefulness of this phenomenon. It was noted that in many species leaves do not roll until the water content is reduced to below lethal levels (Parker, 1968).

Diminutive water conduction tissue is characteristic of drought hardy xerophytes. Black (1968) notes that a relatively small diameter of conducting elements leads to comparatively high resistance to water translocation. Thus, it may be speculated that grasses possessing large diameter xylem and phloem channels could develop larger root systems and consequently more resistance to drought.

The Physiological Basis of Drought Resistance

Drought resistance is considered to be an interaction of morphological and physiological characters which enables a plant to resist drought. Structural, xeromorphic, features were previously considered but will be reviewed more intimately in the following discussion as will physiological phenomona related to drought.

Plants of the temperate zone generally have osmotic pressures (OP) of approximately 10 atmospheres, whereas those plants of the Arizona desert possess an average osmotic pressure of 20 atmospheres. Variations of OP occurs throughout the day. Minimum OP occur during early morning and the maximum at midday. Increased OP is a result of decreasing water content of the cells which increase

cell sap concentration and through photosynthesis additions of soluble carbohydrate.

High OP provides the advantage of reduced transpiration by inducing a higher diffusion pressure deficit (DPD). A higher DPD provides a favorable gradient of water absorption from dry soil.

The OP is not an indispensable criterion of drought resistance. It is only one of the means of defense against drought that is inherent at different degrees within a species. A high osmotic pressure increases the ability of cells to retain water, which lessens the degree of cell contraction (Iljin, 1957).

Bound water content of plants has been correlated with drought resistance; however, this is not necessarily valid. As pointed out by Steward (1959) water bound so firmly that it cannot be removed by evaporation or freezing is probably not available for physiological activity.

An arrangement of grasses tolerant to drought determined on a basis of bound water percentages was noted by Schultz and Hayes (1938).

Wheatgrass = 11.7% bound water

Bromegrass = 10.3% bound water

Kentucky bluegrass = 5.3% bound water

Timothy = 4.5% bound water

As was previously mentioned, the measurement of bound water may be a poor correlation of drought resistance. According to Carrol (1943) the measurement of bound water shows no significant differences between grasses representing extremes in drought tolerance.

According to Steward (1959) DPD or suction tension is a more sensitive indicator of internal moisture condition than OP. DPD is a measure of the net tendency of water to diffuse into a plant cell. In a fully turgid cell the DPD approaches zero. As a water deficit develops, wall and turgor pressure decreases and the DPD will rapidly increase (Steward, 1959). When a water deficit occurs the various tissues and organs will compete for water. Water will move along gradients of increasing DPD's. The deficits are a result of increased concentration of the cell sap and decreased wall pressure and imbibitional forces, resulting from evaporation of water from cell walls (Steward, 1959). As a water deficit builds up those tissues with the highest DPD will obtain water at the expense of tissues having lower DPD. Young leaves are more drought-resistant than older leaves due to higher osmotic values and their higher protein content (Levitt, 1951).

Plants are known to respond to external water deficits by converting starch to sugar. Plants have subsequently been grouped ecologically and an increase of sugar content is characterized by plants found in dry habitats. Sugars increase cell sap concentrations

and increase the water absorbing ability of plants. This reduces water losses. Maximov (1930) suggests that the accumulation of unknown substances might protect the protoplasm from coagulation and desiccation, and that a high solute concentration may prevent visible evidence of wilting for a long period in spite of increasing water deficits.

Iljin (1957) suggests that tissues consisting of small, elongated cells with a large ratio of surface to volume are most resistant to dehydration. Slowly dehydrated tissue is consequently able to endure more desiccation than those tissues which are rapidly dehydrated or rehydrated.

Drought hardy tissues normally are characterized by a small cell size with a small vacuole or with a large portion of the cell space occupied by cytoplasm or food reserves such as oil, protein, and starch. In cells such as these, there would be little change in volume as water passes out of the cell, the protoplasm is therefore not subjected to excessive mechanical stress (Curtis and Clark, 1950).

Plant Responses to Water Deficits

Plant responses to deficits range from injury to death. Internal water deficits restrict elongation and growth stops. Moisture stress has only a minimal effect upon cell division, causing only a slight reduction in cell number (Black, 1968). Cells are reduced in size due

to drought which causes a decrease in leaf size and therefore total leaf area.

Moderate soil moisture stress will stimulate root growth. A severe deficit will affect shoots much more than roots, thus increasing the root-shoot ratio.

Depth of rooting, although initially increased, is reduced during dry periods of longer duration. A sudden replenishment of moisture following impoverishment results in rapid shoot growth for a while, with very little root growth (Gerakis et al., 1975).

Plant water deficits also accelerate cell maturation rate and promote eventual senescence. The lower, older leaves generally die from water stress. This causes a reduction in total leaf area. As noted earlier, apical meristems and younger leaves possess a higher DPD and are preferentially supplied with water at the expense of older leaves.

Generally, the effects of water stress upon growth tends to be more pronounced on rapidly growing tissues (Crop Science Society of America, 1971).

The water conducting channels may be more efficient if the size of conducting tubes per unit leaf surface are larger and the vein and parenchyma cells in the leaf are distributed so that all cells are close to the supplying veins. This can be significant since the osmotic movement from cell to cell is relatively slow (Curtis and Clark, 1950).

Drought inhibits photosynthesis by decreasing the size of stomatal aperatures which limits CO_2 absorption. Photosynthesis is also reduced because of a less effective, dehydrated protoplasm. Plant chlorophyll content declines as water is required for chlorophyll synthesis (Goss, 1973).

Wilting causes an increase of respiration in mesophytes as starches are being converted to sugar. The decrease in assimilatory activity and the stimulated breakdown of organic substances accounts for the decrease in dry weight of the entire plant during warm and droughty conditions (Iljin, 1957).

A summary of physiological modifications, which were previously discussed, that result from plant water deficits include: decreased succulence, higher osmotic pressure, decreased photosynthetic rate, increased soluble carbohydrate content, decreased protein content and increased bound water.

Many of the aforementioned morphological and physiological effects of drought were noted in turfgrasses by Beard (1973). Turfgrass plants grown under continual moisture stress have lower tissue water content, and consequently a higher osmotic pressure. Physiological activity is generally reduced when turf is under drought stress. The effect of water deficits in decreasing photosynthesis is dramatic in turfgrass. Dehydration reduces respiration in seeds and certain tissues, but stimulates respiration of actively growing tissue.

Factors in Seedling Drought Hardiness

Drought hardiness of turfgrass vary according to stage of development. Seeds of turfgrasses are extremely hardy since the protoplasm is in a dry resting state. Most turfgrass seeds are able to withstand extended periods of exposure to dry air conditions without significant losses in viability. Dormant buds on rhizomes and stolons are also drought hardy. Seedling stages exhibit a high degree of drought tolerance when compared to mature tissues (Beard, 1973). Levitt (1956) noted that grass seedlings are the most hardy of all species.

Water stress may alter the metabolic activity of imbibing and germinating seeds to the extent at which internal processes are delayed or germination ceases (Crop Science Society of America, 1971). Investigators believe that the seedling stage is the most critical period of drought tolerance of perennial grasses.

Stocker (1960) noted that wheat seedlings exhibit three distinct age periods and associated with these periods are differing degrees of drought resistance. Beginning with the dormant embryo until the coleoptile is 3 to 4 mm long, seedlings were completely resistant to drought. Until the emergence of the first leaf the plants were not permanently injured by moisture losses as high as 98 percent; however, elongating roots are killed. At later stages of development less water deficiencies were necessary to induce death of tissues. It was

apparent from Stocker's (1960) study that the stages of drought resistance were related to the proportion of meristematic and elongated cells. Meristematic tissue was shown by Stocker to be completely drought resistant.

Schultz and Hayes (1938) subjected 30 and 60 day old seedlings of Kentucky bluegrass to drought in a drought machine for 10, 16 and 20 hours. The drought machine was a modified oven with light and air movement control. Plugs of sod were also placed in the drought machine for 16, 20 and 26 hour intervals. Their results are recorded below.

	30 day seedlings			60 day seedlings			sod		
Hrs.	10	16	20	10	16	20	16	20	26
	3.2*	0	0	8.0	7.0	1.0	5.0	2.5	1.0

*ratings were based on a 0-10 scale, 10 equating the best survival

Heat Resistance

Critically high temperatures normally accompany periods of prolonged drought. High temperatures injure foliage by: increasing respiration and increasing food requirements, increase evapotranspiration which decreases the amount of water available, and by causing direct heat injury or death (Julander, 1945). Weaver and Albertson (1940) stated that high temperatures in grasslands are not the direct cause of plant death, but merely one of several factors which intensify

drought. They also felt that death from drought is the result of a lack of water.

Reports by Julander (1945) indicate that heat resistance is a measure of drought resistance. He noted that the ability of a species to resist heat corresponds with the aridity of their natural habitat. Julander (1945) also maintains that plants with higher food reserves are more tolerant to heat injury as it was shown that hardened plants possess higher food reserves.

Grasses like buffalograss, blue grama and Kentucky bluegrass tiller near the soil surface and are able to maintain enough foliage to produce reserve carbohydrates, although maintained under moderately heavy clipping (Julander, 1945).

Julander's (1945) studies indicate that Kentucky bluegrass displays little resistance to heat and is not as drought resistant as buffalograss, common bermudagrass (Cynondon dactylon), western (Agropyron smithii) and crested wheatgrass (Agropyron desertorum) (Black, 1968; Carrol, 1943).

The subject of heat resistance was discussed in detail by Beard (1968) and Watschke et al. (1972).

In turfgrass, the initial effects of high temperature results in a browning and die-back of the root system towards the soil surface. Roots will develop a brown, spindly, weak appearance. Growth is slowly reduced. The stress increases maturation and death of roots

and blocks the interaction of any new root development from meristematic tissue (Beard, 1968).

The detrimental effects upon the roots results in the reduction of shoot growth. There also is a reduction in leaf length, leaf width, leaf area, rate of new leaf appearance and succulence. This restriction of shoot growth limits the ability of turf to recuperate.

According to Beard (1973) the direct injury caused by heat is attributed to either a destruction of heat sensitive enzymes involved in synthesis or an imbalance between certain, undefined, metabolic processes. Beard based this hypothesis on findings which revealed that there is a decline in protein levels, an increase in free ammonia and a severe reduction in the amide level, especially glutamine at high temperatures. Beard concluded that direct high temperature kill is caused by a denaturation of proteins located within the protoplasm.

Transpiration cools leaves by utilizing large quantities of heat energy to vaporize water. As long as stomates remain open and water is actively transpired the thermal death point of a leaf is retarded. Drought, which creates internal water stress, impairs transpiration and lethal leaf temperatures may subsequently develop.

Excess nitrogen fertility stimulates rapid tissue growth and reduces heat resistance. Heat injury may be alleviated by good air movement. Beard (1973) reported that air movement of only 4 mph will cool turf from 12 to 14^{o}F. Syringing will reduce soil and leaf temperatures and retard heat injury.

The following is a review of an investigation by Watschke et al. (1972). It reinforces work reported in this thesis by providing meaningful insights into the physiological activities of Kentucky bluegrass under heat stress. During periods of high temperature stress, photosynthesis decreases and respiration increases. If stress is prolonged, CO_2 fixation becomes inadequate to supply the plants metabolic demands for carbon. Carbon reserves are depleted and growth decreases. One must assume that plants whose carbohydrates decline slowly will tolerate high temperatures for longer periods. Kentucky bluegrass fixes carbon via the Calvin C-3 pathway. Plants which are categorized as C-3 plants, photorespire. Photorespiration liberates CO_2 from leaves without supplying any usable energy to plants. Warm season grasses, conversely, typically do not photorespire. Lack of photorespiration will provide for a lower CO_2 compensation point since more fixed CO_2 remains within the plant and is not respired. The results of these workers (Watschke et al., 1972) reveal a trend for those varieties of Kentucky bluegrass, including Belturf, Merion, P-56 and Ba 61-24, with low compensation points to also rank high in photosynthesis and low in respiration. Varieties which are capable of producing top growth at high temperatures are apparently able to fix enough carbon for all metabolic demands. Watschke (1973) further related low photorespiration to some mechanism which reduces the oxygen content in the chloroplast. This mechanism may be a function

of glycolate because as glycolate is oxidized (photorespiration) oxygen concentration is reduced. Variability among Kentucky bluegrass varieties appears to control carbon fixation and utilization. Those genotypes best adapted to high temperatures (Merion, Belturf and Ba 61-24), rank highest in photosynthesis. Watschke et al. (1972) also were able to show that low oxygen concentrations increased net photosynthesis by inhibiting photorespiration. They concluded that breeders should obtain genotypes which are more efficient in CO_2 fixation.

Watschke et al. (1972) reported that bentgrasses are able to tolerate high daytime temperatures longer when night temperatures were cool. Cool nights contribute to decreased dark respiration and a subsequent conservation of previously fixed photosynthate. This finding is of consequence as there is a great diurnal fluctuation between night and day temperatures in Colorado.

The CO_2 compensation point of the ten cultivars tested by Watschke et al. (1972) did not differ significantly; however, there was a tendency for cultivars with high photosynthesis and low respiration to have the lowest CO_2 compensation point.

Related to the superior efficiency of warm season grasses during high temperatures is their ability to fix CO_2 at light intensities above 6000 to 7000 foot candles. Cool season grasses are unable to fix CO_2 above the 6000 to 7000 foot candle level.

Watschke (1973) substantiated Julander's (1945) work by pointing out that increase temperatures increased dark respiration. As a result stored carbohydrate was reduced by losses of CO_2 to the atmosphere, carbon use will surpass uptake; exhausted reserves may eventually produce lethal aberrations unless dormancy is initiated.

The recommendation of the investigation (Watschke et al. (1972) was that carbohydrate should be conserved by frugal utilization of nitrogen fertility, and mowing less frequently to increase leaf area and reduce uses of carbohydrates for regrowth..

Pellet and Roberts (1963) reported that neither phosphorus or potassium levels are directly correlated with heat resistance. Turf subjected to high levels of nitrogen and phosphorus were less heat resistant than turf grown at low levels. High potassium and nitrogen increased heat resistance of turf over that maintained at high nitrogen and low potassium levels (Pellett and Roberts, 1963).

Youngner and Nudge (1968) have reported that Merion and 0217 (Fylking) increased tillering with increased temperature, supporting the Watschke et al. (1972) findings. Newport, however, showed little tolerance to warm temperatures and was unable to adapt to warm temperatures. Those varieties, included in Youngner and Nudge's (1968) investigation, which adapted to high temperatures were also able to maintain higher carbohydrate reserves. Higher carbohydrate

reserves provided these varieties with an adaptation which enabled them to better survive heat stress.

Drought Hardening

Hardened protoplasm is typically less susceptible to coagulation or rupture during drought. Hardened protoplasm is also more permeable to water, is more viscose and colloidal, and has a greater capacity for binding water than protoplasm which is unhardened (Julander, 1945).

Xeromorphic structures, although not always effective in retaining water, frequently aids in moisture retention. Xeromorphic characters may be promoted by growing plants under conditions of high light intensity (Parker, 1968). Also, in early spring, when transpiration rates are low, drought hardiness may be induced by restricting irrigation. By moderating soil moisture tension during these periods, limited foliar growth, decreased cell size and increased root development were promoted to enhance drought hardiness and resistance (Schmidt, 1973).

Implementation of bright illumination, suggested by Parker (1968) promoted greater thickness of leaf veins per leaf surface; greater number of stomatal openings per unit surface area; smaller size of stomata; smaller size of epidermal and mesophyll cells; greater number of hairs per surface area, but shorter hairs; and thicker outer walls of the epidermis and cuticle.

Plants can be hardened to atmospheric drought by brief exposure to either soil or atmospheric drought (Carrol, 1943).

Drought hardening results in an increase of protoplasmic permeability of polar substances (Beard, 1973; Levitt, 1951). Hence, drought hardiness is the ability to endure tissue desiccation and heat injury. When high temperatures during drought cause an increase in respiration a reserve of carbohydrates is necessary to support respiration as well as enable roots, crowns and rhizomes to become hardened to withstand dehydration and heat.

Cultural Practices that Minimize Heat and Drought Injury

Perhaps the most effective cultural practice a turf manager could employ to combat drought conditions would be to harden the turf. Carrol (1943) noted that Kentucky bluegrass hardens very swiftly, as compared to other turfgrasses. Withholding moisture during early spring, as suggested by Schmidt (1973) promotes hardiness swiftly and efficiently.

Surface mulches will provide moisture conservation in several ways. They shade the soil and reduce soil temperatures. Lower temperatures will decrease evaporation from the soil and the rate of diffusion. A surface mulch also acts as a windbreak and increases the distance through which water vapor must diffuse. Evaporation from the soil is reduced by the reduction in vapor pressure gradient.

Planting thinly limits the evapotranspiration potential. Thus, stands will utilize water more slowly, whereas thick stands will tend to dehydrate more swiftly.

Weeds, insects and diseases can influence drought stress by competition for water, and causing injuries which predisposes plants to desiccation.

Antitranspirants as a means of reducing drought stress are being investigated; however, these materials have been unsuccessful due to their inhibitory effects upon photosynthesis. An acceptable anti-transpirant should be inexpensive, manage stomates without impairing photosynthesis, and be washed off immediately by rainfall sufficient to end drought.

Turf grown upon sandy soils may chronically suffer from drought. Such soils can be improved by top dressing the established turf with a one-half inch loamy to heavy soil (Sprague, 1970). Root development is improved on heavy soils, which compact, by annual aerification.

Of utmost importance is the proper manipulation of fertility and irrigation practices.

The root systems of cool season grasses develop primarily in April and May. Excess nitrogen fertility at that time should be avoided. Nitrogen applied at that time will stimulate top growth, utilize reserve carbohydrates and limit root development (Schmidt,

1973). This condition will result in grass with shallow root systems more prone to drought injury.

Dexter (1937), Carrol (1943) and Levitt (1951) have shown grasses highly fertilized with nitrogen suffered greater injury from drought than those grasses maintained at low nitrogen levels. Excess nitrogen will stimulate rapid shoot growth, enlarge cells, increases tissue hydration and cause a general reduction in drought hardiness. A fall application of a complete fertilizer will stimulate root and rhizome development. Top growth is limited by cool temperatures in the fall while the root tips of Kentucky bluegrass are capable of dividing, even at temperatures approaching 32^{o}F (Hanson and Juska, 1969). It is also reported that the growth of turf in May exceeds the growth of fertilized grass in the fall (Hanson and Juska, 1969). Thus, spring lushness will preclude the need for fertility at that time.

As might be assumed, water requirements of plants can be reduced by use of fertilizers; the reduction being more dramatic on poor soils and only slight on fertile soils. Correction of nutrient deficiencies increases the water use efficiency of plants. Use of fertilizers are perhaps the least expensive and most realistic means of increasing water use efficiency.

Phosphorus fertilizers have been shown to increase drought hardiness of wheat, barley and cotton. Phosphorus increases the number of stomates per unit leaf surface, increases water retaining

capacity of leaves, increases bound water and yields in these crops (Parker, 1968). Beard (1973) reported that potassium deficiencies will reduce drought hardiness. It has been concluded by Levitt (1951) that boron increases the drought resistance of plants because boron-treated plants possessed the following xeromorphic characteristics that untreated plants did not: better developed root systems, higher moisture content of leaves, higher transpiration rates and longer periods of stomatal opening but no increase in succulence or osmotic pressure.

Frequent irrigations, particularly during periods of maximum root development, will prevent proper gas exchange and limit root development. This practice also produces grasses with large cells and large air spaces between the cells. Excess watering has other detrimental effects such as increasing opportunity for soil compaction, greater evaporation and leaching.

Turfgrass which is maintained with a limited soil moisture level possesses greater drought hardiness than grasses grown under an adequate moisture level. Hydrated tissue which develops during intensive irrigation is unable to harden and may thin out due to severe desiccation injury. During soil drought, turf will eventually lapse into dormancy and the foliage becomes brown. Normally the turf soon recovers with an adequate application of water. This brown, dormant turf, according to Beard (1973) is in a better physiological

condition for drought extremes than excessively or inadequately watered turf.

A rather descriptive study performed by Deal and Engel (1962) is also supportive of restrictive irrigation. Working with Merion Kentucky bluegrass, Deal and Engel (1962) observed that rewatering when 60 percent of the soil moisture was depleted produced the best color, quality and the greatest total dry weight of shoots and dry weight per shoot. Furthermore, by allowing the grass to utilize more than half of the available water before irrigating, a very high quality turf was produced. They also reported that very little quality was lost by prolonging irrigation to the wilting point of the soil.

When turf wilts during conditions of atmospheric drought a light syringing will cool the grass leaves and reduce transpiration. The small quantity of water which is absorbed through leaves after a syringing may be of major significance in maintaining a favorable plant-water balance and prevent desiccation injury by allowing roots to catch up with the water demands of the shoots.

Many turf managers agree that a heavy irrigation late in the fall will significantly aid turf in withstanding winter desiccation.

Thatch build-ups should be avoided as they limit water infiltration and storage in the soil and thus increase drought stress.

Raising mower height in the spring will permit more leaf area and consequently an increase in photosynthate. This additional

carbohydrate will enable the plant to develop a more extensive root system. Maintaining a higher turf during the summer will provide additional insulation and reduce the evapotranspiration rate.

Breeding for Drought Resistance

Stocker (1960) has provided good definitions of phenotypic and genotypic drought resistance. Phenotypic drought resistance involves changes which plants make in response to exposure to drought. Genotypic drought resistance is the difference between drought resistant and drought sensitive species. To better utilize water it will be necessary that breeding and selecting for phenotypic and genotypic characteristics be implemented. It is expected that diversity exists for drought resistance. It is, therefore, probable that these diverse clones can be selected from dry habitats when they evade or endure drought. As is pointed out by Butler (1975), Kentucky bluegrass is found persisting in hot, arid regions of the United States.

Watschke (1973) suggested that germplasm of cool season grasses from the south, which do not photorespire or are able to regulate photorespiration, should be incorporated into breeding programs to enhance drought and heat tolerance.

Kentucky Bluegrass - Ecology and Water

Kentucky bluegrass is native or has been naturalized in areas were approximately 20 to 60 inches of rainfall occurs yearly.

Kentucky bluegrass has two maximum water utilization periods. One period occurs during bloom in May and another in July, although the later period is not as pronounced as for many other grasses (Weaver, 1941).

Weaver (1941) who studied the ecology of many grasses indigenous to the Great Plains, investigated Kentucky bluegrass. He noted that the early, rapid growth of Kentucky bluegrass resulted in an increase of water losses after May 6. During the hot summer both pasture and prairie bluegrasses become somewhat dormant. Soil moisture declined from June 30 to July 20 in response to a mid-summer drought. A decrease in water losses occurred in response to lower temperatures after July 20.

Kentucky bluegrass grows rapidly in early spring. It produces flower stalks in May and becomes semi-dormant as temperatures of summer increase. Growth resumes in the fall with the advent of lower temperatures. Weaver (1941) calculated that water usage in unprotected pastures to be 21 percent greater than water losses in the prairie.

According to Weaver (1941) Kentucky bluegrass begins to bloom after vernalization, and, anthesis is hastened by drought. Drought may reduce the number and height of flower stalks, approximately to one-third to one-half of normal size. Bluegrass grown in pastures rooted almost entirely in the surface 30 inches of soil and was

practically all dried by May 15. In the prairie where bluegrass plants are protected by other grasses and not mowed or grazed, the Kentucky bluegrass remained green until the end of May. The OP of the sap increased gradually from 15 atmospheres on April 10 to 29 atmospheres when the grass was completely dry on May 25.

Water is the major constituent of Kentucky bluegrass and it comprises 85 to 95 percent of the actively growing tissues. Water is the basis of photosynthetic activity; it maintains turgidity and serves as the transport medium of nutrients. When this water becomes a limiting factor leaf blades lose turgidity, bulliform cells collapse, leaf blades fold and the grass develops a blue-gray cast. The grass plants respond by increasing leaf thickness. When drought becomes prolonged Kentucky bluegrass undergoes a substantial reduction in shoot growth. Summer dormancy occurs if drought persists and the foliage becomes brown and dry. While in this dormant state, Kentucky bluegrass is able to survive extended periods of drought and will initiate new shoot growth from the nodes of rhizomes and crowns when moisture conditions are favorable. He further noted that the cells of buds are quite devoid of vacuoles. As these buds develop vacuoles are formed and simultaneously resistance to drought decreases. When drought terminates an adequate turf cover may be formed in two to three weeks.

Kentucky bluegrass is able to conserve water when drought becomes prolonged (Hanson and Juska, 1969). Evapotranspiration losses, recorded for Merion Kentucky bluegrass, were approximately 0.19 inches per day during the 14 day period following irrigation. During the third week evapotranspiration averaged 0.17 inches per day and further declined to 0.09 inches and 0.07 inches during the fourth and fifth weeks following irrigation. It was noted that Kentucky bluegrass may extract available water from a depth of 30 inches (Hanson and Juska, 1969).

Mowing height also influences water use. The water use rate of Kentucky bluegrass increases as the cutting height increases. A reduction in leaf area causes a corresponding decrease in the total transpiration rate per plant, but water loss rate per unit leaf area will increase (Beard, 1968). Mowing turfgrasses with a dull mower mutilates leaf tissue and results in increased loss of water from ruptured plant tissue.

Frequent and severe mowing will generally produce a turf low in carbohydrate reserves and with a weak root system. High carbohydrate reserves are necessary as regrowth and production of more and newer tillers rely upon these reserves. Drought and accompanying high temperatures may reduce carbohydrates which can result in severe injury if turf is mown frequently at low heights (Youngner and Nudge, 1968).

Madison and Hagan (1962) subjected Kentucky bluegrass to three mowing heights. They discovered that total rooting was less in pots receiving one-half inch cut. It was shown that short mowing combined with frequent irrigation produced plants with reduced root systems. Severe mowing halted further root growth for several days and caused the death of older roots in some cases. Depth of soil water extraction was shown to be directly proportional to mowing heights.

Diseases, such as rusts and stripe smut, disrupt the leaf epidermis and cause water losses. Turfgrass subject to intense traffic will likewise have increased water losses.

FIELD STUDY

Methods and Materials

The literature suggests that a reliable test for drought tolerance of turfgrass is to grow it under droughty field conditions (Butler, 1975). The primary objective of this study was to determine the relative drought tolerance of 25 varieties and 5 blends of Kentucky bluegrass under field conditions.

Clarification of some terms used in this study is necessary. Drought resistance is defined as the ability of the protoplasm to endure desiccation. Drought resistance implies survival and persistence. Drought hardiness refers to morphological and physiological adaptations which enables plants to remain green and turgid for long drought periods. Drought tolerance is a nebulous, all inclusive drought term. Drought tolerance implies that a plant's ability to withstand drought is due to unspecified or unknown morphological or physiological reasons.

In these studies water stresses were developed by restricting irrigation. Drought stress was easy to achieve under the semi-arid conditions of Fort Collins, Colorado. Average precipitation for Fort Collins is approximately 15 inches per year.

Turfgrass is especially suited for study because as drought proceeds, the leaves fold and change color through several shades,

ultimately developing a light brown color. In the field, varietal differences became increasingly conspicuous as color changes occurred. Also, this study was facilitated by the prompt renewal of growth once adequate moisture was resupplied to the area.

Varieties and blends were planted in 1971 at the W. D. Holley Plant Environment Research Center on Lake Street adjacent to the Colorado State University campus in Fort Collins. The 30 varieties and blends were replicated three times. The 90 plots were randomized and measured 10' x 10' (3 meters x 3 meters). Each plot was divided in half. One half was maintained at three-fourths inch (18 mm) and the other half at a one and one-half inch (36 mm) mowing height.

At the first sign of drought stress in the field the 90 plots were rated. Thereafter, the plots were rated daily until the first variety began to develop dry, blue-gray to brown leaf blades. At that time the entire field was irrigated twice daily for two to four days. Irrigations were continued until the area was again green and grass was turgid with no indication that any variety was showing signs of drought. With each daily rating three cores of soil, measuring approximately 4" x 4" (10 cm x 10 cm) were randomly removed from the test plots, the grass shoots were removed and the cores were weighed. The soil core samples were then oven dried at 105°C for 72 hours and re-weighed to determine percent of moisture in the field at the time of rating. At the conclusion of the experiment, in September, 1975, the

rating sheets were divided into three categories based upon percent moisture in the field. From July to September each variety was evaluated on 26 occasions. The data were statistically analyzed using analysis of variance. The three moisture categories were:

Low	8.86 - 10.60	Percent soil moisture
Medium	10.61 - 11.47	Percent soil moisture
High	11.48 - 16.69	Percent soil moisture

A moisture tension curve was calculated and the wilting point of the soil was determined to be approximately 15 percent soil moisture, Appendix Figure 1. The series of observations began July 15 and continued until September 5, 1975. Spring was not suitable to begin the study as late snow storms and rain showers kept the turf in a turgid condition until July.

Ratings of the turf were based upon a 0 to 10 scale, determined by visual observation.

Rating	Visual Turf Characteristics
10.0	Maximum greenness and turgidity
9.5	Green, turgid, less than 50% of blades folding
9.0	Green, turgid, more than 50% of blades folding
8.5	Green, slightly wilting, less than 50% of blades tightly folded
8.0	Green, progressed wilting, color changes evident, more than 50% of the blades tightly folded
7.5	More than 75% of blades tightly folded, wilting (foot-printing), a general blue-gray color
7.0	All blades folded, wilted-cascading blades, blades moist to the touch, blue-gray color
6.5	Dark, blue-gray color, blades dry to the touch

6.0	Light gray color, blades dry, thinning of turf begins, adequate recovery possible if irrigated immediately
5.5	Less than 25% of the plot light brown. If watered, less than 20% loss
5.0	More than 50% of the plot light brown. If watered, less than 40% loss
4.5	More than 75% of the plot light brown. If watered, more than 50% loss
4.0	More than 90% of the plot light brown. If watered, more than 75% loss
3.5	100% of the plot light brown, soil very hard, recovery very slow

The plots were mowed once weekly and clippings were removed. The plots received no fertilizer during 1975. All data collected were statistically analyzed, Appendix Table 18. The F ratio indicates significant differences of the parameters. The Least Significant Difference (LSD) test was used for determining significant differences. The LSD graph is read by placing a straightedge on the base of a bar, any bar intersected by the straightedge indicates that there is no significant difference among those varieties. In the tables, data are ranked according to mean values.

Climatological data for Fort Collins, Colorado was obtained from the National Oceanic and Atmospheric Administration, The Environmental Data Service, Asheville, North Carolina. The climatological data for the field test period is in Appendix Table 2.

A soil test and soil tension curve, located in Appendix Figure 1, Table 1, were determined by the Colorado State University Soil Testing Laboratory.

Two commercial sources of South Dakota Common were utilized. The varieties are delineated S. D. Common #1 and S. D. Common #2.

Results and Discussion

Moisture Interaction

In Figure 1, Appendix Table 3, the varieties are categorized for various moisture regimes. A rank of one (1) denotes that the variety exhibited the best drought tolerance and 26 denotes the variety that exhibited the least tolerance. As would be expected there were varieties with similar ranking. The means of these varieties are represented by an LSD graph, Figure 1. Where the bars of the LSD graph overlap, no significance occurs.

The performance of the varieties at the low moisture regime (Figure 1), 8.86 to 10.60 percent soil moisture in the field, was generally of most interest.

Those varieties which had a mean value above 8 on the 0 to 10 scale are, from a drought tolerance standpoint, of most importance to the turf manager interested in water conservation. Those varieties with a rating above 8 had an acceptable appearance and would not, at that stage of drought stress, be injured appreciably by traffic. Below a rating of 8, it appears that the grass will require considerably more irrigation to maintain an acceptable quality turf.

The blend, South Dakota Common + Kenblue and Arboretum exhibited the best tolerance to drought. Unfortunately, these common

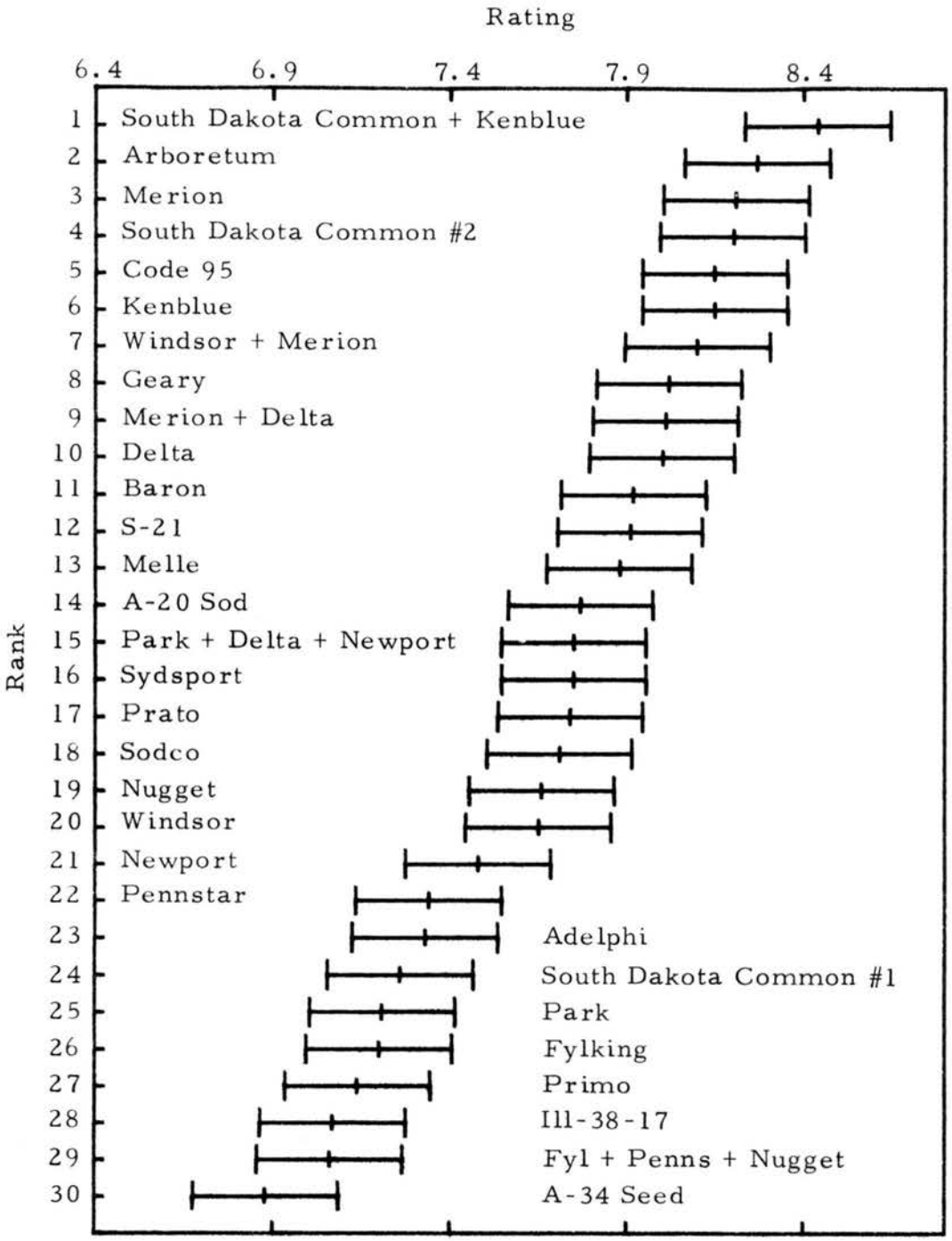

Figure 1. Depicts LSD separation of Kentucky bluegrass varieties at the low moisture level. LSD (1% level) bars are 0.41 units long.

types do not possess characteristics which are normally desirable of turfgrasses such as good color, density, and texture. A density, color and texture evaluation for all varieties included in this work is located in Appendix Table 4. For high quality turf, the savings these varieties may bring in water conservation would likely be offset by increased costs for weed and disease control.

Merion ranked excellent as a drought tolerant variety, and it also possesses desirable turf characteristics such as a dark green color and a dense stand. Code 95 also ranks quite high in drought tolerance. Code 95's superior drought tolerance was complemented by good color and texture. Although the field plot area was uniform in topography and soil condition, one of the three replicates of Code 95 appeared to be located on a hard pan which caused that replication to wilt early, perhaps slightly lowering the overall drought rating for Code 95. Although color and density of Code 95 were good throughout the summer, these characteristics diminished in the fall. The turf characteristics evaluation in Appendix Table 4 was made late in the season and the poor rating of Code 95 at that time indicated an early entrance into dormancy.

Baron and Sydsport, varieties with excellent turf characteristics, displayed intermediate tolerance to drought. Popular commercial varieties that exhibited poor tolerance to drought at the low moisture level were Pennstar, Adelphi, Park, Fylking, and Warren's A-34.

In Figure 2 all drought data was massed regardless of moisture level or mowing height. The graph shows that the common-type varieties (S. D. Common #2, Kenblue, Arboretum, Code 95, Geary, S21) with the exception of South Dakota Common #1, generally exhibited more tolerance to drought than the other varieties. Although the commons do exhibit drought tolerance superiority they generally have poor color and density when compared to the other varieties. Hence, the common types appeared to have naturally adapted indicating a survival of the fittest under drought conditions. Continued research for better quality turfgrasses possessing high levels of drought tolerance is needed.

The ranking of the varieties at the low and medium moisture categories are closely related, Figure 1, Appendix Table 3a. In the high moisture category notable changes occur in the overall ranking of varieties, Appendix Table 3b. All varieties under the high moisture regime of 11.48 to 16.69 percent soil moisture had mean values above 8, or an acceptable rating, on the 0 to 10 scale. Varieties possessing excellent turf characteristics, as Sydsport and Baron, are ranked high with mean values greater than 9. Although this moisture regime is termed high moisture it should be pointed out that soil moisture tension at 15 percent soil moisture is approximately 15 bars, Appendix Figure 1. Hence, even the high moisture category has a significantly high soil tension. Maintaining the soil in this

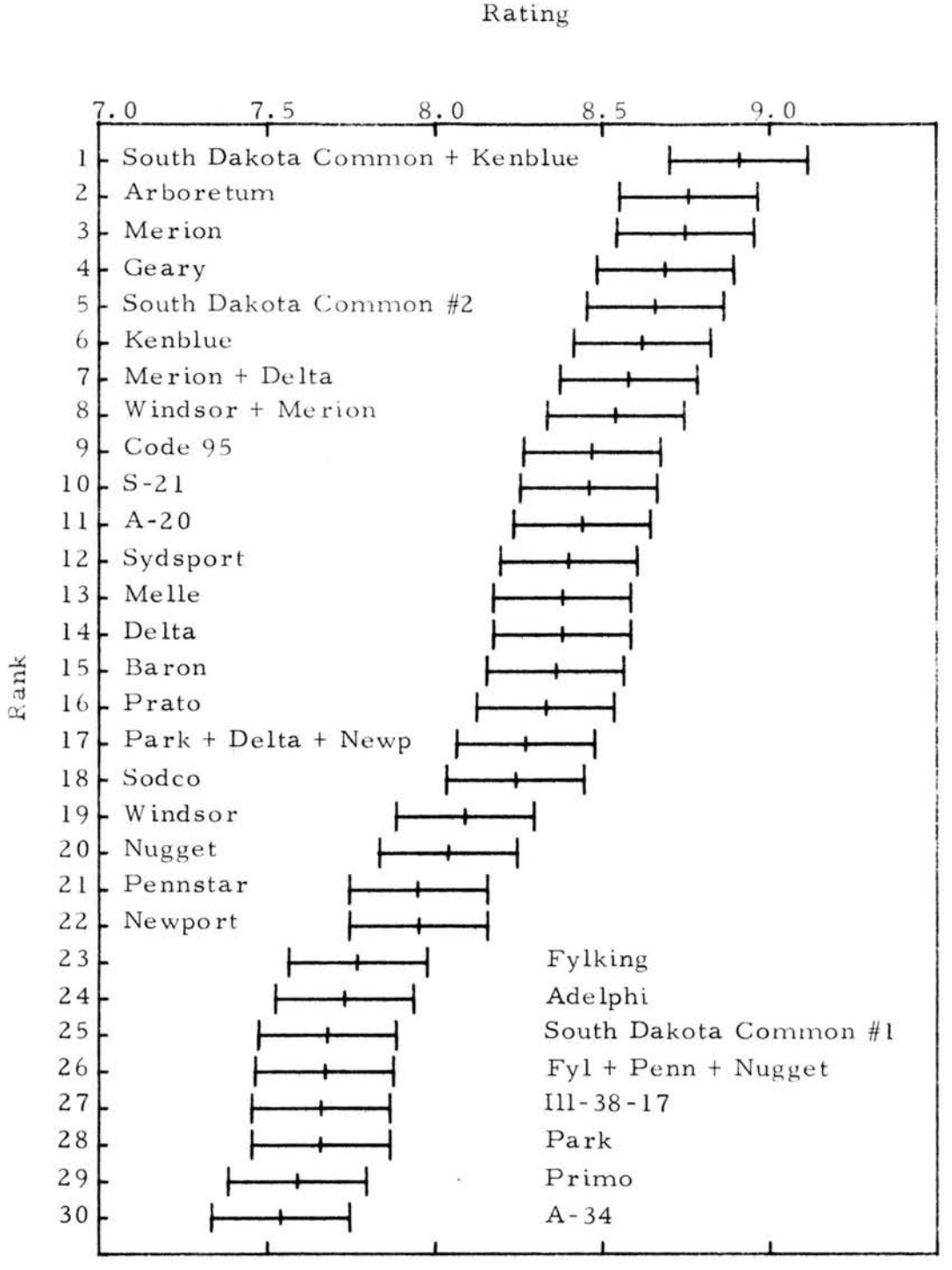

Figure 2. Depicts LSD separation of the varieties, massed drought data. LSD (1% level) bar are 0.4 units long.

tension range would accord appreciable water economy and would also allow more freedom to use higher quality turf varieties. However, where water economy is of utmost importance those varieties performing best at the low moisture level should get first consideration.

Low, Medium and High Soil Moisture Level Interaction

As was expected, a linear progression of less drought affect with increments of moisture was obtained. The mean values at low, medium and high soil moisture are graphically represented in Figure 3. This linear progression validates the rating methodology employed.

Mowing and Soil Moisture Interaction

The interaction of these parameters are diagramatically represented in Figures 4, 5, 6, and 7. This data substantiates the literature which states that turf maintained at a higher mowing height will tolerate more drought than turf maintained at a lower height. Figure 7 shows that the higher mowing height exhibits more tolerance to drought at the three moisture levels established in the study. A comparison of the mean values, however, at low and high mowing do not indicate dramatic differences at either low, medium or high moisture levels, Figures 4 and 7.

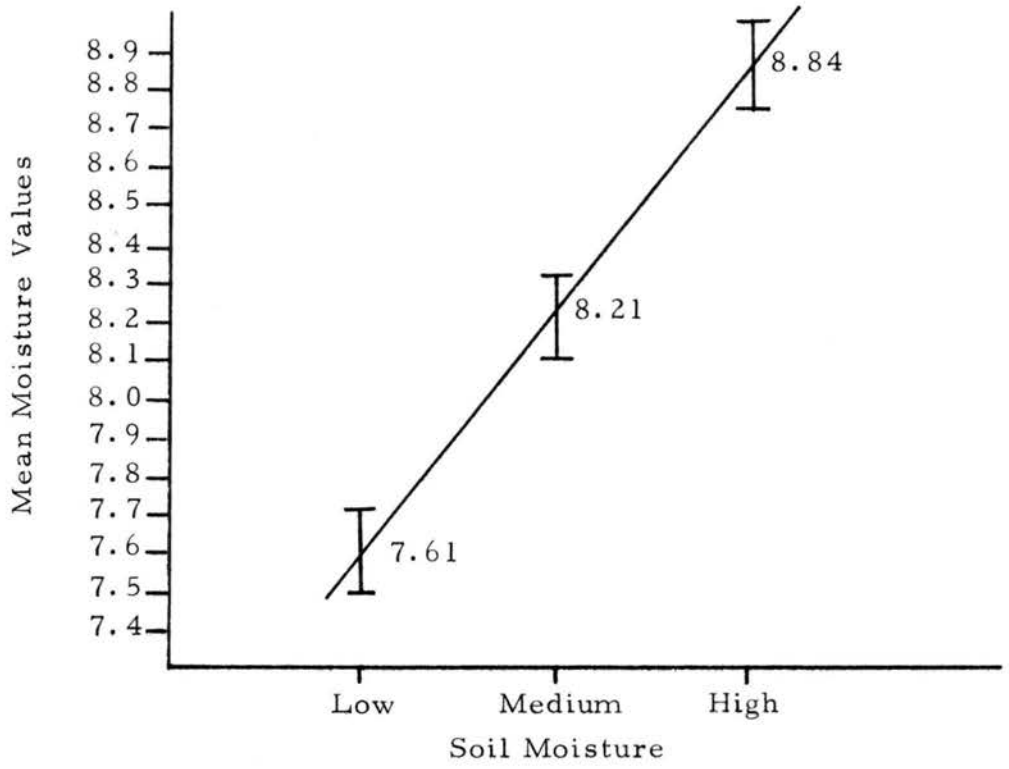

Figure 3. Mean values of drought quality at low, medium and high moisture levels are plotted. Significant at the 1% level.

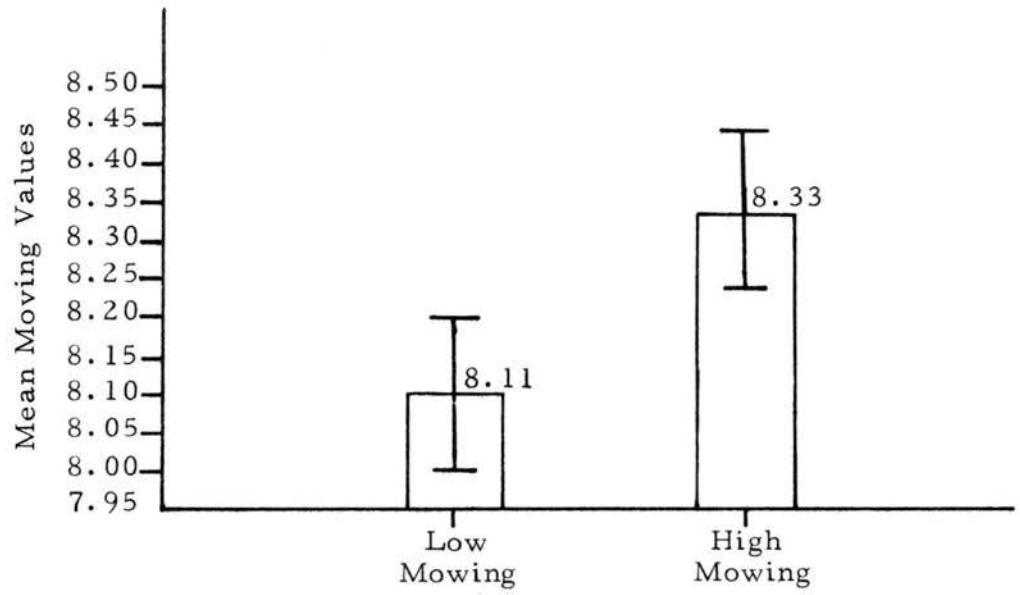

Figure 4. A comparison of low and high mowing. Significant at the 5% level.

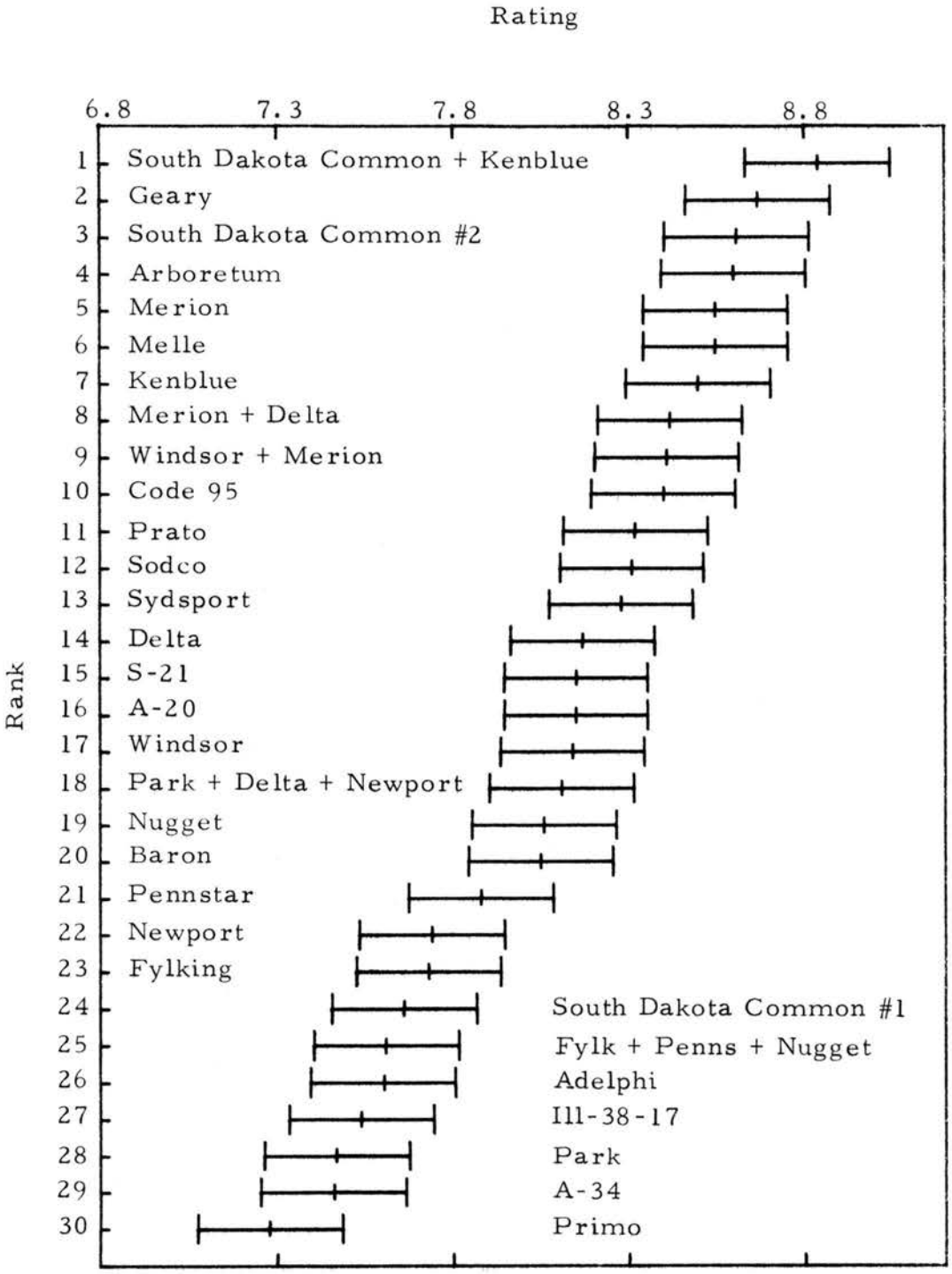

Figure 5. Depicts LSD separation of the varieties at low mowing and low moisture. LSD (1% level) bars are 0.40 units long.

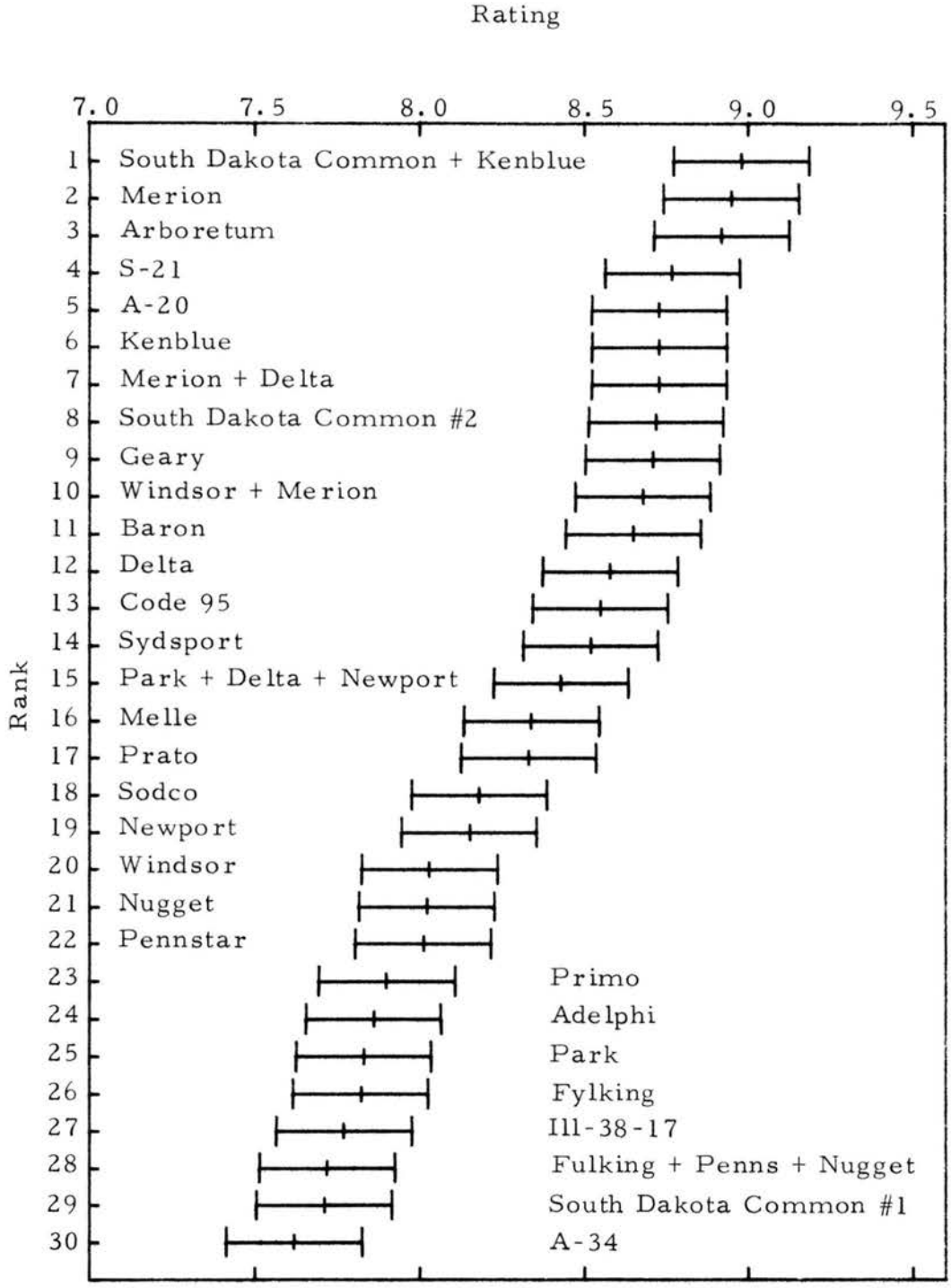

Figure 6. Depicts LSD separation of varieties at high mowing and low moisture. LSD (1% level) bars are 0.40 units long.

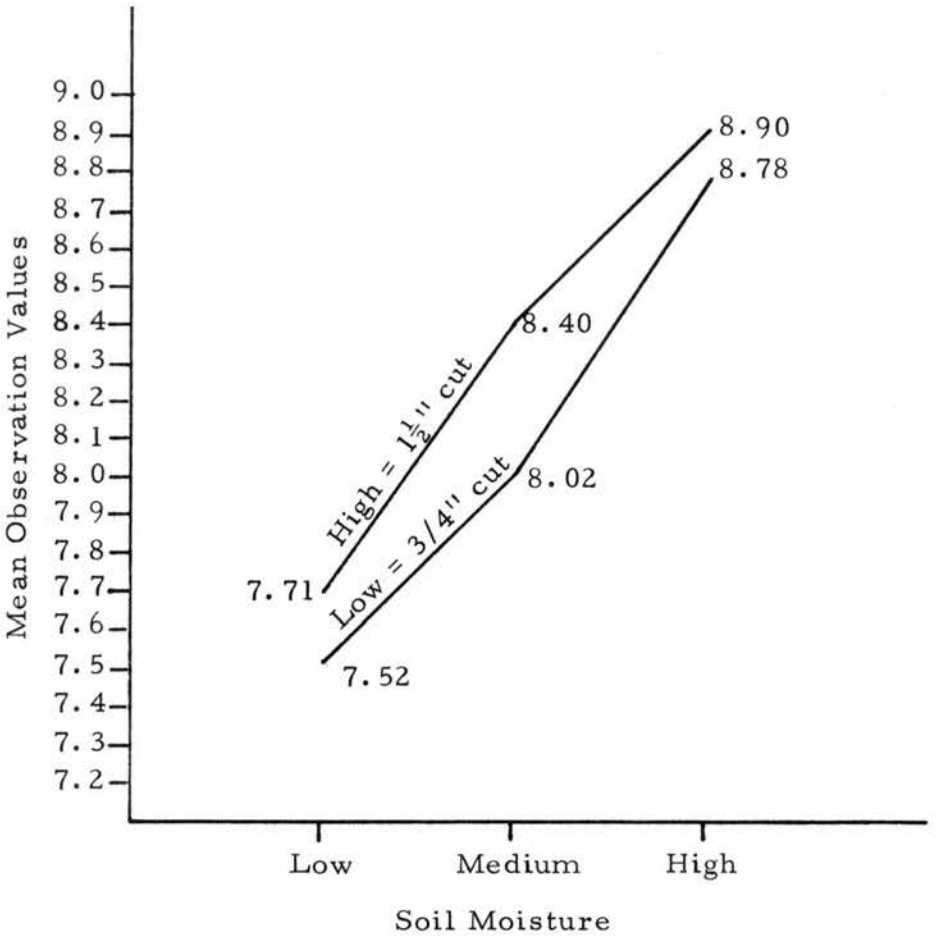

Figure 7. Observed turf quality for low, medium and high moisture levels at two mowing heights are plotted.

Low and High Mowing Interaction

The data show that an increased mowing height will enable turf to better withstand drought stress. A comparison of the mean values, Figure 7, again indicates that a reduced mowing height will not cause an appreciable decline in turf quality during drought.

With the advent of warmer summer temperatures, those who maintain turfgrass are often advised to increase mowing height to $2\frac{1}{2}$ to 3 inches (6 cm - 7 cm). By increasing the height of the turf, evapotranspiration is reduced and the total photosynthesizing surface is increased. An increase of surface area, however, may also result in an increase in transpiration.

The data presented supports a higher $1\frac{1}{2}$ inches over a lower 3/4 inch cut for increased drought tolerance. Turf mowed frequently will have a smaller transpiring surface and greater density, as mowing promotes tillering. Tillering at the crown produces a denser turf, plants with increased photosynthesizing area and shade which reduces evapotranspiration. An increase in number of stomata per unit area and smaller stomata would also be expected to occur. As a result of increased density and a decrease in stomata size and increase in stomata number, a cooler more humid microclimate amidst the dense plants would result. Such a microclimate would retard the movement of water vapor from stomatal cavities to the atmosphere. A more complete discussion of the role of stomata and their

relationship with drought is presented in the anatomy study. It is shown, in the anatomy study, that smaller and increased numbers of stomata on the upper leaf surface of Kentucky bluegrass probably creates water vapor diffusion shells that decrease the diffusion vapor gradient at the leaf surface.

Varieties with adaptive mechanisms for reducing transpirational losses would be expected to maintain turgidity longer during periods of drought stress. Postponing internal moisture stress will enable plants to produce more photosynthate, increase rooting depth, and store more carbohydrate to combat the injurious effects of heat and drought.

Although the data is supportive of increasing mowing height during drought stress, it was shown that little quality and tolerance to drought is sacrificed when hardened turf is maintained at 3/4 inches (18 mm). An illustration may better clarify this concept. On golf course fairways, home lawns, and parks turf hardened and maintained at $1\frac{1}{2}$ inches might require irrigation only every 21 to 25 days, while that cut at 3/4 inch may need water every 18 to 20 days. This illustration was drawn from the specific conditions experienced in Fort Collins, Colorado during the summer of 1975. Thus, where turf is cut short, the data indicate that there has probably been a tendency to over irrigate and waste water.

Light intensity is another integral factor in the environment which warrants consideration in the discussion of drought and low versus high mowing. The leaves of Kentucky bluegrass, or any turf, are not oriented perpendicular to incoming radiation, hence very high light intensities may be necessary for the plant to reach their light saturation points. A study, noted by Beard (1973), dealing with Bermudagrass, illustrates the role which light may have had on the short and high mowing heights used in this study. Bermudagrass cut at 1 inch was shown to fix more CO_2 than turf cut at 2 inches. The 2 inch turf had leaves which were vertically oriented while the 1 inch turf had many short overlapping leaf stubs. Hence, the 1 inch leaf blades were able to obtain more sunlight and therefore accumulated more CO_2. The increased net accumulation resulted in greater leaf, stem, rhizome and root growth as well as a greater root to shoot ratio. Because of the high light intensities and number of clear days in Colorado, it is probable that both the low and high mowed plots received sufficient sun to satisfy their light saturation levels.

Variety, Mowing Height and Soil Moisture Interaction

The interaction of these parameters, although not statistically significant, does enable a better visualization of the effect low moisture levels have upon mowing height, see Table 1 and Appendix Tables 5a, 5b, 5c and 6a, 6b and 6c. Below, several varieties from Appendix Tables 5a and 6a are compared. Slight differences between

low and high mowing, noted in Table 1, existed to indicate that hardened turf at 3/4 inch height would necessitate irrigation one day earlier in a three-week period than turf mowed at $1\frac{1}{2}$ inches.

Table 1. Differences between mean values of several varieties of Kentucky bluegrass at high and low mowing. No significant differences among varieties at two mowing heights.

Variety	Difference
SD Common + Kenblue	0.10
Arboretum	0.23
Merion	0.37
SD Common #2	0.17
Code 95	0.20
Geary	0.10

It was observed that all varieties increased in drought hardiness as the summer progressed. Early in the testing program the plots were able to maintain optimum turgidity and greenness for four to six days before drought symptoms appeared. During the final phase of the study the field was able to withstand 21 days between irrigations before drought problems developed. At the conclusion of the 21 day cycle only Code 95 maintained acceptable greenness and turgidity with a mean rating above 8. Cooler night time temperatures of August and September undoubtedly postponed internal moisture stress during the final cycle of the experiment.

Conclusion

This study indicated that certain Kentucky bluegrass varieties are more drought tolerant than others. Those varieties which produced a mean rating above 8 in the low moisture category, 8.86 to 10.60 percent soil moisture, are Kentucky bluegrass varieties that should be considered where maximum water conservation is desired. Varieties such as South Dakota Common, Kenblue and Arboretum, although drought tolerant, possess poor turf quality while Merion and Code 95 provide a desirable turf. It was further shown that turf mowed at $1\frac{1}{2}$ inches (4 cm) performed better under droughty conditions than 3/4 inch (2 cm) turf. However, little quality and drought tolerance was sacrificed by mowing at the lower height.

SEEDLING STUDY

Methods and Materials

Ten varieties of Kentucky bluegrass were sown in sterilized field soil in rectangular plastic flats measuring 12 cm wide, and 20 cm long and 6.5 cm deep. Chemical and physical properties of the soil were similar to that of the field study. Initially there were four sets of flats and each variety was replicated four times in each set.

The seed was sown at a rate of one pound per 1,000 square feet (93 square meters) on June 18, 1975. All flats were kept outdoors and watered daily. All varieties had begun emergence between July 5 and July 11. Park germinated first followed by Windsor, Fylking, Vantage, South Dakota Common, Pennstar, Newport, Merion, Adelphi and Warren's A-20, Appendix Table 7.

The flats became infected with Dollar Spot, Sclerotinia homoeocarpa, F. T. Bennett, and drought studies were delayed until the disease symptoms had been eliminated, Appendix Figure 2. The varieties were in the 6 to 8 tiller stage when the drought trials began. Warren's A-20 was subsequently removed from the study because of poor density. The flats were moved into the greenhouse in September for better control of stress manipulation.

All flats were saturated with water at the beginning of each drought trial. After 24 hours of draining and evapotranspiration the

soil was considered to be at field capacity. At that time all flats were weighed to the nearest gram. Several days elapsed without further irrigation. When the grass appeared to be near the permanent wilting point the blades of grass were tightly folded, cascaded and had a blue-gray color. At that time all flats were rated on a scale similar to that used in the field study. After rating, the flats were reweighed. The soil at this time was assumed to be at a moisture tension comparable to the approximate permanent wilting point, as judged by the wilted appearance of the turf.

The seedling drought trials were rerun as described above on eight occasions, and significant results were achieved in three of the trials. The same flats were utilized for all trials. Other, non-significant, seedling drought trials are located in Appendix Table 8a, 8b; 9a, 9b, 9c.

Temperature and relative humidity were monitored in the greenhouse. Averages of this data are given below:

Daytime high temperature	70 - 75°F
Nighttime low temperature	65 - 68°F
Daytime relative humidity	61%
Nighttime relative humidity	76%

Trial 1: Results and Discussion

Results of the initial trial are shown in Figure 8. Adelphi, Fylking and Park exhibited the best tolerance to drought of the nine varieties tested. Pennstar, Windsor and Vantage were intermediate

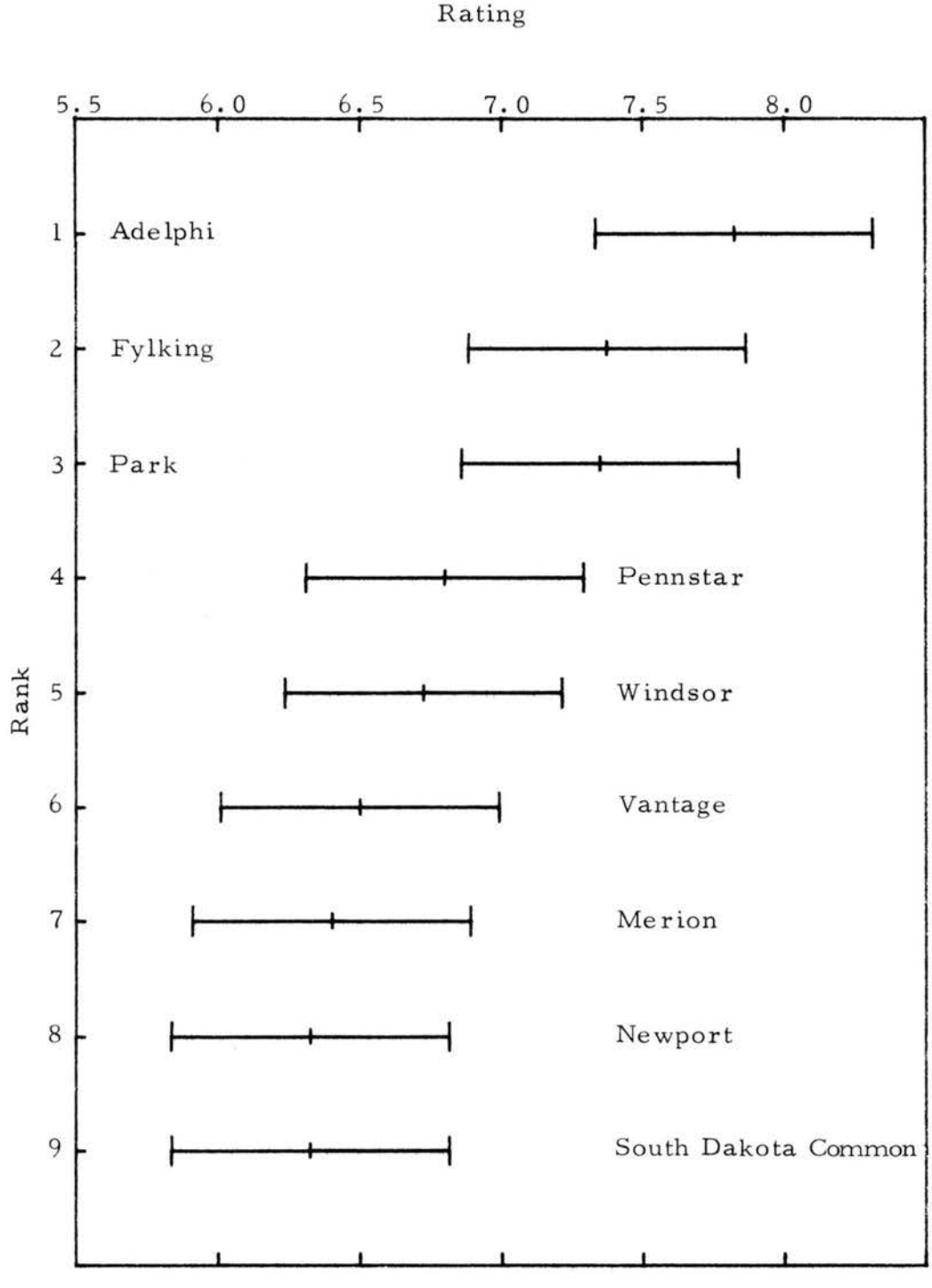

Figure 8. Depicts LSD separation of seedling varieties, Trial 1. LSD (5% level) bars are 0.98 units long.

in tolerance and Merion, S. D. Common and Newport had shown least tolerance to drought.

The seedlings were able to withstand only brief exposures to drought as compared to mature plants. Generally, the seedlings required irrigation within five to eight days before permanent injury occurred. This reduced tolerance was apparently due to thinner cuticles, poor rhizome development and reduced root systems. An interrelationship of little carbohydrate reserve and highly hydrated tissue was undoubtedly related to the seedlings inability to withstand even brief periods of drought.

An anomaly was revealed when the performance of the seedlings and mature plants were compared, Table 2. Those varieties which performed well under drought stress in the field study did not do so as seedlings. Adelphi, which ranked highest in tolerance as a seedling, performed poorly in the field study. Merion, conversely, ranked third in the field study but poorly in the seedling investigation. This information implies that drought tolerance is directly related to rate of rhizome and secondary root development and maturity. Merion was slow to emerge and had not produced a dense stand one month after emergence. It is speculated that if these seedlings were transplanted into the field that Merion would, in time, surpass the other varieties in its ability to tolerate drought. Therefore, it

Table 2. Comparison of 9 mature and seedling Kentucky bluegrass varieties.

	Mature Plants Field Study	Seedlings Greenhouse Study
Adelphi	Lower Third	Upper Third
Fylking	Lower Third	Upper Third
Park	Lower Third	Upper Third
Pennstar	Lower Third	Middle Third
Windsor	Lower Third	Middle Third
Vantage	Not Tested	Middle Third
Merion	Upper Third	Lower Third
South Dakota Common	Upper Third	Lower Third
Newport	Lower Third	Lower Third

appears that drought tolerance of established turf cannot be determined by observing seedling grasses, as established by the criterion used in this study.

A better understanding of the contradiction between the seedling and mature plants investigation was somewhat clarified upon close inspection of the seedlings varieties surviving a severe drought test.

One set of the varieties was subjected to a ten-day period without irrigation. The objective of this test was to evaluate survival and recovery of seedlings subjected to severe drought. The grass blades were tightly folded, twisted and gray at the conclusion of the ten days drought. All flats were irrigated daily for three weeks. Data gathered after three weeks are recorded in Table 3. Adelphi again ranked highest with a 15.5 percent recovery. Fylking, which performed well in the previous drought test, had a poor survival percentage. Pennstar, Vantage and Park also ranked lower when subjected to severe drought, whereas S.D. Common, Merion, Newport and Windsor increased in ranking.

An inspection of the roots had shown that those varieties which had appreciable recovery, also had developed rhizomes. It would seem logical that varieties which produce rhizomes early in development would be more tolerant of drought.

Trial 2:

Three months were allowed to elapse between Trial 1 and Trial 2. The purpose of this time gap was to evaluate the drought tolerance of older seedlings to see if trends would support the field test data.

In Figure 9 it is shown that Adelphi's position had shifted from a ranking of first in the initial seedling test to ninth. Windsor, Merion and Newport, which earlier performed poorly, were ranked highest in this test. Obviously, the maturity of the seedlings played a dominant role in the shift of seedling drought tolerance. General trends indicate similarity in the performance of mature seedlings to that observed in the field study. Merion was shown to increase in drought tolerance, whereas Adelphi had improved so little that all of the varieties were able to surpass its drought tolerance.

Conclusion

The inconsistency of the data accumulated during the nine month seedling investigation is difficult to explain. Undoubtedly, varietal drought tolerance is a dynamic process, changing as the plants mature. The shortening and gradual lengthening of days, fluctuations in the greenhouse environment which differ from outdoor environmental changes are other variables which probably affected the performance of the seedlings. Also, the artificiality of the greenhouse, its shadows, fans, cool and warm spots, placement of heat pipes, et cetera are other sources that influence results.

Table 3. Seedlings ranked according to percent recovery from severe drought, a 0.10 value equals one plant. Data not significantly different.

Rank	Variety	% Recovery
1	Adelphi	15.50
2	South Dakota Common	15.00
3	Windsor	5.10
4	Park	3.80
5	Merion	1.50
6	Newport	0.50
7	Pennstar	0.03
8	Fylking	0.03
9	Vantage	0.00

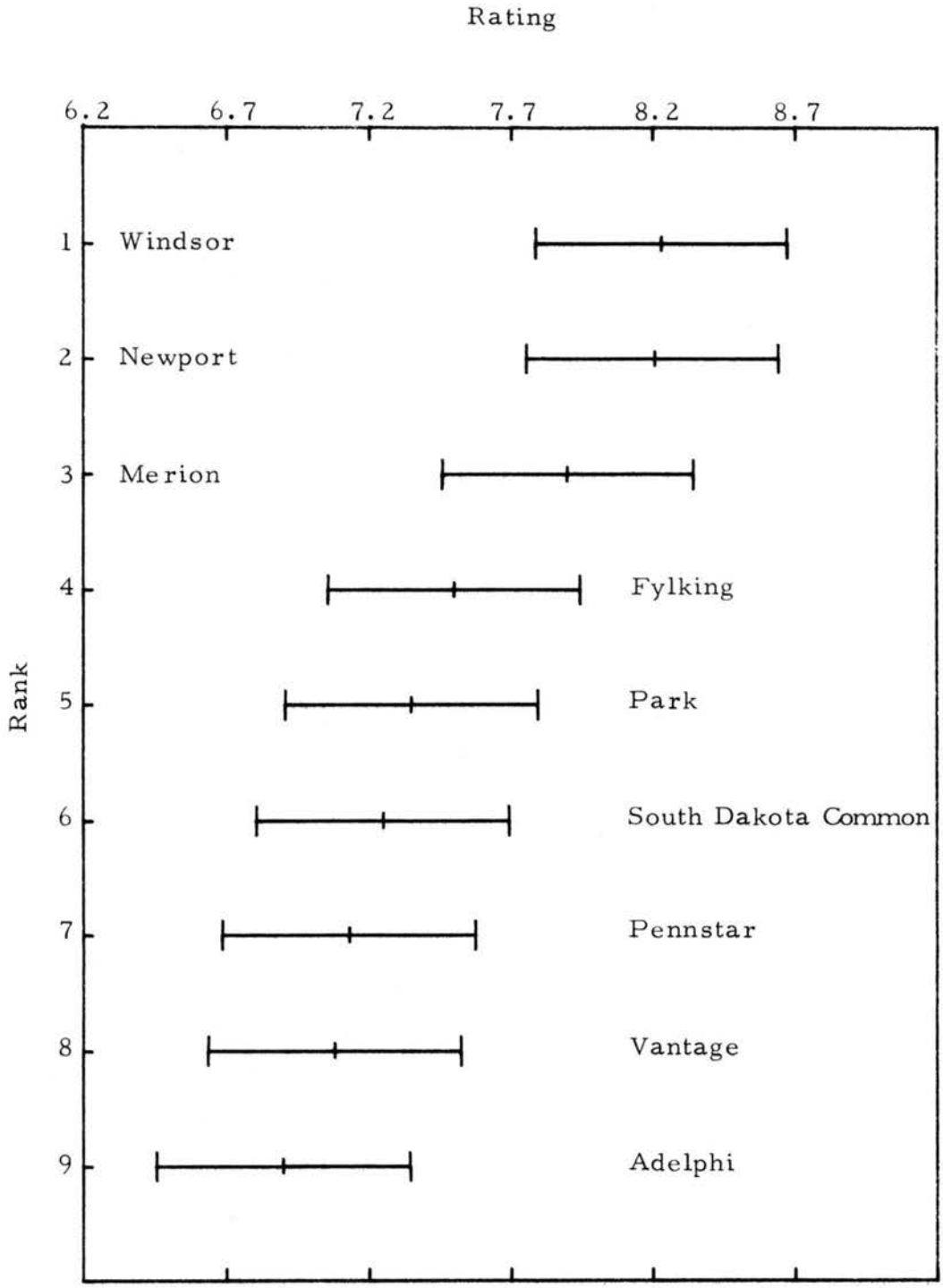

Figure 9. Depicts LSD separation of seedling varieties, Trial 2. LSD (5% level) bars are 0.88 units long.

Although this investigation does have its incongruities, several important insights into drought tolerance were evident. It can be concluded that drought tolerance is not a parameter that can be selected for when grass plants are in the seedling stage. Determining drought tolerance among seedlings, however, may be possible if rate of rhizome and root development were used as a criterion. Also, it has been substantiated that drought tolerance of Kentucky bluegrass is a function of maturity.

GREENHOUSE STUDY

Methods and Materials

In order to continue investigation of the 30 varieties and blends from the field study plugs of sod were taken from the field plots and grown in plastic buckets.

The soil utilized was obtained from an area adjacent to the plots. Before planting the plugs the soil was screened and sterilized. The plastic buckets used were 4 gallons in size. Six 7 mm holes were drilled on the underside of each container and four 7 mm holes were drilled on the sides at the base of the container. A 5 mm depth of course gravel was placed in the bottom of each bucket. The containers were then filled with field soil to within 5 cm of the top.

Three plugs of each of the 30 different varieties and blends, measuring 21 cm in diameter and 5 cm in depth, were planted in the containers. The 90 buckets were transferred to the greenhouse where they received their initial watering. The sod was maintained at a favorable moisture level for two months before being placed under stress. At that time the turfgrass was well established and rooted.

Beneath 30 plugs gypsum blocks were inserted at a depth of 8 cm. These blocks were to be utilized in monitoring soil tension during experimentation. Calibration of the gypsum blocks revealed

inconsistencies existed between meter readings and percent moisture in the soil. Also, the gypsum blocks were normally not sensitive enough for making measurements at the extremely droughty conditions that were induced.

Failure on the part of the moisture blocks necessitated a better means for determining soil moisture. Hence, percent moisture was determined by removing soil plugs and calculating soil moisture upon a dry weight basis. This time consuming method was very reliable. The soil plugs for moisture determination were taken to a depth of 10 cm.

When the first variety in the test exhibited signs of drought stress all of the varieties were rated and a soil sample was taken to determine the percent of soil moisture. This procedure was repeated daily until the grass became blue-gray in color and dry to the touch. At that time the grass was irrigated. At the conclusion of the experiment the data was categorized and statistically analyzed, Appendix Table 18.

Other problems, besides soil moisture determinations, were encountered in this study. The clay-loam field soil utilized was extremely slow to dry in the greenhouse. Evapotranspiration and growth were also retarded by cool temperatures and a reduced light intensity in the greenhouse utilized. As a result 57 days were required to reduce soil moisture to the level where visual expression of drought occurred. The containers were subsequently transferred to

another greenhouse range where temperature and light were more optimum for growth.

When drought research is confined to a greenhouse the investigator must realize that ecological factors are altered by these artificial surroundings. In the greenhouse, turf is not subjected to the diurnal temperature fluctuations, relative humidity, duration, quality and intensity of light that they would normally encounter in the field. Even in the greenhouse, Colorado winter light intensities are likely to be greater than summer time light intensities found in many other areas in the United States. Thus, these variables may not affect greenhouse studies in Colorado as much as elsewhere in the United States and the data obtained from this study may be applicable to other areas where light intensities are low.

Temperature was monitored within the greenhouse during this study. On warm, sunny days the daytime high temperatures ranged from 85 to 90^{o}F, while the nighttime lows ranged from 70 to 75^{o}F. On cold, cloudy days the daytime highs were 70 to 75^{o}F, and the nighttime lows were 65 to 70^{o}F.

In this study the plugs of Kenblue were contaminated with Poa trivalis, hence data presented should not be considered.

Results and Discussion

The Kentucky bluegrass varieties are categorized as follows: high moisture, 9.5 to 11.5 percent soil moisture; low moisture, 8.8 to 9.9 percent soil moisture; and the lower limit or pre-permanent wilting point.

The varieties do not vary greatly as shown in appropriate graphs (Figures 10 to 12); this is probably a result of the rating system employed. It should be noted that a variety rated between 7.3 and 7.5 was green and relatively turgid. At 7.0 to 7.3 the grass is noticeably wilted and has lost some of its greenness. A 6.2 to 6.5 rating indicates that the turf is blue-gray and dry to the touch, but the turf would recover completely with adequate water.

The high moisture range approximates the lowest level at which most Kentucky bluegrasses should be maintained without any permanent injury. The ranking of the varieties in Figure 10 does not indicate which varieties tolerate the greatest soil tensions. Delta, which is ranked third at this range, could not persist at the low moisture level. Therefore, the varieties Code 95 and Merion are ranked low, but they exhibit superior tolerance in very dry soils. Warren's A-20 and A-34, Delta, and Arboretum performed significantly better at 9.5 to 11.5 percent soil moisture than Prato, Windsor, S-21, and Pennstar as shown in Figure 10. Soil moisture tension ranged from 28 to 36 bars at the 9.5 to 11.5 percent soil moisture level, Appendix Figure 1.

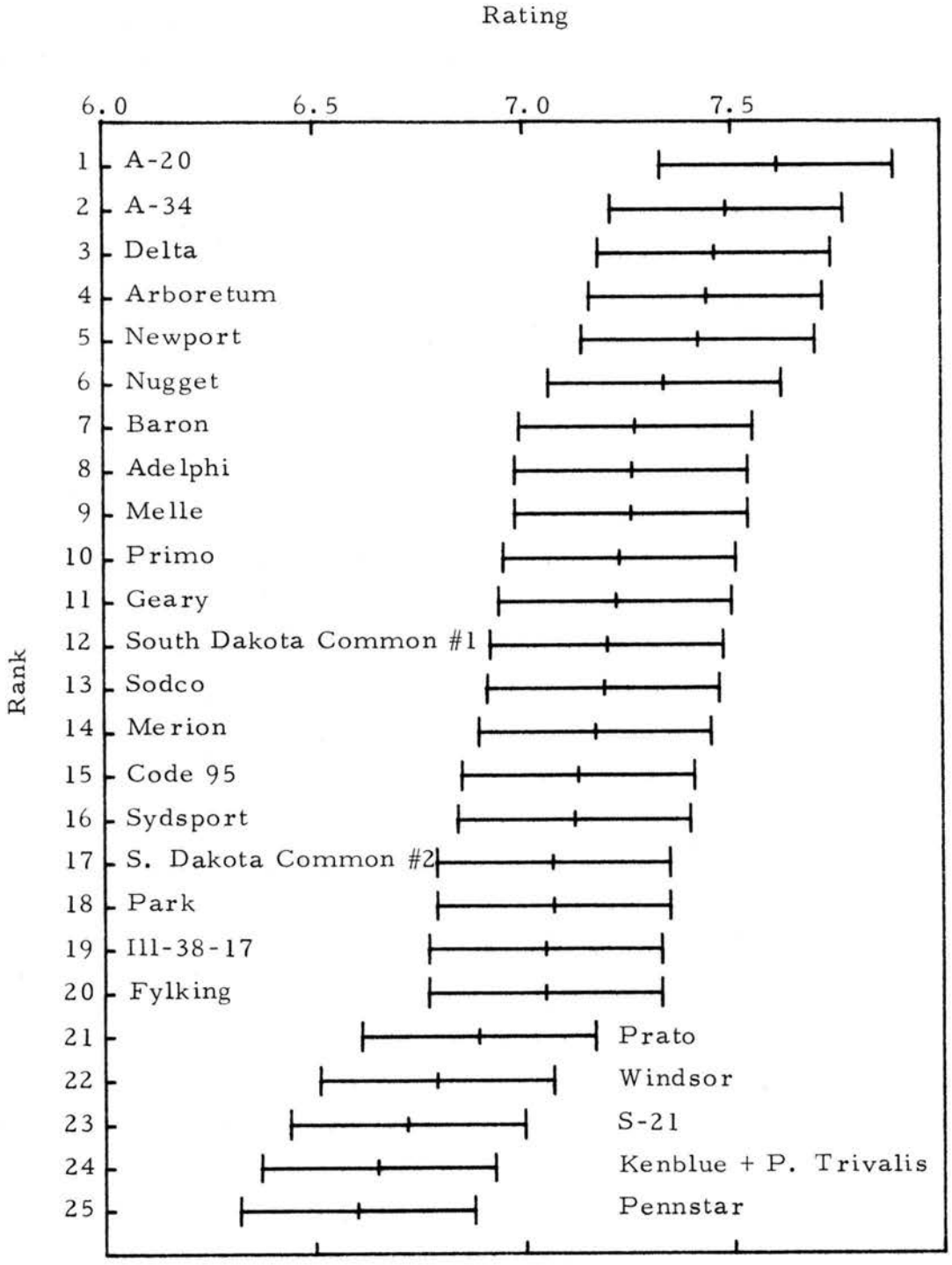

Figure 10. Depicts LSD separation of varieties at the 9.5 to 11.5% moisture level. LSD (5% level) bars are 0.56 units long.

Only 12 of the 25 varieties tested were able to tolerate soil moisture levels of 8.8 to 9.9 percent (35 to 42 bars), long enough for sufficient data to be accumulated as shown in Figure 11. Thus, these 12 varieties were considered more drought tolerant, under greenhouse conditions than the 13 varieties that did not persist. Varieties maintained at these high tensions incurred 15 to 20 percent injury. Injury was localized in the center of the sod. These center plants grow more swiftly, thus they probably did not possess an adequate storage of carbohydrate for recovery. Warren's A-34, Code 95, and Nugget exhibited the best tolerance to drought, Figure 11. Warren's A-34 and Nugget ranked poorly in the field study. Warren's A-34 and Nugget are shade tolerant grasses, and this physiological adaptation was undoubtedly favored by the greenhouse environment. It should also be noted that these varieties were slow growing as shown in Figure 19. Adaptation to less light and slow growth rates may have resulted in a greater root to shoot ratio and subsequent increase of stored carbohydrate and less hydrated tissue. Such an adaptation may enable these varieties to resist drought under greenhouse conditions in the winter. Fylking, a poor shade performer, and Sydsport were shown to be the least tolerant of drought of the 12 varieties.

The third category represented the lowest moisture level a variety could tolerate before above ground shoots die and buds enter into dormancy as shown in Figure 12. Figure 12 shows that varieties

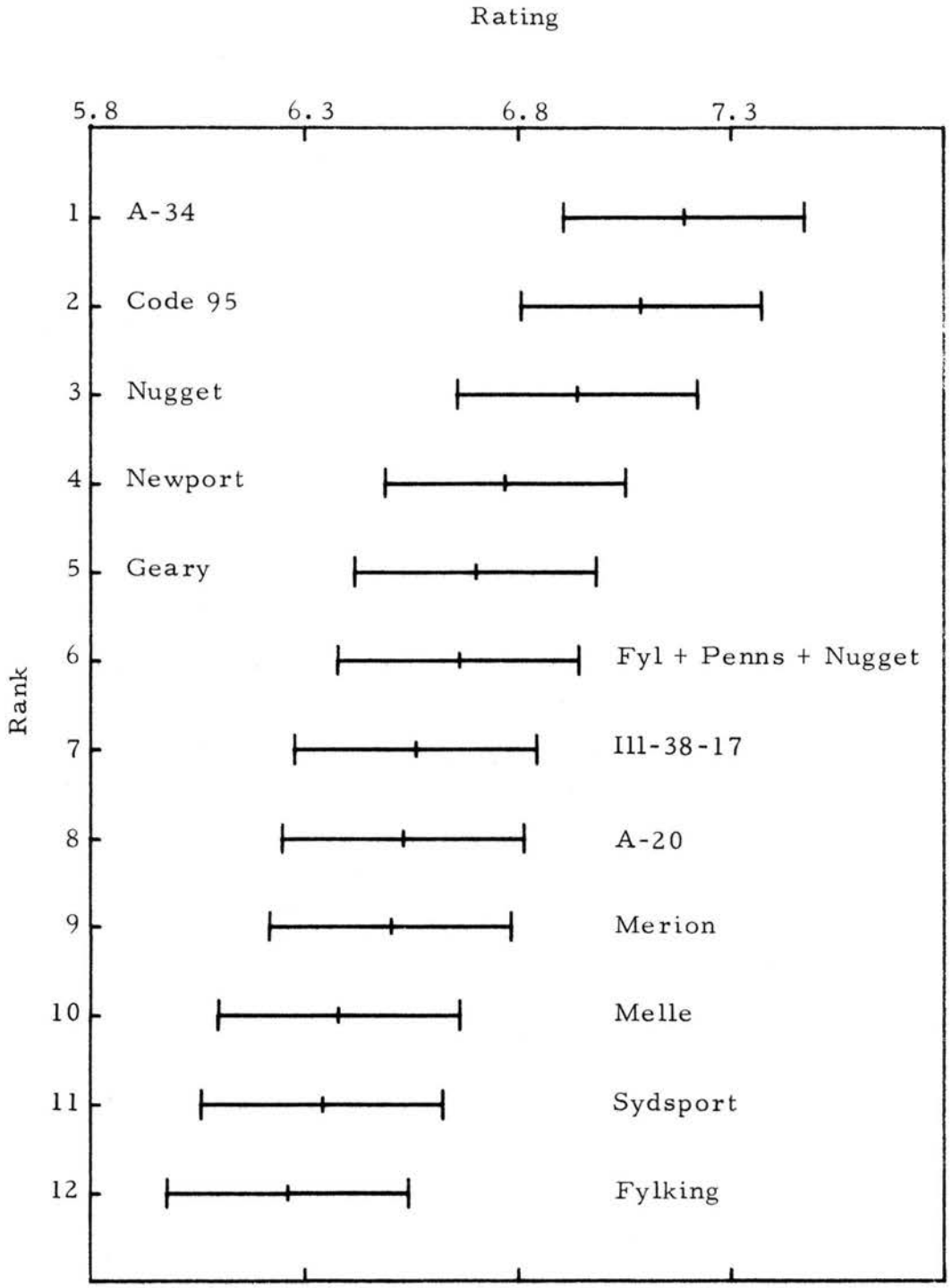

Figure 11. Depicts LSD separation of the varieties at the 8.8 to 9.9% moisture level. LSD (5% level) bars are 0.56 units long.

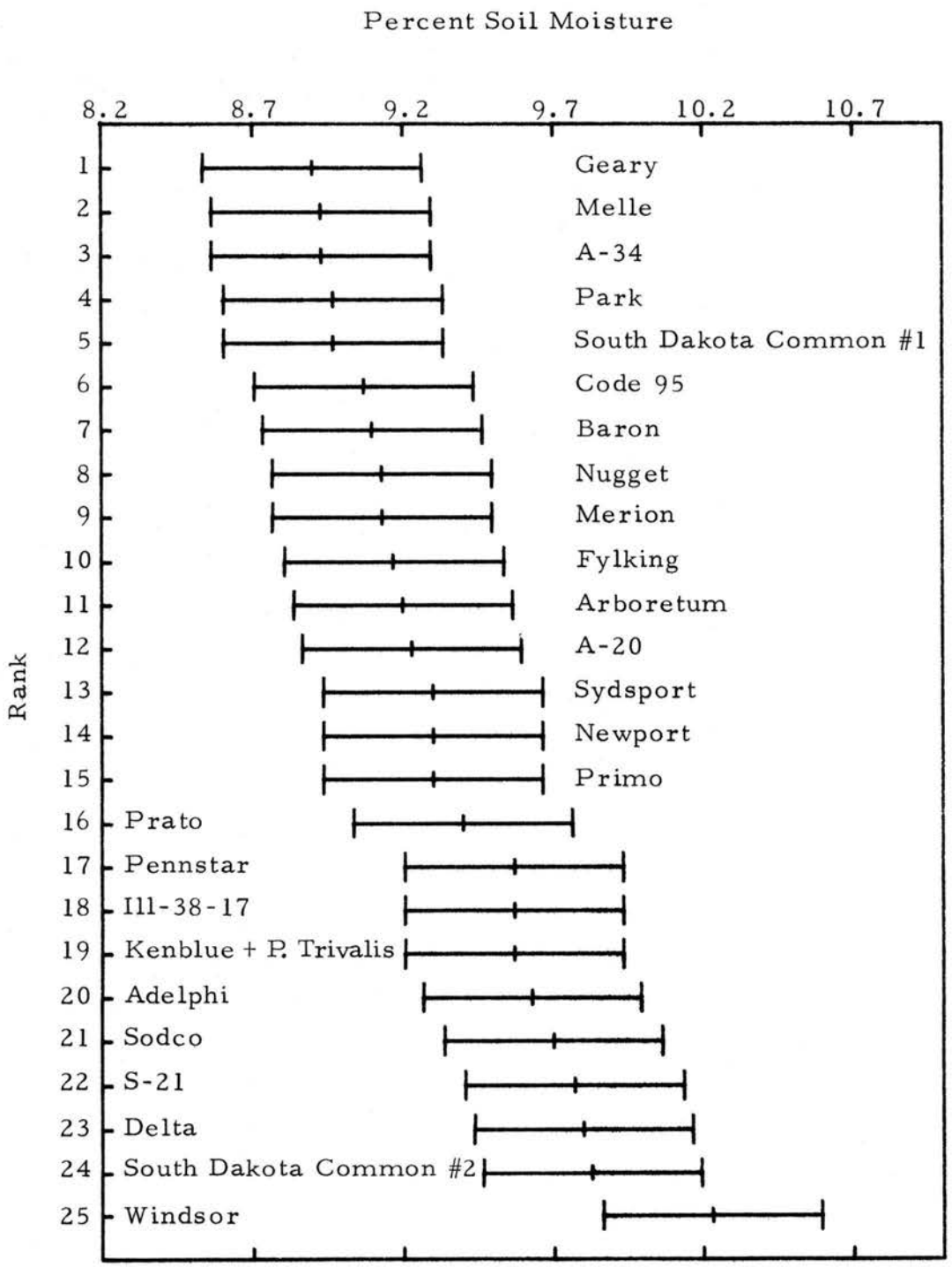

Figure 12. Depicts LSD separation of varieties at the lower limits (pre-permanent wilting point). LSD (1% level) bars are 0.73 units long.

such as Geary, Melle, Warren's A-34, Park, S.D. Common #1 and Code 95 tolerated the lowest limits of soil moisture. Excellent turf varieties such as Baron, Merion, Fylking, Warren's A-20 and Sydsport also ranked high whereas Adelphi, Delta and Windsor were varieties that ranked poorly.

All 25 varieties in the greenhouse remained turgid and green at moisture levels ranging from 13.5 to 15 percent or 15 to 20 bars tension, Appendix Figure 1. The ability of Kentucky bluegrass to grow well at these low moisture levels indicates that there is undoubtedly a tendency to over-irrigate and consequently a needless waste of water.

Conclusion

This greenhouse experiment did produce results which conflicted with the field experiments; however, basic trends were reinforced. Varieties such as Code 95, Geary and Merion had shown good tolerance to drought in both studies. The supportive data for the drought tolerance of these three varieties strengthens field study findings. It may be concluded that these varieties are among the most conservative of water of the many varieties of Kentucky bluegrasses on the market. More experimentation will be necessary to substantiate the drought tolerance of Warren's A-34 and Nugget as applied to environmental conditions imposed by this study. Pennstar and Windsor performed poorly in both greenhouse and field studies

and should not be considered where maximum water conservation is desired. It was also shown that Kentucky bluegrass can maintain optimum greenness and turgidity at lower soil moisture levels than is normally employed by turfgrass managers.

ANATOMY STUDY

The objective of this study was to explore those interrelationships between the gross morphology and the tolerance to drought of Kentucky bluegrass.

The tissue utilized for this study was obtained from Kentucky bluegrass varieties maintained in the greenhouse. As was previously noted, these plants did not receive the duration of light, diurnal temperature fluctuations or humidity encountered in the field.

Light, with the exception of soil moisture, is the most important factor affecting plant form and structure (Weaver and Clements, 1929). Due to a reduction of light during the winter months, it is conceivable that a change in leaf form and structure will differ from that found in the field in the summer. A change in daily opening and closing of the stomata and variations in the loss of water from chloroplasts and cells may also occur. Whether these changes are negated by the quality of sunlight occurring in Colorado during the winter time was not substantiated. It was assumed that any changes which may occur in the gross morphology of the tissue, because of greenhouse conditions, will be proportional rather than inversely proportional. Upon this basis, the data presented should be valid and useful for future comparative work and should be able to widen insights into Kentucky bluegrass drought tolerance.

Xerophytes inherently possess anatomical and physiological adaptations which enables them to postpone internal moisture stress and withstand the harmful effects of desiccation. These structural modifications, commonly occurring in xerophytes, are also found in mesophytes which frequently experience periods of drought (Weaver and Clements, 1929). Consequently, it is anticipated that the more drought tolerant varieties might possess several xeromorphic adaptations. Such adaptations may include more numerous, larger, longer vessels and vessels with thicker walls; duller (absorbing less light) leaf color; narrow leaves; dwarfness, pubescent or shiny leaves, much branched and deep roots densely covered with root hairs; smaller intercellular spaces and compactness of tissue; heavy cuticularization and lignification; vertical growth habit; more stomata per unit leaf area; smaller number of chloroplasts per stomata; smaller stomata; stomata in furrows; rolling or folding of the leaf blades; a lower surface heavily cutinized and woody fibers to provide rigidity to the flaccid leaf (Weaver and Clements, 1929; Beard, 1973).

Methods and Materials

The scope of the anatomy investigation was limited to four varieties of Kentucky bluegrass representative of the high, intermediate, and low drought tolerance, as determined by the field study. Arboretum, Merion, Code 95 and South Dakota Common #2 were highly tolerant; Baron, Warren's A-20, Sydsport and Windsor were

intermediate; Pennstar, Fylking, Ill-38-17 and Warren's A-34 were least tolerant to drought.

All tissues were sectioned approximately 1 cm below the keeled tips of the grass blades. One dozen 5 mm longitudinal peridermal sections and one dozen 5 mm cross sections were made from each of the 12 varieties. The general principles and methods for killing and fixing tissue, infiltration and embedding in paraffin wax and microtoming was performed as outlined by Sass (1958). Principles and methods for affixing paraffin sections to slides and the staining of paraffin sections was performed as outlined by Johansen (1940).

Stomatal aperture measurements were made using the techniques described by Zelitch (1961). Viscuous silicone rubber (RTV-11) was mixed with a curing catalyst and quickly spread on the upper and lower surface of the grass blades. After hardening, the rubber forms a negative replica of the leaf surface. The rubber impressions were then coated with cellulose acetate (clear fingernail polish) to form a positive replica. When dried the film was peeled off the rubber and mounted dry on a slide under a cover slip. This process was repeated on three plants of each variety for both lower and upper epidermis. Three randomly selected stomates from each of the three plants were measured to the nearest one-half micron and were averaged to give an estimate of the stomatal aperture for each variety.

Results and Discussion

Stomata Studies

Meyer and Anderson (1949) have noted that the quantity of water vapor diffusing through small openings in a given period of time is proportional to the perimeters, not the area of the pores. Reduction in the area of the elliptical stomatal opening results in an increase of the perimeter relative to its area. In small apertures a large proportion of the diffusion occurs at the edge of the opening, whereas diffusion occurring through its center is almost completely obscured. Hence, the number of water vapor molecules escaping through the stomatal aperture from a point near the rim per unit time interval will greatly exceed the number escaping from a point near the center of the opening. Consequently, smaller stomatal openings lose proportionally more water than larger stomatal openings. In addition to small stomatal perimeter size, stomata frequency per unit area generally increases in plants grown in dry habitats. The stomatal investigation performed in this study supports these factors and enhances the understanding of the role of stomata and drought tolerance of Kentucky bluegrass.

In Kentucky bluegrass stomatal frequency was shown to be significantly greater on the upper (adaxial) surface compared to the lower (abaxial) surface, Figures 13, 14. The upper leaf surface has a center depression in which the majority of the stomata are located.

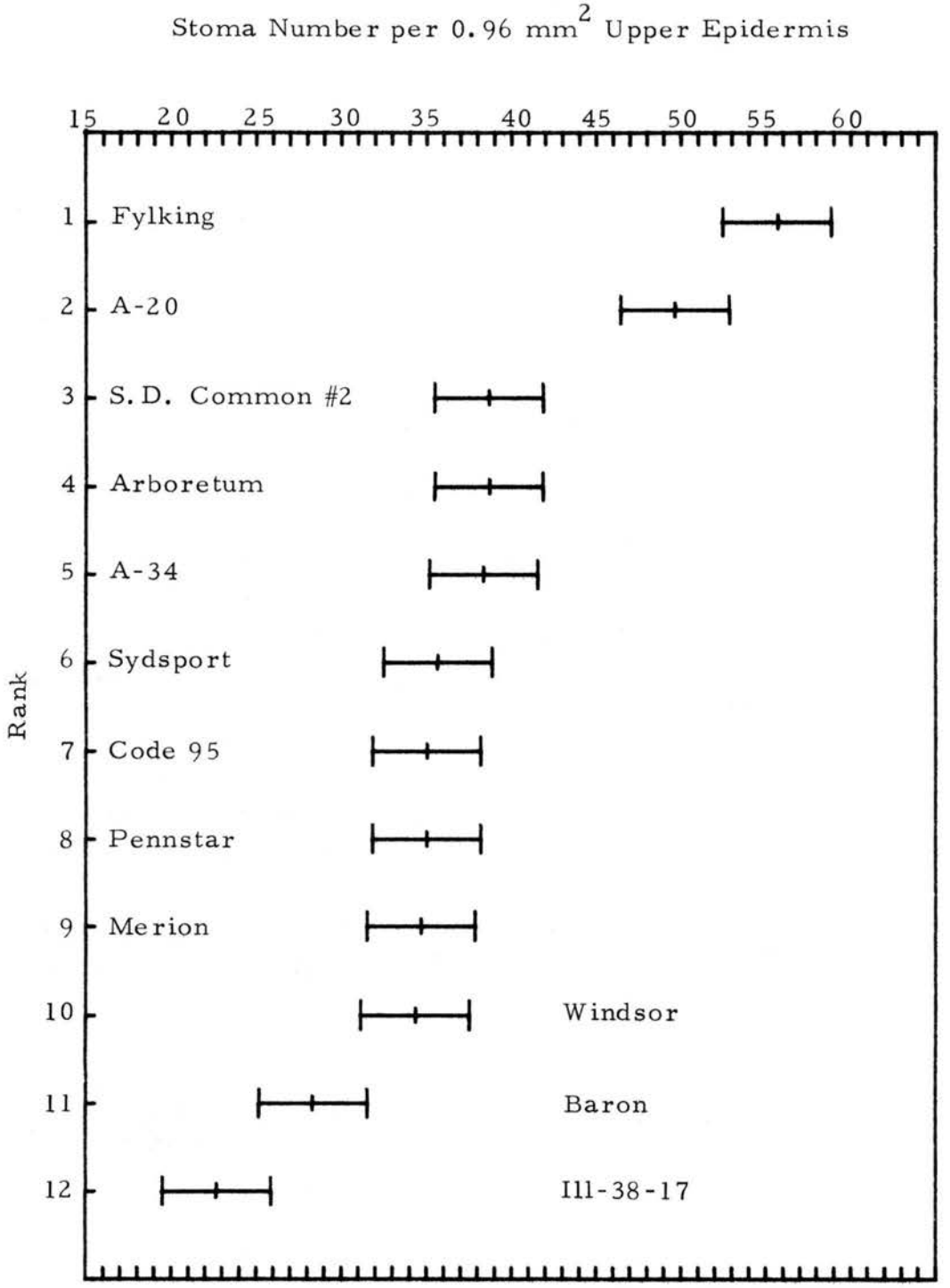

Figure 13. Depicts LSD separation of stoma number per 0.96 mm^2 upper leaf epidermis. LSD (1% level) bars are 6.33 units long.

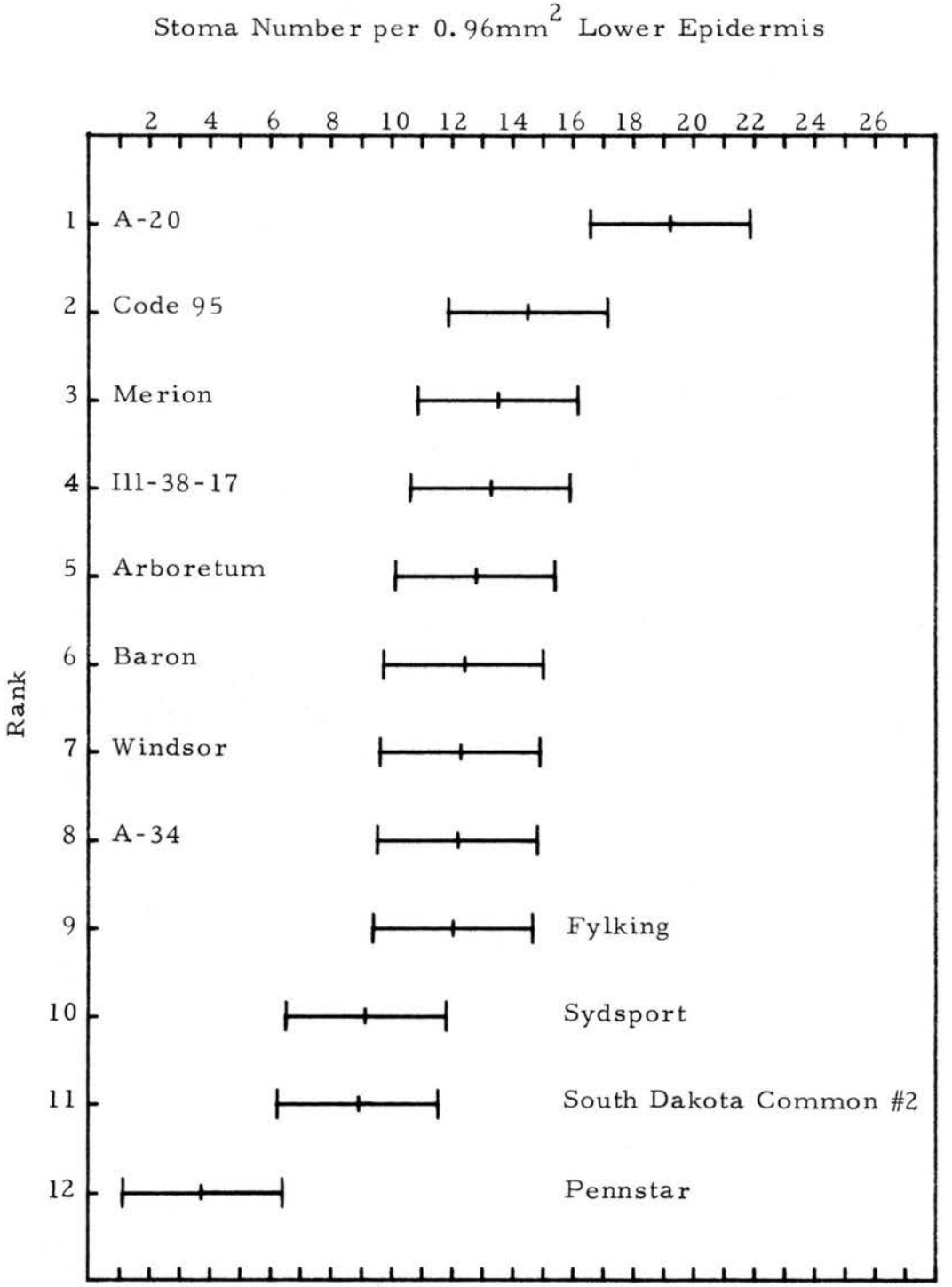

Figure 14. Depicts LSD separation of stoma number per 0.96 mm^2 lower leaf epidermis. LSD (1% level) bars are 5.26 units long.

This depression coupled with the ability of Kentucky bluegrass to fold its leaves when subjected to drought stress undoubtedly contributes to a reduction of moisture losses during stress. The stoma in a depression are able to produce a rather thick boundary layer of water vapor above the leaf surface. This boundary layer increases resistance to water vapor escape from stomatal cavities into the atmosphere. Hence, it appears that the large number of stomata in the adaxial depression, and the folding of the leaves are evolutionary, water conserving mechanisms of Kentucky bluegrass.

The drought tolerant varieties, Arboretum, Code 95, Merion and South Dakota Common #2, possess smaller stomatal perimeters on the upper surface than all other varieties tested, with the exception of Fylking, Figures 15, 16. Fylking, however, possesses a significantly greater number of stomata than all other varieties tested. Although this seems indicative of a xerophyte, it indicates that there may be an upper limit of stomatal frequency beyond which the plant is hindered rather than benefited. Stomatal frequency ranged from 34 to 38 stomata per 0.96 mm^2, adaxial surface, for the drought tolerant varieties, Figure 13. Pennstar and Windsor, which are poor drought varieties, also were within this range.

The drought tolerant varieties possessed stomata with larger perimeters on the abaxial surface than the upper surface, Figure 16. Conversely, the poor drought tolerant varieties had smaller stomatal

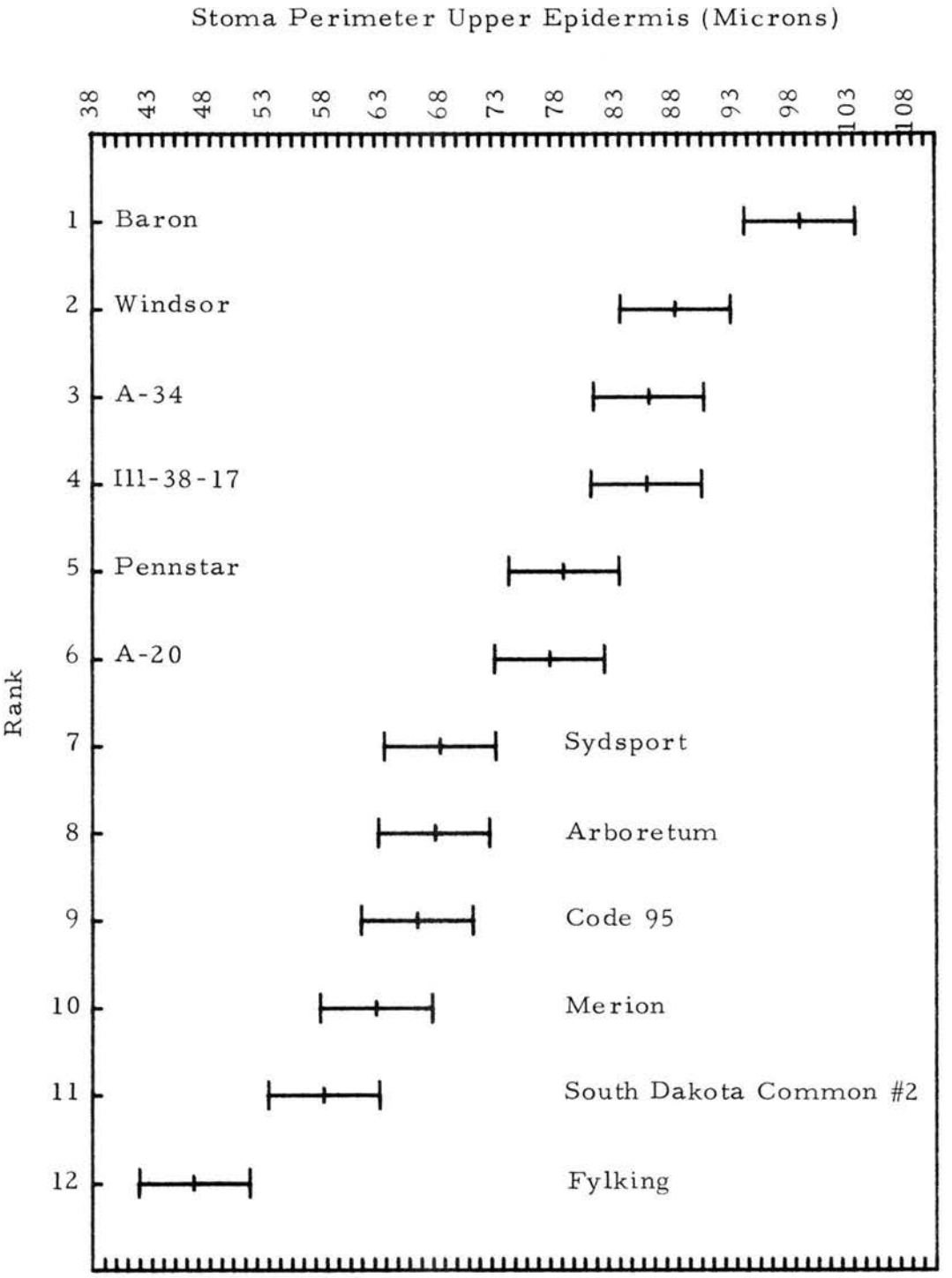

Figure 15. Depicts LSD separation of stomatal perimeters on upper leaf epidermis. LSD (1% level) bars are 9.42 units long.

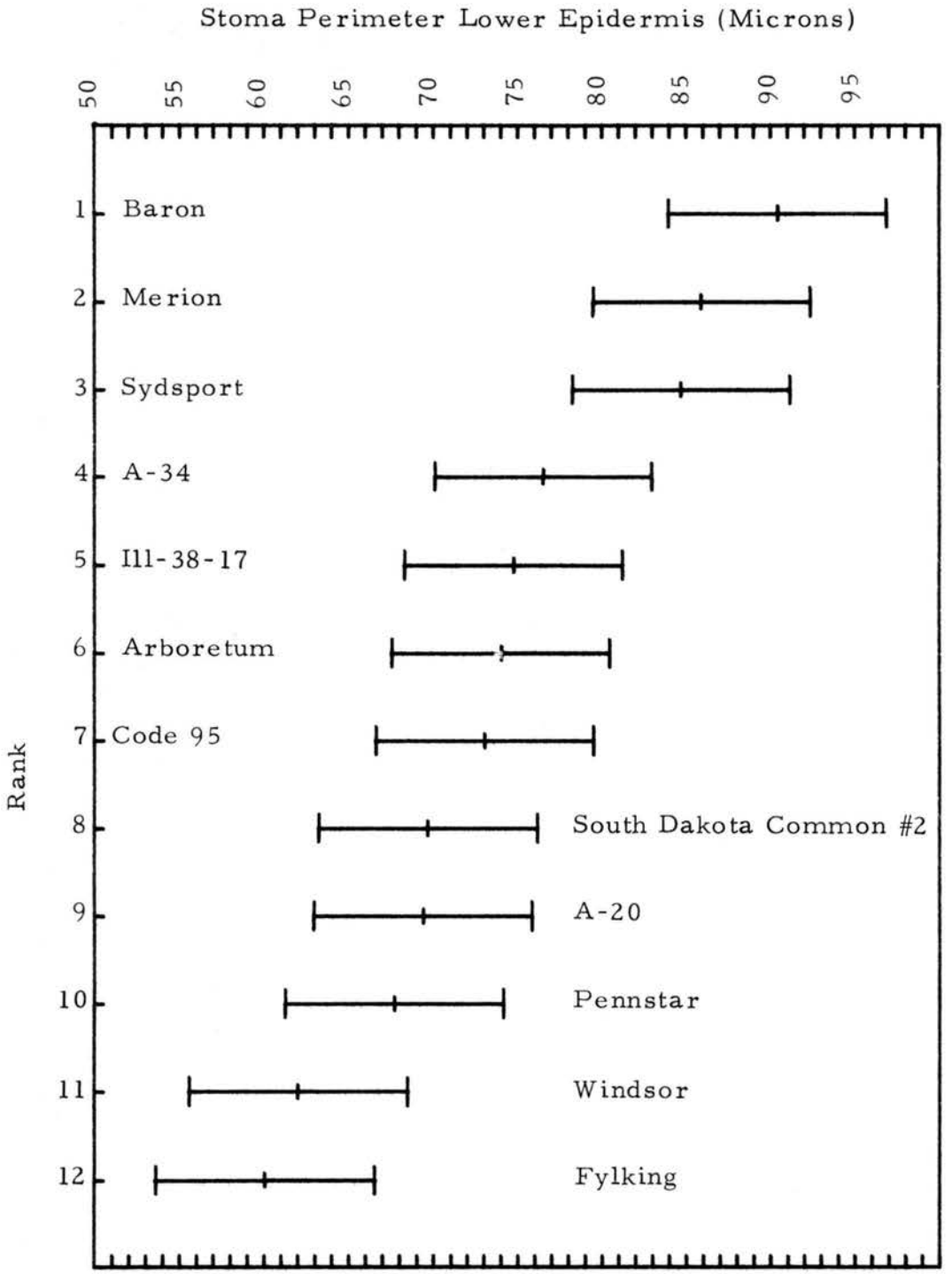

Figure 16. Depicts LSD separation of stomatal perimeters on lower leaf epidermis. LSD (1% level) bars are 12.86 units long.

perimeters on their abaxial surface than on their upper surface. The only exception was Fylking. The stomatal frequency was greatly reduced, hence overlapping of diffusion shells is minimal. With the exception of Pennstar and Warren's A-20, stomatal frequency for the varieties was relatively uniform on the lower epidermis, Figure 14. Therefore, while leaves are folded during stress, the less drought tolerant varieties are losing proportionately more water vapor because of smaller stomatal perimeters and minimal diffusion shells on the abaxial surface.

Hence, the drought tolerant varieties possess many, small stomata per unit area of upper leaf surface. When the blades are folded during stress the droughty varieties are losing proportionately less water per unit area. This interaction of stomatal frequency and size may adequately explain the superiority of one variety to another in their relationship with moisture stress.

Bulliform Cells

The mechanism of leaf folding in Kentucky bluegrass is attributed to the bulliform or motor cells. These bulliform cells are situated in groves on either side of the midvein. These motor cells are generally triangular or wedge shaped; however, considerable irregularities in shape existed among the varieties. These cells are typically much larger than the epidermal cells, except in Fylking where bulliform cells could not be delimited from epidermal cells.

The lengths of bulliform cells were measured and when a comparison was made, three of the four drought tolerant varieties were shown to have significantly longer bulliforms, Figure 17. South Dakota Common was the exception, with shorter bulliform cells while Ill-38-17 was found within the same range as Merion, Code 95 and Arboretum, Figure 17. Whether these longer bulliforms are more likely to collapse and close the leaf earlier than shorter bulliform cells during stress is unknown.

More detailed information regarding size, number and position and shape of bulliform cells is located in Appendix Table 10.

Vascular Bundles

Because the vascular bundles on either side of the midvein were similar in their corresponding position within the leaves, measurements were made on only one side of the midvein.

Six or seven bundle sheaths were generally located on each side of the midvein. Sydsport had only five vascular bundles, while Code 95 had nine bundles on each side of the midvein. The increased number of vascular bundles in Code 95 may be related to this variety's outstanding tolerance to drought, especially during conditions favoring atmospheric drought.

Merion, Arboretum and Code 95 as well as less drought tolerant varieties such as Warren's A-20, and Windsor and Pennstar had bundles which were close together, Figure 18. A closer

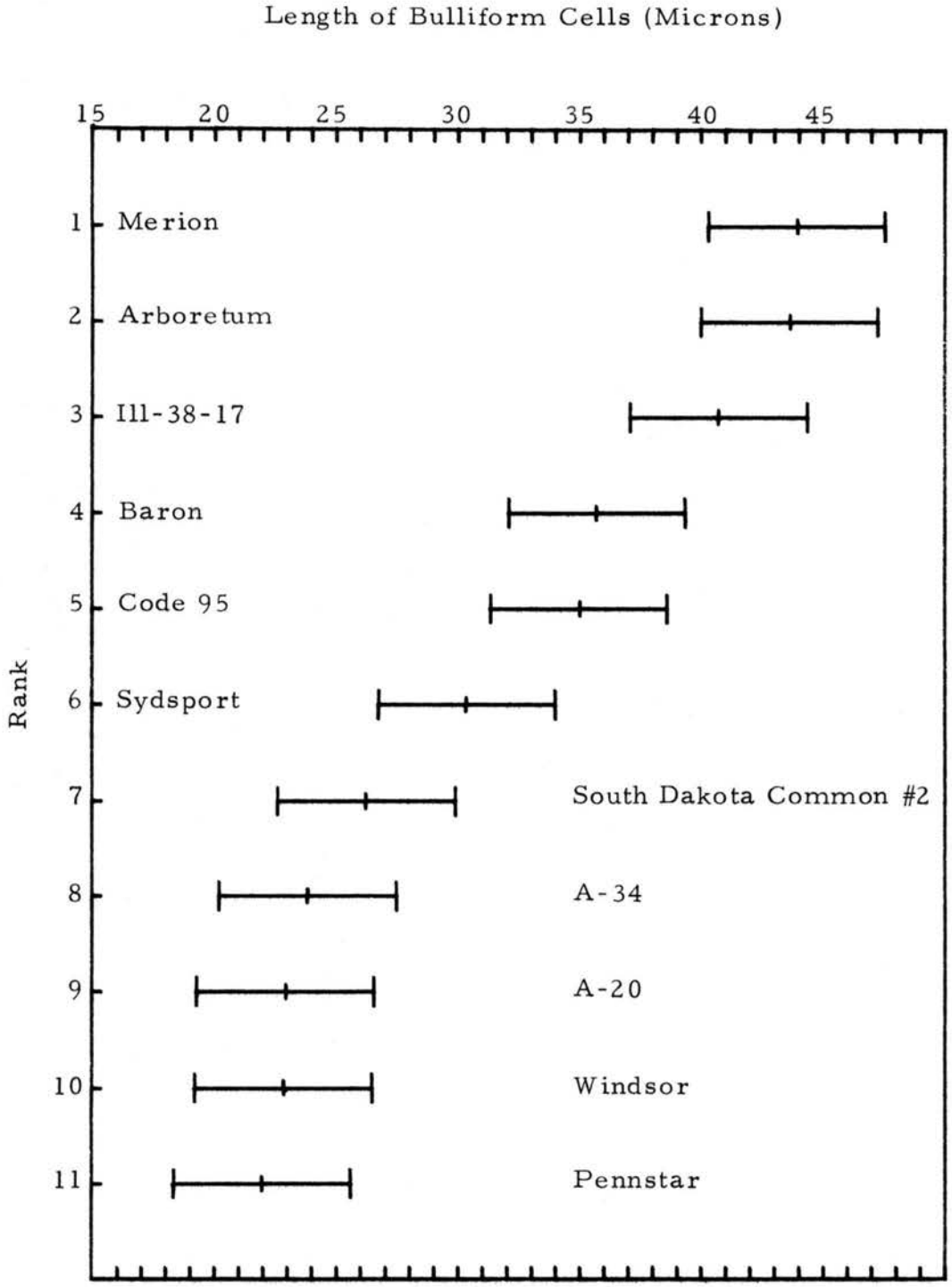

Figure 17. Depicts the LSD separation of lengths of leaf bulliform cells. LSD (1% level) bars are 7.24 units long.

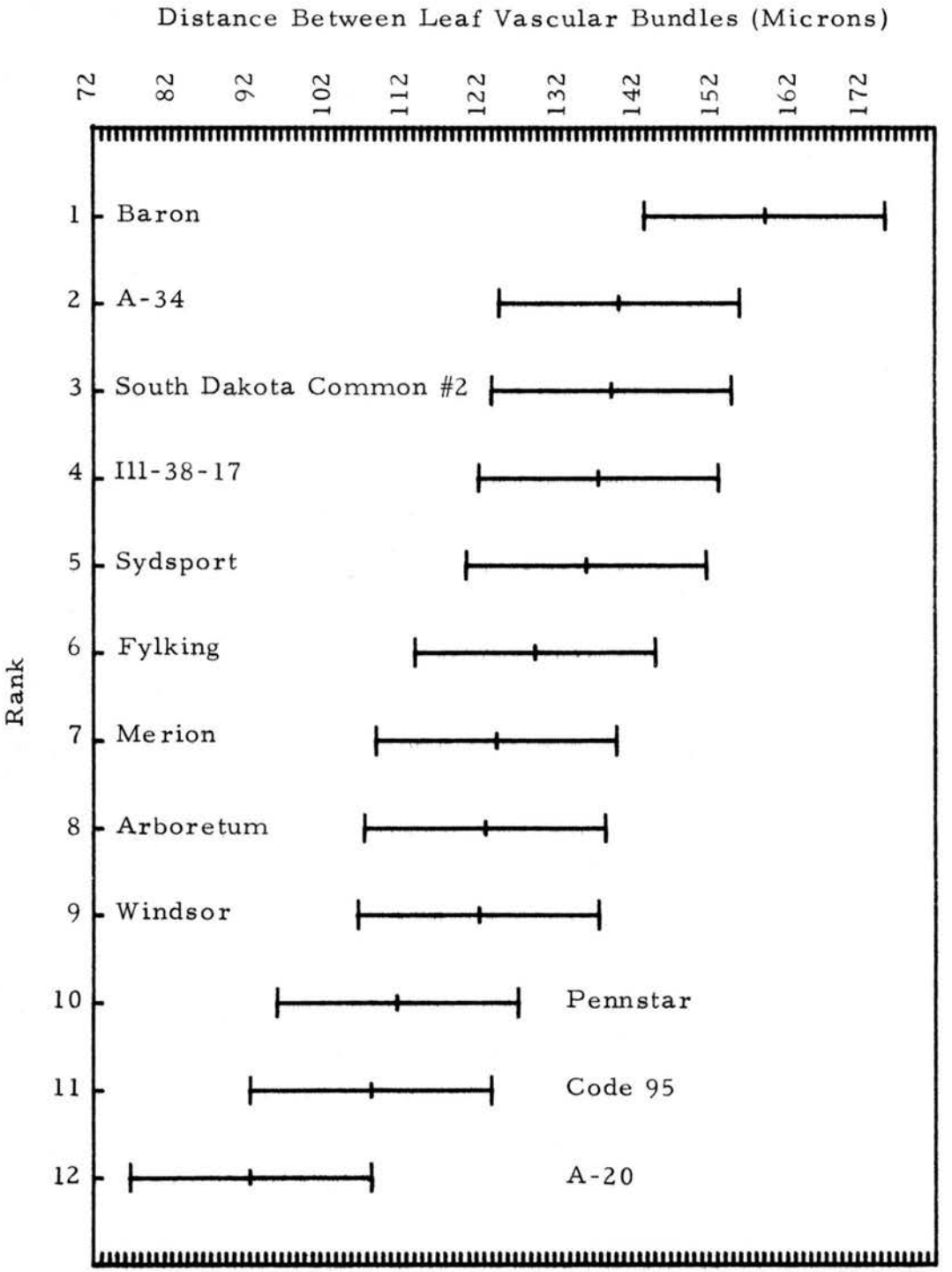

Figure 18. Depicts LSD separation of distance between leaf vascular bundles. LSD (1% level) bars are 30.87 units long.

orientation would reduce the distance water would need to move from conducting tissue to adjacent mesophyll cells.

Diminutive conducting tissue is another general characteristic of xerophytes. Although the varieties did not statistically differ in bundle size, Merion and Code 95 had the smallest diameter vascular bundles and small metaxylem vessels, Table 4. The metaxylem and protoxylem vessels were generally located in the second and fourth bundles and the midvein. Code 95, South Dakota Common and Windsor possessed metaxylem and protoxylem vessels in three bundles, while Sydsport had these larger vessels in only the second bundle and midvein. This increase in water conducting vessels may aid Code 95 and South Dakota Common in resisting atmospheric drought.

Recorded in Appendix Tables 11, 12 and 13 are additional data pertaining to distance between bundles, bundles with metaxylem and protoxylem cells and diameter of metaxylem.

Sclerenchyma Fibers

The vascular bundles of Kentucky bluegrass are enclosed in two sheaths. The inner sheath is composed of small, thick walled cells while the outer sheath is made up of large cells which were usually thin walled. These outer sheaths were not always well defined. Metaxylem and protoxylem vessels and phloem cells were located in the larger bundle sheaths. The protoxylem vessels were occasionally broken down leaving lacunae. The smaller bundles had only a few

Table 4. Comparison of the mean diameters of leaf vascular bundles, in microns. Not significant.

Rank	Variety	Diameter (in microns)
1	A-34	36.2
2	South Dakota Common	36.0
3	Baron	35.7
4	Pennstar	34.3
5	Ill-38-17	32.3
6	Arboretum	31.5
7	A-20	31.4
8	Sydsport	30.8
9	Fylking	30.6
10	Windsor	28.3
11	Merion	27.7
12	Code 95	25.2

phloem elements and only tracheids and fibers in the xylem. Strands of sclerenchyma fibers and radial chlorenchyma accompanied many of the larger vascular bundles of most of the varieties. These strands formed an I-beam of mechanical tissue. These I-beams varied in composition among the varieties and may or may not extend to both the lower and upper epidermis. Rows and clusters of fibers were occasionally found developing along the epidermis above and/or below the bundles. These I-beams are better described for each of the varieties in Appendix Table 14.

Sclerenchyma fibers were also located in rows and clusters along the outer edges of the leaf blades and also in the lower epidermis opposite the midvein, Appendix Table 15.

The more drought tolerant varieties such as Merion and Code 95 had no I-beams, while the I-beams in Arboretum were composed of only radial chlorenchyma. Conversely, the less drought tolerant varieties possessed more sclerenchyma tissue, particularly those I-beams located in Pennstar, Fylking and Windsor. Although it was anticipated that the drought tolerant varieties would have a greater proportion of these rigid, supportive fibers this was not the rule.

Leaf Color and Shinyness

Blades of grass that are shiny and a lighter green color may have an advantage in combating drought by reflecting more light and thusly, reducing rapid transpiration.

Harivandi (1975) who investigated iron chlorosis of Kentucky bluegrass had measured chlorophyll content of those varieties utilized in this drought investigation. An examination of Harivandi's data revealed no direct correlation between leaf color and drought tolerance. Ill-38-17, which contained significantly high levels of chlorophyll, tolerated drought poorly. However, drought tolerant South Dakota Common + Kenblue blend possessed more chlorophyll than Ill-38-17. Many of the drought tolerant varieties were grouped at an intermediate chlorophyll level ranging from 2.3 to 2.6 mg/g of chlorophyll.

Shinyness, or reflectivity, is another character which may enable a particular variety to withstand drought longer. A close, visual inspection of the varieties revealed no observable differences in leaf shinyness.

Rate of Growth

Grasses that grow swiftly generally have highly hydrated tissues and less stored carbohydrate. Such grasses would not be expected to withstand or recover swiftly from drought injury. However, data in Figure 14 shows that the more drought tolerant varieties of Kentucky bluegrass grow the swiftest. With the exception of Merion, all of the drought tolerant varieties were shown to be more rapid growing than the other varieties tested, Figure 19. The competitive and adaptive

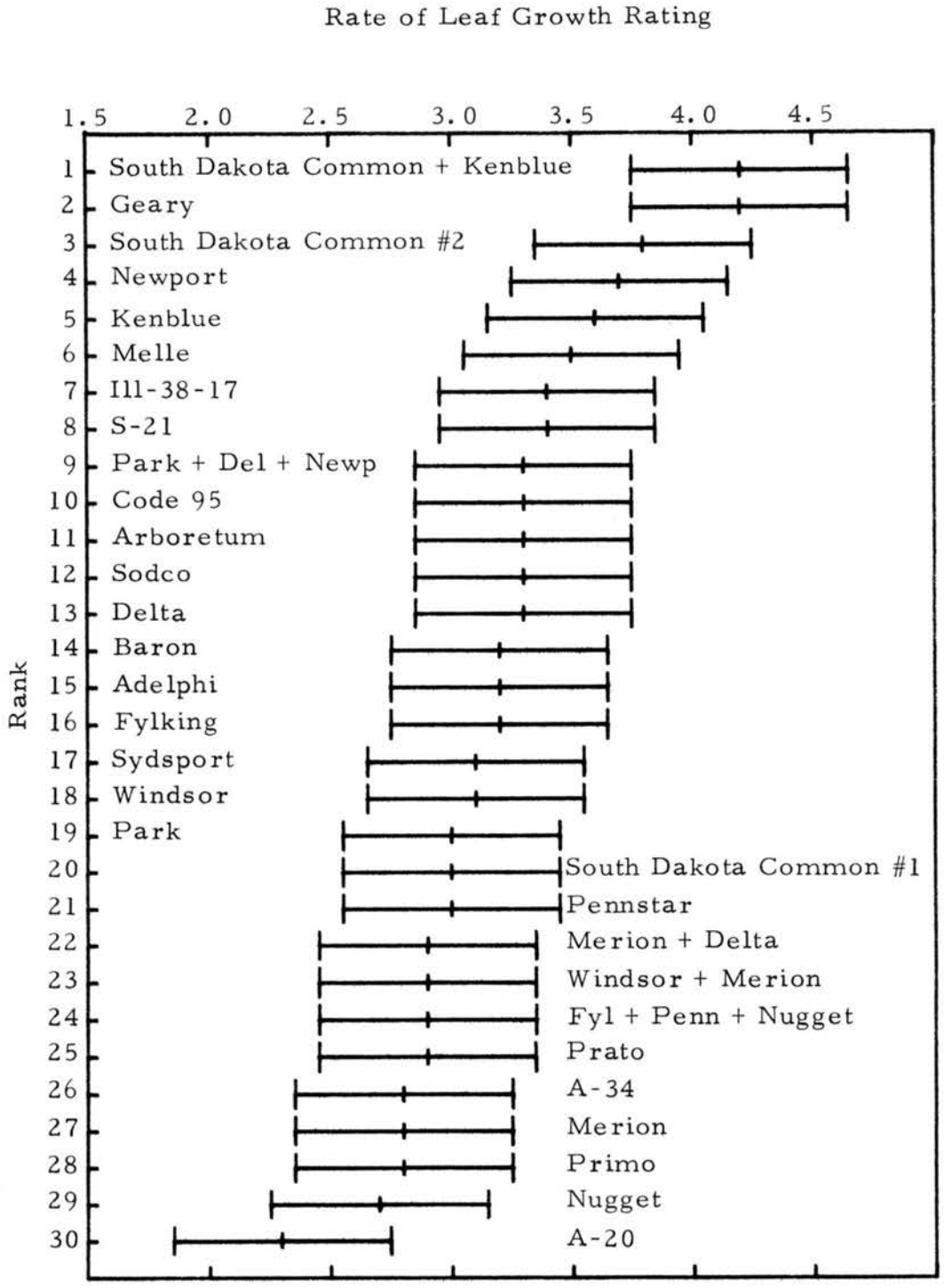

Figure 19. Depicts LSD separation of leaf growth rates. LSD (1% level) bars are 0.89 units long. Growth rates are based on a 0 to 5 scale where 5 = maximum growth and 0 = no growth.

capabilities of the drought tolerant common-types as well as the ability of taller grasses to reduce evapotranspiration is a probable explanation for this phenomenon.

Tissue Weight

Xerophytes are generally characterized by small cell size, small vacuoles, and thick cell walls and cuticles. Xerophytic tissues are less hydrated and therefore possess a greater proportion of tissue weight to water weight than mesophytes.

To compare tissue weights of the varieties, 10 to 12 grams of fresh, turgid tissue were harvested from each of the three replications, weighed and oven dried at 65°C for 48 hours. From this data a percent tissue weight was calculated. Statistical analysis showed no significant differences between the varieties for this parameter, Table 5.

Tissue of the drought tolerant varieties were generally more hydrated. This was anticipated because of the rapid growth rates of the drought tolerant varieties. To conclude that rapid growing, highly hydrated tissues are characteristic of drought tolerant grasses would not be valid. The varieties were grown under ideal conditions when being evaluated for these parameters. Hence, the greenhouse environment undoubtedly negated the validity of this data. Collecting tissue grown under droughty, field conditions would yield more realistic data for these parameters.

Table 5. Comparison of percent tissue dry weights. No significance.

Rank	Variety	Percent Tissue Dry Weights
1	South Dakota Common #2	23.6
2	Sodco	22.5
3	A-20	21.9
4	Park	21.6
5	A-34	21.5
6	Adelphi	21.4
7	South Dakota Common #1	21.1
8	Prato	21.1
9	Delta	20.9
10	Windsor	20.7
11	Baron	20.6
12	Nugget	20.5
13	Arboretum	20.5
14	Pennstar	20.4
15	Merion	20.4
16	Fylking	20.3
17	Melle	20.2
18	S-21	20.2
19	Newport	20.1
20	Kenblue + P. Trivalis	20.0
21	Geary	19.9
22	Primo	19.9
23	Ill-38-17	19.8
24	Sydsport	19.5
25	Code 95	19.4

Width of Blades

Transpiration can be reduced by decreasing the area of the transpiring surface. Daubenmire (1959) notes that small size is normally compensated for by greater numbers of leaves and a reduction in the vapor layer which accumulates above the evaporative surface. Hence, a reduction in the size of individual leaf blades may have no apparent significance with respect to reduced transpiration.

The width of leaves from five plants per container were measured, one cm down from the keeled tip, to the nearest 0.1 mm. The data in Table 6 indicated no direct correlation between leaf width and drought tolerance. Both poor and excellent drought tolerant varieties are found at both extremes of leaf widths. Although no direct correlation exists, it cannot be assumed that narrow or wide bladed varieties were not benefited nor hindered by their width. The narrow leaves of Code 95, Geary and South Dakota Common #2 may have aided these varieties in combating the harmful effects of drought.

Miscellaneous Morphology and Anatomy

The compactness of tissue and pore space could not be adequately measured quantitatively. Generally, the varieties appeared similar in compactness. Pennstar appeared more compact than drought tolerant Code 95. Windsor had more frequent and larger intercellular spaces and was the least compact of the varieties observed.

Table 6. Comparison of the mean leaf widths in millimeters. Significant at the 99% level.

Rank	Variety	Mean Width
1	Ill-38-17	2.71
2	Primo	2.71
3	Arboretum	2.41
4	S.D. Common + Kenblue	2.39
5	Melle	2.31
6	Baron	2.23
7	Merion	2.20
8	S-21	2.19
9	Sydsport	2.17
10	Fylking	2.14
11	Pennstar	2.07
12	Newport	2.07
13	Kenblue	2.06
14	Prato	2.03
15	Park	2.02
16	A-20	2.01
17	Sodco	2.00
18	Code 95	1.99
20	Windsor	1.97
21	Nugget	1.96
22	Geary	1.95
23	Delta	1.91
24	S.D. Common #2	1.90
25	A-34	1.88
26	S.D. Common #1	

Unfortunately, cuticle thickness was also not measurable. The inability to measure cuticle thickness was probably due to a problem of staining and because the greenhouse environment was not conducive to thick cuticle development.

The distances between the midveins and the edges of each side of the leaf blades varied in length for most of the varieties. There was no indication that degree of non-symetry had a relationship to drought tolerance.

Leaf thicknesses were compared as well as lengths and widths of epidermal cells. Here again no correlation to drought tolerance could be made, Appendix Table 16, 17.

Conclusion

The purpose of this anatomical investigation was to develop a foundation for future anatomy studies involving Kentucky bluegrass. It was also intended to devise a simple means of judging the relative drought tolerance among turfgrass varieties. These objectives were met, however, continued and more in-depth investigations are needed to substantiate these findings. Of particular interest would be an anatomical comparison of the varieties grown under various environmental conditions in the field.

The drought tolerant varieties possessed several anatomical similarities which were statistically validated. Some deviations, as might be expected, occurred. The drought tolerant Kentucky

bluegrass varieties were more rapid growing; had many, small stomata on the upper leaf surface and few, large stomata on the lower leaf surface; comparatively long bulliform cells; closely oriented vascular bundles; small vascular bundle and metaxylem cell diameters and absence of heavy sclerenchyma development.

SUMMARY AND CONCLUSIONS

The common type Kentucky bluegrasses were shown to be more drought tolerant. South Dakota Common, Kenblue and Arboretum exhibited outstanding drought tolerance, but poor color, texture and density. Code 95 and Merion are excellent drought tolerant varieties that produce turf with good color, texture and density. Turf mowed at $1\frac{1}{2}$ inches displayed slightly more drought tolerance than grass maintained at 3/4 inches. Windsor and Pennstar did not adequately tolerate drought stress.

The seedling investigation revealed that drought tolerance for mature turfgrass could not be adequately determined from seedlings. Generally, seedlings withstood only five to eight days between irrigations without permanent wilting.

Greenhouse observations substantiated that Code 95, and Merion are among the most drought tolerant Kentucky bluegrasses. It was also evident that Kentucky bluegrass can maintain optimum greenness and turgidity at lower soil moisture levels than is normally employed by turfgrass managers.

Drought tolerant varieties possess several anatomical and morphological characters which may account for their drought tolerance in part. Of most importance was the relationship of stomata number and perimeter size.

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APPENDIX

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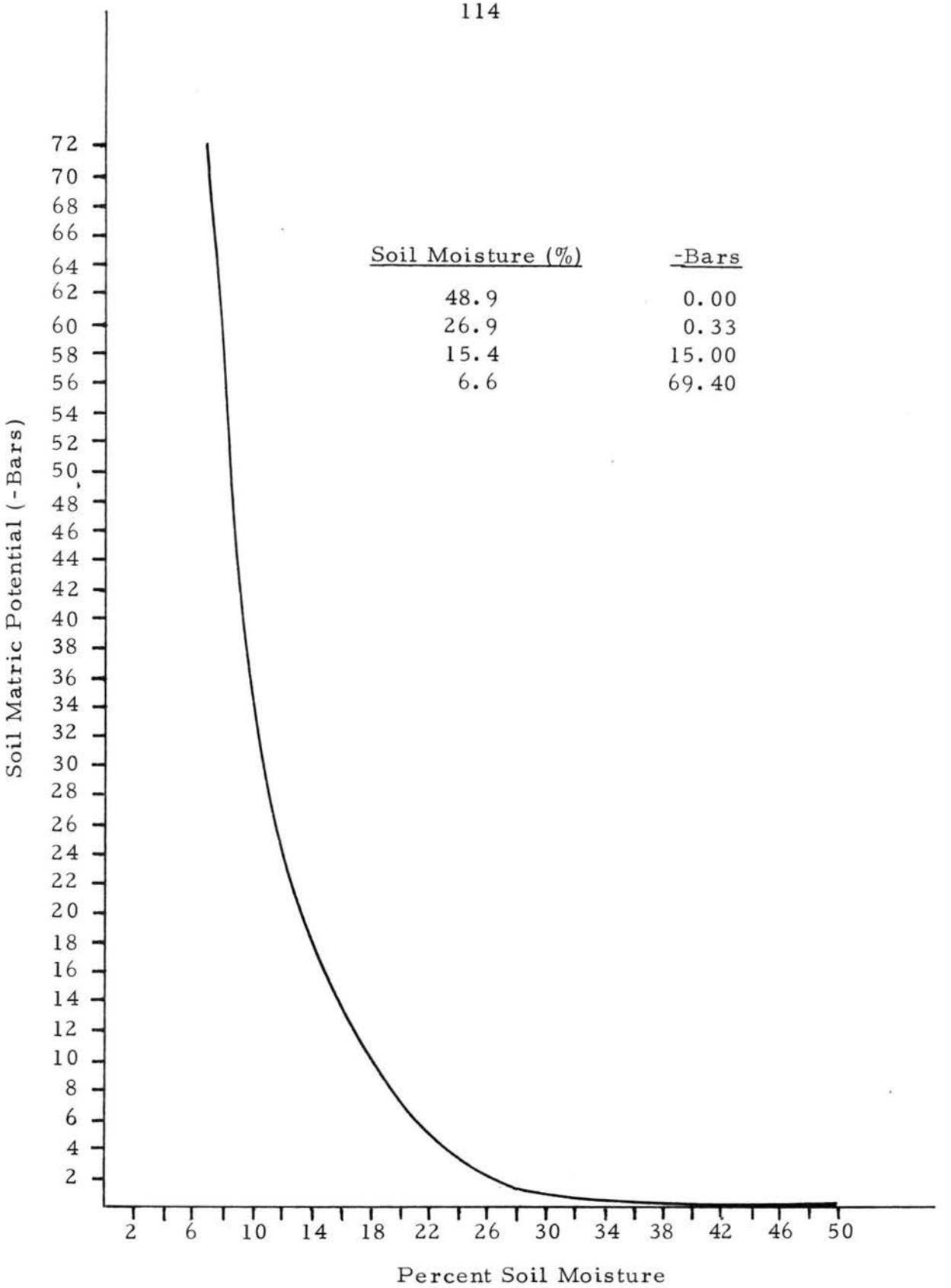


Appendix Figure 1. The moisture tension curve plotted from data points obtained from the soil test. The 69.4 bars (6.6%) soil moisture point was derived by allowing soil to equilibriate with a known water potential.

Appendix Table 1. Routine Colorado Soil Test with SAR.

pH	Conductivity	Lime	% O. M.	ppm P	ppm K	ppm NO_3-N	ppm Zn	ppm Fe	Texture	SAR
7.9	3.8	Medium	4.9	230	1200	76	4.4	17.0	Clay Loam	.33
			Relative Levels for Kentucky Bluegrass Turf							
Mod. High	Mod. High	Mod.	High	High	High	High	High	High		Extremely Low

Appendix Table 2. Climatological data for Fort Collins, Colorado (1975) derived from the National Oceanic and Atmospheric Administration, The Environmental Data Service, Asheville, North Carolina.

	Temperature							
	Avg. Max.	Avg. Min.	Avg.	Highest	Date	Lowest	Date	Degree Days
June	77.6	49.4	63.5	91	30	36	11	92
July	85.5	57.8	71.7	94	1	51	12	1
August	90.3	48.8	69.6	101	6	39	30	6
Sept. 1-5	79.4	52.0	65.7	85	2	47	5	0

	Number of Days			
	Maximum 90° or Above	32° or Below	Minimum 32° or Below	Total Precipitation
June	2	0	0	1.77 in. (.59" in 1 day)
July	4	0	0	0.92 in. (.24" in 1 day)
August	17	0	0	2.66 in. (2.0" in 1 day)
Sept. 1-5	0	0	0	0.03 in.

Appendix Table 3a, b. Comparison of the Kentucky bluegrass varieties at medium and high moisture levels. The varieties were rated on a 0 to 10 scale with 10 denoting maximum greenness and turgidity. The varieties are ranked by mean values. Significance is at the 99% level.

3a. Medium Moisture			3b. High Moisture		
Rank	Variety	Mean	Rank	Variety	Mean
1	SD Comm + Kenbl	9.000	1	Merion + Delta SD Comm + Kenbl	9.316
2	Geary, Merion	8.866	2	Geary	9.250
3	Arboretum	8.800	3	Sydsport	9.233
4	Kenblue	8.716	4	Merion, A-20 Sod	9.183
5	S-21, Common (SD #2)	8.650	5	Comm (SD #2) Arbor	9.166
6	Code 95	8.616	6	Windsor + Merion	9.116
7	Melle	8.533	7	Baron, Pk + Del + Newp	9.083
8	Windsor + Merion	8.550	8	Kenblue	9.066
9	Merion + Delta	8.500	9	Delta	9.000
10	A-20 Sod, Prato	8.416	10	S-21, Sodco	8.960
11	Sydsport, Delta	8.266	11	Nugget	8.883
12	Sodco	8.200	12	Prato	8.866
13	Baron	8.183	13	Melle	8.850
14	Windsor	8.116	14	Windsor	8.816
15	Park + Del + Newp	8.000	15	Pennstar	8.800
16	Newport	7.900	16	Fyl + Penns + Nugget	8.730
17	Pennstar	7.866	17	Newport, Code 95	8.683
18	Nugget	7.816	18	Fylking	8.483
19	Adelphi	7.783	19	A-34 Seed	8.416
20	Ill-38-17	7.766	20	Adelphi	8.266
21	Fylking	7.750	21	Ill-38-17	8.216

Appendix Table 3a, b. (continued)

Medium Moisture			High Moisture		
Rank	Variety	Mean	Rank	Variety	Mean
22	Common SD #1	7.733	22	Park	8.200
23	Park	7.633	23	Common SD #1	8.183
24	Primo	7.600	24	Primo	8.080
25	Fyl + Penns + Nugget	7.400			
26	A-34 Seed	7.366			

Appendix Table 4. Non-drought comparison of color, density, texture and overall appearance of 25 varieties and 5 blends of Kentucky bluegrass. Ratings on a 0 to 10 scale with 10 representing optimum color, density, texture and overall appearance. Significant at the 99% level.

3/4" Cut -- Drought Excluded

Rank	Color Rating Variety	Mean	Rank	Density Rating Variety	Mean	Rank	Texture Variety	Mean	Rank	Overall Variety	Mean
1	Sydsport Baron	9.50	1	Sydsport Merion	9.33	1	Ill-38-17	6.50	1	Sydsport	9.50
2	Fylking	9.33	2	Baron	9.17	2	Kenblue	6.17	2	Baron	9.33
3	Penns, Ill-38-17	9.17	3	Windsor, A-34 Seed	9.00	3	Delta, Melle Adelphi, Baron	6.00	3	Merion	8.83
4	Fyl + Penns + Nugget	9.00	4	Penns, Wind + Merion	8.83	4	A-20 Sod	5.83	4	Ill-38-17 A-34 Seed Pennstar, Fylking	8.67
5	Melle A-20 Sod	8.50	5	Mer + Del, Sodco Ill-38-17, A-20 Sod Adelphi, Fylking	8.67	5	Sydsport, Windsor Sodco, Arboretum, Mer + Delta	5.67	5	Adelphi, Windsor Merion + Delta	8.50
6	Kenblue, Merion SD Comm + Kenbl, Adel	8.33	6	Nugget	8.50	6	SD Comm + Kenblue	5.50	6	Melle, Fyl + Penns + Nug	8.33
7	Wind + Mer, Mer + Del A-34 Seed	8.17	7	Primo, Fyl + Penns + Nug Melle	8.33	7	Merion, Park, Newp	5.33	7	Primo, A-20 Sod	8.17
8	Nugget	8.00	8	Newport	7.67	8	A-34 Seed, Nugget	5.17	8	Sodco	8.00
9	Windsor	7.83	9	Arboretum	6.67	9	Fylking, Prato	5.00	9	Nugget	7.83
10	Primo, Sodco, Prato	7.67	10	Kenblue	6.50	10	Wind + Mer, Pk + Del + Newp, Pennstar	4.83	10	Newport	7.33
11	Newport	7.50	11	SD Comm + Kenblue	6.33	11	Kenblue, S-21	4.67	11	SD Comm + Kenbl Arboretum, Kenblue	6.83
12	Arboretum	7.17	12	Park + Del + Newp	6.00	12	Fyl + Penns + Nug	4.50	12	Prato	6.17
13	Code 95	6.67	13	S-21, Geary	5.67	13	Geary	4.33	13	Pk + Del + Newp, Code 95	5.83
14	Geary	6.50	14	Prato, Code 95	5.50	14	Delta, Code 95 SD Comm #1 & 2	4.17	14	Geary, S-21, SD Comm #2	5.67
15	Delta, S-21	6.33	15	Common (SD #2)	5.33				15	Park	5.17
16	Park	6.00	16	Delta	4.83				16	Delta	5.00
17	Common (SD #2)	5.83	17	Park	4.67				17	Common (SD #1)	4.17
18	Park + Del + Newp	5.67	18	Common (SD #1)	3.50						
19	Common (SD #1)	5.33									

Appendix Table 5a, b, c. Comparison of the varieties at low mowing height for low, medium and high moisture levels. Data not significantly different.

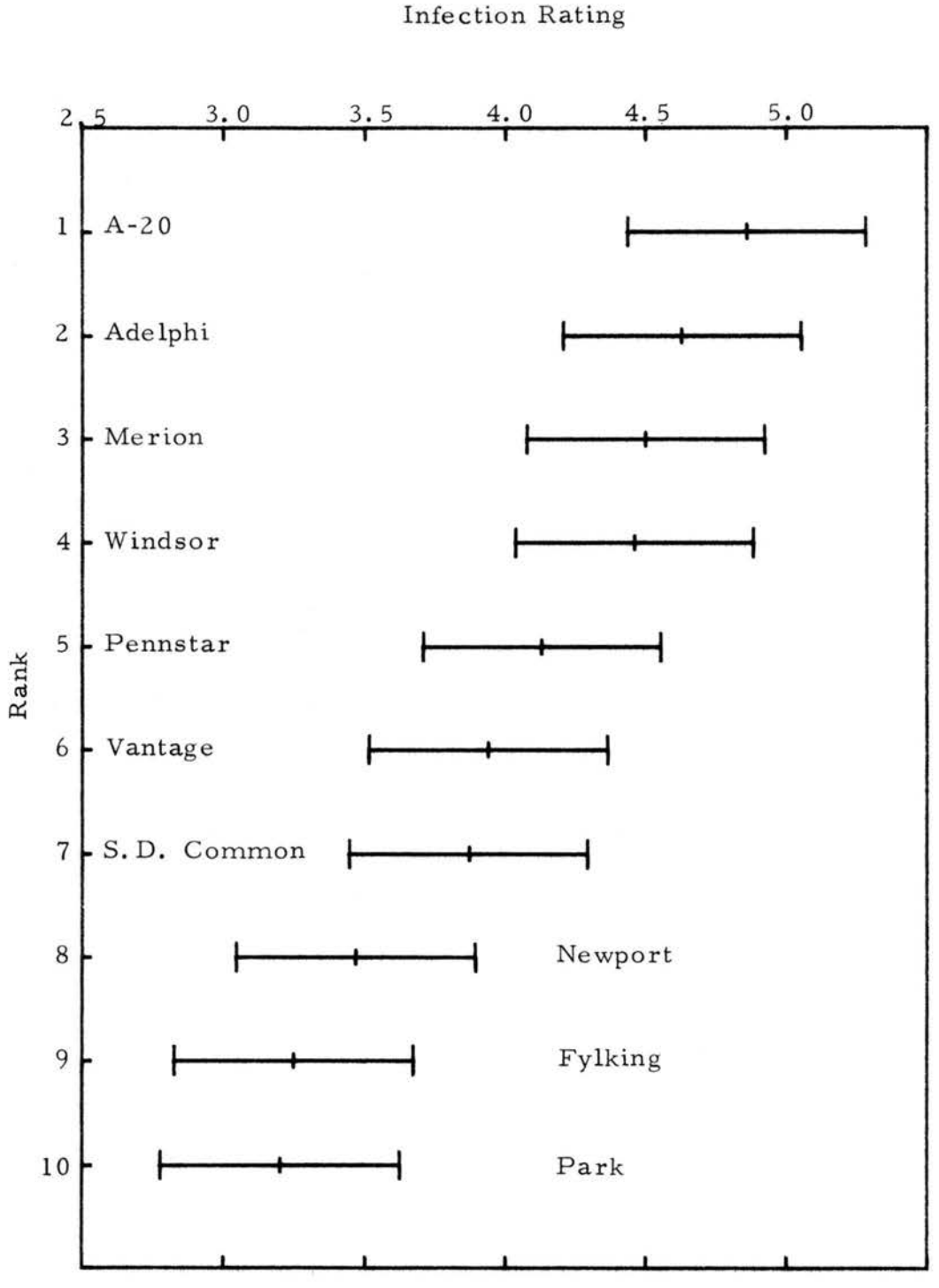
5a. Low Moisture			5b. Medium Moisture			5c. High Moisture		
Rank		L. Mow Mean	Rank		L. Mow Mean	Rank		L. Mow Mean
1	SD Comm + Kenbl	8.36	1	SD Comm + Kenbl	8.83	1	SD Comm + Kenbl	9.33
2	Arboretum	8.20	2	Geary	8.80	2	Sydsport	9.30
3	Common (SD #2)	8.10	3	Arboretum, Merion, Code 95	8.60	3	Common (SD #2)	9.26
4	Code 95	8.03	4	Kenblue	8.56	4	Merion + Del, Geary	9.23
5	Merion	8.03	5	Common (SD #2)	8.46	5	Sodco	9.20
6	Geary	8.00	6	Melle	8.43	6	Windsor + Merion	9.16
7	Kenblue	7.96	7	Prato	8.33	7	A-20 Sod	9.06
8	Melle	7.86	8	S-21, Merion + Del	8.30	8	Merion	9.03
9	Windsor + Merion	7.83	9	Windsor + Merion	8.23	9	Arboretum	9.00
10	Prato	7.76	10	Windsor	8.13	10	Kenbl, Pk + Del + Newp	8.96
11	Merion + Delta	7.73	11	Sodco, Sydsport	8.06	11	Delta, Melle, Baron	8.93
12	Delta	7.70	12	A-20 Sod	8.03	12	Nugget	8.90
13	Sodco	7.66	13	Delta	7.90	13	Prato, Windsor	8.86
14	S-21, Pk + Del + Newp	7.60	14	Nugget	7.83	14	Pennstar	8.76
15	Sydsport, Baron	7.50	15	Penns, Pk + Del + Newp	7.76	15	Fyl + Penns + Nug	8.73
16	Nugget	7.46	16	Baron	7.73	16	S-21, Newp, Code 95	8.56
17	Windsor	7.43	17	Fylking	7.70	17	Fylking, A-34 Seed	8.40
18	A-20 Sod	7.36	18	Adel, Comm (SD #1), Ill	7.60	18	Common (SD #1)	8.30
19	Pennstar	7.13	19	Newport	7.56	19	Adelphi	8.16
20	Fyl, Comm (SD #1), Newp	7.10	20	Park	7.46	20	Ill-38-17	8.13
21	Adelphi	7.03	21	Fyl + Penns + Nug	7.30	21	Park	7.96
22	Park	7.00	22	A-34 Seed	7.26	22	Primo	7.83
23	Ill-38-17, Primo	6.90	23	Primo	7.13			
24	Fyl + Penns + Nug	6.80						
25	A-34 Seed	6.73						

Appendis Table 6a, b, c. Comparison of the varieties at high mowing height for low, medium and high moisture levels. Data not significantly different.

6a.	Low Moisture		6b.	Medium Moisture		6c.	High Moisture	
Rank	Variety	H. Mow	Rank	Variety	H. Mow	Rank	Variety	H. Mow
1	SD Comm + Kenbl	8.46	1	SD Comm + Kenbl	9.16	1	Merion + Delta	9.40
2	Arboretum	8.43	2	Merion	9.13	2	S-21	9.36
3	Merion	8.40	3	S-21, Arboretum	9.00	3	Arboretum, Merion	9.33
4	Common (SD #1)	8.26	4	Geary	8.93	4	A-20 Sod, SD Comm + Ken	9.30
5	Code 95	8.23	5	Winds + Mer, Kenbl	8.86	5	Geary	9.26
6	Kenblue	8.16	6	Common (SD #2)	8.83	6	Baron	9.23
7	Baron, A-20 Sod Windsor + Merion Merion + Delta	8.10	7	A-20 Sod	8.80	7	Park + Del + Newp	9.20
8	Delta	8.03	8	Merion + Delta	8.70	8	Kenblue	9.16
9	S-21, Syds, Geary	7.93	9	Del, Melle, Code 95, Baron	8.63	9	SD Comm #2, Delta Windsor + Merion	9.06
10	Park + Del + Newp	7.86	10	Prato	8.50	10	Prato, Nugget	8.86
11	Prato, Melle	7.63	11	Sydsport	8.46	11	Pennstar	8.83
12	Sodco	7.46	12	Sodco	8.33	12	Newport, Code 95	8.80
13	Newport	7.43	13	Newp, Pk + Del + Newp	8.23	13	Windsor, Melle	8.76
14	Nugget	7.40	14	Windsor	8.10	14	Sodco, Fyl + Penns + Nug	8.73
15	Primo	7.30	15	Primo	8.06	15	Fylking	8.56
16	Adelphi, Park	7.26	16	Pennstar, Adelphi	7.96	16	Park, A-34 Seed	8.43
17	Pennstar, Windsor	7.23	17	Ill-38-17	7.93	17	Adelphi	8.36
18	Common (SD #1)	7.20	18	Common (SD #1)	7.86	18	Primo	8.33
19	Fylking, Ill-38-17	7.10	19	Fyl, Nug, Park	7.80	19	Ill-38-17	8.30
20	A-34 Seed	6.96	20	Fyl + Penns + Nug	7.50	20	Common (SD #1)	8.06
21	Fyl + Penns + Nug	6.93	21	A-34 Seed	7.46			

Appendix Table 7. Comparison of the rate of emergence and density of seedlings. A rank of 1 denotes swiftest emergence and best density.

Emergence 7-5-75 to 7-11-75		Density Rated 8-4-75	
Rank	Variety	Rank	Variety
1	Park	1	Park
2	Windsor	2	Fylking
3	Fylking	3	Vantage
4	Vantage	4	South Dakota Common
5	South Dakota Common	5	Pennstar
6	Pennstar Newport	6	Newport
7	Merion	7	Merion
8	Adelphi A-20	8	Windsor
		9	Adelphi
		10	A-20



Appendix Figure 2. LSD statistical treatment of data representing the susceptibility of Kentucky bluegrass seedlings to Dollar Spot (Sclerotinia homoeocarpa). Based on a 0 to 5 rating scale where 0 = highly susceptible and 5 = resistant. A-20 exhibits best tolerance, Park is most susceptible. LSD (1% level) bars are 0.85 units long.

Appendix Table 8a, b. Seedling trials, no statistical significance. Supportive data for Trial 1.

8a.

Rank	Variety	Mean
1	Windsor	8.54
2	Adelphi	8.49
3	Park	8.08
4	Newport	7.99
5	Pennstar	7.88
6	Merion	7.61
7	Fylking	7.49
8	South Dakota Common	7.28
9	Vantage	7.26

8b.

Rank	Variety	Mean
1	Adelphi	6.70
2	Windsor	6.55
3	Pennstar	6.50
4	Newport	6.45
5	Vantage	6.43
6	Merion	6.43
7	Fylking	6.40
8	Park	6.35
9	South Dakota Common	6.23

Appendix Table 9a, b, c. Seedling trials, no statistical significance. Supportive data for Trial 2.

9a.

Rank	Variety	Mean
1	Windsor	6.60
2	Fylking	6.40
3	Merion	6.36
4	Pennstar	6.36
5	Park	6.35
6	South Dakota Common	6.35
7	Newport	6.34
8	Adelphi	6.34
9	Vantage	6.26

9b.

Rank	Variety	Mean
1	Park	6.81
2	Newport	6.69
3	Pennstar	6.62
4	Vantage	6.56
5	Windsor	6.44
6	Fylking	6.38
7	Adelphi	6.38
8	South Dakota Common	6.12
9	Merion	5.75

9c.

Rank	Variety	Mean
1	Newport	7.40
2	Park	7.35
3	South Dakota Common	7.33
4	Windsor	7.25
5	Vantage	7.19
6	Fylking	7.19
7	Merion	7.18
8	Pennstar	7.18
9	Adelphi	7.16

Appendix Table 10. Length of bulliform cells for each variety measured along the longest axis. The position, shape and length for each variety are recorded. Only one cross section from each variety was observed.

Bulliform Cells

Sydsport

5 bulliform cells on one side of midvein, 4 on other side of midvein.

Shape: Irregular, pear-shaped.

Sizes

1	23.30 microns	1	33.30 microns
2	29.97 microns	2	36.63 microns
3	31.64 microns	3	36.63 microns
4	28.30 microns	4	29.97 microns
5	23.30 microns	Mean =	34.13 microns
Mean =	27.30 microns		

Windsor

4 bulliform cells on one side of midvein, 3 on other side of midvein.

Shape: Rounded, wedge-shaped.

Sizes

1	19.98 microns	1	23.31 microns
2	26.64 microns	2	26.64 microns
3	24.98 microns	3	16.65 microns
4	21.64 microns	Mean =	22.20 microns
Mean =	23.31 microns		

Code 95

3 bulliform cells on each side of midvein.

Shape: Wedge-shaped.

Sizes

1	39.96 microns	1	33.30 microns
2	36.63 microns	2	39.96 microns
3	29.97 microns	3	29.97 microns
Mean =	35.52 microns	Mean =	34.41 microns

Appendix Table 10. (continued)

Merion

4 bulliform cells on each side of midvein.

Shape: Irregular, wedge-shaped.

Sizes

1	38.30 microns	1	36.63 microns
2	46.62 microns	2	43.29 microns
3	39.96 microns	3	46.68 microns
4	43.29 microns	4	56.61 microns
Mean =	42.04 microns	Mean =	45.79 microns

Baron

5 bulliform cells on one side of midvein, 4 on other side of midvein.

Shape: Wedge-shaped; left and right sides have different shapes.

Sizes

1	26.64 microns	1	28.30 microns
2	38.30 microns	2	36.63 microns
3	39.96 microns	3	39.96 microns
4	38.30 microns	4	43.29 microns
Mean =	35.80 microns	5	29.97 microns
		Mean =	35.63 microns

A-20

3 bulliform cells on each side of midvein.

Shape: Rounded - wedge shaped.

Sizes

1	23.31 microns	1	23.31 microns
2	26.64 microns	2	25.97 microns
3	21.64 microns	3	16.65 microns
Mean =	23.86 microns	Mean =	21.98 microns

Appendix Table 10. (continued)

Ill-38-17

6 bulliform cells on one side of midvein; 5 on other side of midvein.

Shape: Wedge-shaped.

Sizes

1	36.63 microns	1	29.97 microns
2	33.30 microns	2	29.97 microns
3	63.77 microns	3	49.95 microns
4	41.62 microns	4	49.95 microns
5	43.29 microns	5	36.63 microns
6	33.30 microns	Mean =	39.29 microns
Mean =	41.90 microns		

Fylking

No bulliform cells apparent -- appear to be 2 slightly enlarged epidermal cells -- one on each side of midvein in axis.

Size

1	23.31 microns	1	20.65 microns

Arboretum

3 bulliform cells on one side of midvein and 5 on other side of midvein.

Shape: Wedge-shaped.

Sizes

1	48.28 microns	1	38.30 microns
2	49.95 microns	2	46.62 microns
3	44.29 microns	3	44.96 microns
Mean =	47.51 microns	4	39.96 microns
		5	36.63 microns
		Mean =	41.29 microns

Appendix Table 10. (continued)

South Dakota Common

5 bulliform cells on each side of midvein.

Shape: Irregular, amorphous shaped.

Sizes

1	24.98 microns	1	19.98 microns
2	29.30 microns	2	23.31 microns
3	23.31 microns	3	24.98 microns
4	26.64 microns	4	33.30 microns
5	27.31 microns	5	29.14 microns
Mean =	26.31 microns	Mean =	26.14 microns

Pennstar

5 bulliform cells on each side of midvein.

Shape: Irregular, amorphous shape.

Sizes

1	21.64 microns	1	19.98 microns
2	24.98 microns	2	24.98 microns
3	23.31 microns	3	23.31 microns
4	23.31 microns	4	23.31 microns
5	17.32 microns	5	17.32 microns
Mean =	22.11 microns	Mean =	21.79 microns

A-34

5 bulliform cells on each side of midvein.

Shape: Irregular, amorphous shape.

Sizes

1	16.65 microns	1	24.98 microns
2	23.31 microns	2	29.97 microns
3	23.31 microns	3	26.64 microns
4	23.31 microns	4	23.31 microns
5	21.64 microns	5	23.31 microns
Mean =	21.64 microns	Mean =	25.64 microns

Appendix Table 11. Distance between the leaf vascular bundles measured from the edge of the leaf to the middle of bundle 1, from middle of bundle 1 to middle of bundle 2, et cetera to the middle of the midvein. Distance is in microns. Only one cross section from each variety was observed.

	Edge of Leaf to:								
Variety	Bundle 1	Bundle 2	Bundle 3	Bundle 4	Bundle 5	Bundle 6	Bundle 7	Bundle 8	Bundle 9
Sydsport	126.54	149.85	99.90	99.90	199.80	Midvein			
Windsor	91.58	103.23	116.55	119.68	133.20	116.60	133.20	156.50	Midvein
Code 95	96.60	83.25	99.90	99.90	116.50	133.00	115.50	74.25	148.50
Merion	109.89	96.57	106.56	113.22	139.86	126.54	113.22	183.15	Midvein
Baron	113.22	119.88	249.75	136.53	133.20	158.18	196.47	Midvein	
A-20	49.95	83.25	93.24	113.22	119.88	104.89	79.92	Midvein	
Ill-38-17	133.20	103.23	109.89	133.20	154.85	133.20	96.57	229.77	Midvein
Fylking	123.21	113.22	111.56	136.53	141.53	141.53	106.56	154.85	Midvein
Arboretum	119.88	88.25	91.58	113.22	133.20	125.54	91.58	213.12	Midvein
SD Common	113.22	143.19	141.53	149.85	136.53	123.21	126.59	173.16	Midvein
Pennstar	99.90	86.58	93.24	101.56	123.21	114.88	116.55	151.52	Midvein
A-34	99.90	116.55	139.85	124.88	148.80	109.89	173.16	203.13	Midvein

Appendix Table 12. Record of leaf vascular bundles containing both metaxylem and protoxylem vessels for 12 Kentucky bluegrass varieties. Only one cross section from each variety was observed.

Variety		
SD Common	2nd bundle, 4th bundle, 6th bundle, midvein	
Pennstar	2nd bundle, 4th bundle, midvein	
Baron	2nd bundle, 4th bundle, midvein	
Arboretum	4th bundle, midvein	
Fylking	2nd bundle, 4th bundle, midvein	
Windsor	2nd bundle, 4th bundle, 6th bundle, midvein	
Ill-38-17	2nd bundle, 4th bundle, midvein	
Merion	2nd bundle, 4th bundle, midvein	
Code 95	1st bundle, 2nd bundle, 4th bundle, midvein	
Sydsport	2nd bundle, midvein	
A-20	2nd bundle, 4th bundle, midvein	) Other bundles with fibers or perhaps tracheids well developed.
A-34	2nd bundle, 4th bundle, midvein	)

Appendix Table 13. Metaxylem vessels in the midvein vascular bundles. The metaxylem vessels were measured along the axis of greatest diameter. Only one cross section from each variety was observed.

Variety	Number Metaxylem Vessels	Diameter in Microns	Mean Diameter
Merion	1	8.33	7.88
	2	7.33	
Pennstar	1	7.99	8.60
	2	9.16	
Code 95	1	7.66	8.80
	2	9.99	
Arboretum	1	6.66	
	2	9.32	8.80
	3	10.32	
Windsor	1	9.32	9.20
	2	9.16	
Sydsport	1	9.99	9.20
	2	8.32	
Ill-38-17	1	9.99	9.20
	2	8.33	
A-34	1	9.99	9.99
	2	9.99	
Fylking	1	9.99	10.20
	2	10.32	
S.D. Common	1	9.99	10.30
	2	10.66	
Baron	1	10.66	10.50
	2	10.32	
A-20	1	12.65	12.32
	2	11.99	

Appendix Table 14. Radial chlorenchyma and sclerenchyma I-Beam formations for each variety are described. Only one cross section from each variety was observed.

Variety	Number I-Beams	
Sydsport	2nd vascular bundle:	on lower epidermis, opposite bundle are 9 sclerenchyma fibers.
	4th vascular bundle:	on lower epidermis, opposite bundle are 7 sclerenchyma fibers.
Windsor	4th vascular bundle:	radial chlorenchyma I-Beam extending to upper epidermis.
	6th vascular bundle:	radial chlorenchyma I-Beam extending to upper epidermis, and sclerenchyma I-Beam to lower epidermis.
Code 95	No I-Beams	
Merion	No I-Beams	
A-20	4th vascular bundle:	radial chlorenchyma (2 rows) I-Beam to upper epidermis. Sclerenchyma (3 rows) I-Beam to lower epidermis.
	6th vascular bundle:	radial chlorenchyma (2 rows) I-Beam to upper epidermis. Sclerenchyma (2 rows) I-Beam to lower epidermis.
Ill-38-17	4th vascular bundle:	radial chlorenchyma (2 rows) I-Beam to upper epidermis.
Fylking	2nd vascular bundle:	sclerenchyma on epidermis (lower & upper) opposite bundle.
	4th vascular bundle:	sclerenchyma I-Beam (2 rows) to lower epidermis, radial chlorenchyma (2 rows) joining 3 sclerenchyma cells at upper epidermis.
	6th vascular bundle:	sclerenchyma on epidermis (lower & upper) opposite bundle.

Appendix Table 14. (continued)

Arboretum	3rd vascular bundle:	radial chlorenchyma I-Beam (2 rows) to upper epidermis.
	5th vascular bundle:	radial chlorenchyma I-Beam (2 rows) to upper epidermis.
S.D. Common	2nd vascular bundle:	sclerenchyma fibers opposite bundle in lower epidermis.
	4th vascular bundle:	sclerenchyma I-Beam to lower epidermis, terminates in cluster of 8 fibers.
	6th vascular bundle:	similar to 2nd vascular bundle.
Pennstar	2nd vascular bundle:	radial chlorenchyma I-Beam (1 cell row) to lower epidermis, terminated by 12 sclerenchyma fibers.
	4th vascular bundle:	sclerenchyma I-Beam to lower epidermis (2 cell rows), terminates in a cluster of 10 sclerenchyma fibers.
	6th vascular bundle:	radial chlorenchyma I-Beam to lower and upper epidermis terminated by clusters of sclerenchyma.
A-34	2nd vascular bundle:	opposite bundle, lower epidermis with 9 sclerenchyma cells.
	4th vascular bundle:	radial chlorenchyma (2 cell rows) I-Beam to lower and upper epidermis, terminates in cluster of 12 sclerenchyma cells on lower epidermis, and 3 sclerenchyma cells on upper epidermis.
	6th vascular bundle:	same as 4th vascular bundle.
Baron	4th vascular bundle:	radial chlorenchyma I-Beam to upper epidermis. radial chlorenchyma I-Beam to lower epidermis terminated by 4 fibers.

Appendix Table 15. The arrangement and number of sclerenchyma fibers at the edge of a leaf blade is described. One cross section from each variety was observed.

Sydsport	7 fibers, triangular arrangement
Windsor	15 fibers, arranged in 2 rows
Code 95	9 fibers, arranged in 3 rows
Merion	9 fibers, arranged in 3 rows
Baron	9 fibers, single row
A-20	13 fibers, arranged in 3 rows
Ill-38-17	13 fibers, arranged in 4 rows
Fylking	15 fibers, arranged in 4 rows
Arboretum	18 fibers, arranged in a rounded, ball-like configuration
S.D. Common	18 fibers
Pennstar	14 fibers, arranged in 4 rows
A-34	14 fibers, rounded shape

Appendix Table 16. Mean length and width of 10 epidermal cells for each variety was determined. Only one cross section from each variety was observed.

Variety	Length (in microns)	Width (in microns)
Sydsport	13.32 microns	17.11 microns
Windsor	13.89 microns	15.82 microns
Code 95	16.41 microns	16.84 microns
Merion	15.61 microns	16.10 microns
Baron	14.62 microns	18.40 microns
A-20	13.60 microns	12.88 microns
Ill-38-17	16.48 microns	17.45 microns
Fylking	13.99 microns	20.98 microns
Arboretum	15.82 microns	17.21 microns
S.D. Common	19.42 microns	16.65 microns
Pennstar	17.94 microns	13.69 microns
A-34	18.98 microns	13.72 microns

Appendix Table 17. The thickness of the leaf blades were measured from lower to upper epidermis across that area occupied by the largest and smallest vascular bundles. Measurements were not made at the edge of the leaf blades or in the axis of the mid-vein where the leaf tapers. Only one cross section from each variety was measured.

Sydsport	At largest bundle	=	116.55 microns
	At smallest bundle	=	99.90 microns
	Mean	=	108.22 microns
Windsor	At largest bundle	=	136.53 microns
	At smallest bundle	=	129.87 microns
	Mean	=	133.20 microns
Code 95	At largest bundle	=	133.20 microns
	At smallest bundle	=	99.90 microns
	Mean	=	116.55 microns
Merion	At largest bundle	=	153.18 microns
	At smallest bundle	=	133.20 microns
	Mean	=	143.19 microns
Baron	At largest bundle	=	133.20 microns
	At smallest bundle	=	116.55 microns
	Mean	=	124.88 microns
A-20	At largest bundle	=	136.53 microns
	At smallest bundle	=	108.22 microns
	Mean	=	122.38 microns
Ill-38-17	At largest bundle	=	183.15 microns
	At smallest bundle	=	156.51 microns
	Mean	=	169.83 microns
Fylking	At largest bundle	=	133.20 microns
	At smallest bundle	=	109.89 microns
	Mean	=	121.54 microns
Arboretum	At largest bundle	=	169.83 microns
	At smallest bundle	=	149.85 microns
	Mean	=	159.84 microns
S.D. Common	At largest bundle	=	158.18 microns
	At smallest bundle	=	138.20 microns
	Mean	=	148.18 microns
Pennstar	At largest bundle	=	131.54 microns
	At smallest bundle	=	119.88 microns
	Mean	=	125.71 microns

Appendix Table 17. (continued)

A-34	At largest bundle	=	146.52 microns
	At smallest bundle	=	126.54 microns
	Mean	=	136.53 microns

Appendix Table 18. All data were statistically analyzed using the analysis of variance. The F-ratio, degrees of freedom, sum of squares and mean squares for all significant data (at 5% and 1% level) are listed.

	df	SS	MS	F ratio
Field Study				
Mowing	1	6.868	6.868	5.430
Varieties	29	87.445	3.015	2.384
Moisture	2	136.085	68.042	901.000
Mowing, Moisture	2	1.659	0.829	10.980
Moisture, Varieties	58	10.595	0.183	2.420
Seedling Study				
Trial 1	27	12.268	0.454	2.609
Trial 2	18	5.320	0.296	2.839
Dollar Spot Infection	142	122.249	0.861	6.030
Greenhouse Study				
9.5-11.5% Soil Moisture	275	132.734	0.483	1.702
8.8-9.9% Soil Moisture	72	20.120	0.279	2.148
Lower Limits of Soil Moisture	50	5.513	0.110	3.346
Anatomy Study				
Stoma No. Lower Epidermis	82	1301.996	15.878	7.073
Stoma No. Upper Epidermis	24	184.667	7.694	29.012
Stoma Per. Lower Epidermis	60	4207.884	60.000	7.401
Stoma Per. Upper Epidermis	84	4284.467	51.006	33.939
Length of Bulliform Cells	84	2532.82	30.153	21.203
Distance Between Leaf Vascular Bundles	80	77110.48	963.881	2.322
Rate of Leaf Growth	60	10.127	0.169	3.050