THESIS

VARIETY TOLERANCE TO DROUGHT
IN KENTUCKY BLUEGRASS

Submitted by

Peter Hamilton Dernoeden

In partial fulfillment of the requirements
for the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Spring, 1976
COLORADO STATE UNIVERSITY

Spring, 1976

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

Committee on Graduate Work

[Signatures]

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.

Peter Hamilton Dernoeden  
Department of Horticulture  
Colorado State University  
Fort Collins, Colorado 80521  
Spring, 1976
ACKNOWLEDGMENTS

I wish to express my appreciation to the members of my graduate committee: Dr. J. D. Butler, Dr. Jess L. Fults and Dr. Frank D. Moore for their guidance in the preparation of this thesis and the knowledge and experience they have shared with me throughout my graduate career.

Special recognition is extended to Dr. J. D. Butler, my graduate advisor, whose knowledge, encouragement, patience and friendship will always be remembered.

The author is grateful to Dr. Robert V. Parke for his assistance in microtechnique.

I also wish to express gratitude to my fellow Horticulture Graduate Students and friends: William Day, Kathleen Donovan, Mohammed Ali Harivandi and Kenneth Mudge, and others in the Department of Horticulture.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>LITERATURE REVIEW</td>
<td></td>
</tr>
<tr>
<td>Soil Factor</td>
<td>6</td>
</tr>
<tr>
<td>Physiology of Drought Injury</td>
<td>6</td>
</tr>
<tr>
<td>A Classification of Drought Resistance</td>
<td>7</td>
</tr>
<tr>
<td>Escape</td>
<td>9</td>
</tr>
<tr>
<td>Dormancy</td>
<td>10</td>
</tr>
<tr>
<td>Water Absorption Capability</td>
<td>10</td>
</tr>
<tr>
<td>Xeromorphic Features</td>
<td>11</td>
</tr>
<tr>
<td>The Physiological Basis of Drought Resistance</td>
<td>13</td>
</tr>
<tr>
<td>Plant Responses to Water Deficits</td>
<td>17</td>
</tr>
<tr>
<td>Factors in Seedling Drought Hardiness</td>
<td>20</td>
</tr>
<tr>
<td>Heat Resistance</td>
<td>23</td>
</tr>
<tr>
<td>Drought Hardening</td>
<td>24</td>
</tr>
<tr>
<td>Cultural Practices that Minimize Heat and Drought Injury</td>
<td>30</td>
</tr>
<tr>
<td>Breeding for Drought Resistance</td>
<td>31</td>
</tr>
<tr>
<td>Kentucky Bluegrass -- Ecology and Water</td>
<td>36</td>
</tr>
<tr>
<td>FIELD STUDY</td>
<td></td>
</tr>
<tr>
<td>Methods and Materials</td>
<td>41</td>
</tr>
<tr>
<td>Results and Discussion</td>
<td>45</td>
</tr>
<tr>
<td>Conclusion</td>
<td>59</td>
</tr>
<tr>
<td>SEEDLING STUDY</td>
<td></td>
</tr>
<tr>
<td>Methods and Materials</td>
<td>60</td>
</tr>
<tr>
<td>Results and Discussion</td>
<td>61</td>
</tr>
<tr>
<td>Conclusion</td>
<td>66</td>
</tr>
<tr>
<td>GREENHOUSE STUDY</td>
<td></td>
</tr>
<tr>
<td>Methods and Materials</td>
<td>70</td>
</tr>
<tr>
<td>Results and Discussion</td>
<td>73</td>
</tr>
<tr>
<td>Conclusion</td>
<td>78</td>
</tr>
<tr>
<td>ANATOMY STUDY</td>
<td></td>
</tr>
<tr>
<td>Methods and Materials</td>
<td>80</td>
</tr>
<tr>
<td>Results and Discussion</td>
<td>81</td>
</tr>
<tr>
<td>Bulliform Cells</td>
<td>83</td>
</tr>
<tr>
<td>Vascular Bundles</td>
<td>89</td>
</tr>
<tr>
<td>Ecology and Water</td>
<td>90</td>
</tr>
</tbody>
</table>
TABLE OF CONTENTS (CONTINUED)

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sclerenchyma Fibers</td>
<td>93</td>
</tr>
<tr>
<td>Leaf Color and Shinyness</td>
<td>95</td>
</tr>
<tr>
<td>Rate of Growth</td>
<td>96</td>
</tr>
<tr>
<td>Tissue Weight</td>
<td>98</td>
</tr>
<tr>
<td>Width of Blades</td>
<td>100</td>
</tr>
<tr>
<td>Miscellaneous Morphology and Anatomy</td>
<td>100</td>
</tr>
<tr>
<td>Conclusion</td>
<td>102</td>
</tr>
<tr>
<td>SUMMARY AND CONCLUSIONS</td>
<td>104</td>
</tr>
<tr>
<td>LITERATURE CITED</td>
<td>105</td>
</tr>
<tr>
<td>APPENDIX</td>
<td>110</td>
</tr>
</tbody>
</table>
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Differences between mean values of several varieties of Kentucky bluegrass at high and low mowing</td>
<td>58</td>
</tr>
<tr>
<td>2</td>
<td>Comparison of 9 mature and seedling Kentucky bluegrass varieties</td>
<td>64</td>
</tr>
<tr>
<td>3</td>
<td>Seedlings ranked according to percent recovery from severe drought</td>
<td>67</td>
</tr>
<tr>
<td>4</td>
<td>Comparison of the mean diameters of leaf vascular bundles</td>
<td>94</td>
</tr>
<tr>
<td>5</td>
<td>Comparison of percent tissue dry weights</td>
<td>99</td>
</tr>
<tr>
<td>6</td>
<td>Comparison of the mean leaf widths in millimeters</td>
<td>101</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>------------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>1</td>
<td>Depicts LSD separation of Kentucky bluegrass varieties at the low moisture level</td>
<td>46</td>
</tr>
<tr>
<td>2</td>
<td>Depicts LSD separation of the varieties, massed drought data</td>
<td>49</td>
</tr>
<tr>
<td>3</td>
<td>Mean values of drought quality at low, medium and high moisture levels are plotted</td>
<td>51</td>
</tr>
<tr>
<td>4</td>
<td>A comparison of low and high mowing</td>
<td>51</td>
</tr>
<tr>
<td>5</td>
<td>Depicts LSD separation of the varieties at low mowing and low moisture</td>
<td>52</td>
</tr>
<tr>
<td>6</td>
<td>Depicts LSD separation of varieties at high mowing and low moisture</td>
<td>53</td>
</tr>
<tr>
<td>7</td>
<td>Observed turf quality for low, medium and high moisture levels at two mowing heights are plotted</td>
<td>54</td>
</tr>
<tr>
<td>8</td>
<td>Depicts LSD separation of seedling varieties, Trial 1</td>
<td>62</td>
</tr>
<tr>
<td>9</td>
<td>Depicts LSD separation of seedling varieties, Trial 2</td>
<td>68</td>
</tr>
<tr>
<td>10</td>
<td>Depicts LSD separation of varieties at the 9.5 to 11.5% moisture level</td>
<td>74</td>
</tr>
<tr>
<td>11</td>
<td>Depicts LSD separation of the varieties at the 8.8 to 9.9% moisture level</td>
<td>76</td>
</tr>
<tr>
<td>12</td>
<td>Depicts LSD separation of varieties at the lower limits</td>
<td>77</td>
</tr>
<tr>
<td>13</td>
<td>Depicts LSD separation of stoma number per 0.96 mm² upper leaf epidermis</td>
<td>84</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>14</td>
<td>Depicts LSD separation of stoma number per 0.96 mm² lower leaf epidermis</td>
<td>85</td>
</tr>
<tr>
<td>15</td>
<td>Depicts LSD separation of stomatal perimeters on upper leaf epidermis</td>
<td>87</td>
</tr>
<tr>
<td>16</td>
<td>Depicts LSD separation of stomatal perimeters on lower leaf epidermis</td>
<td>88</td>
</tr>
<tr>
<td>17</td>
<td>Depicts the LSD separation of lengths of leaf bulliform cells</td>
<td>91</td>
</tr>
<tr>
<td>18</td>
<td>Depicts LSD separation of distance between leaf vascular bundles</td>
<td>92</td>
</tr>
<tr>
<td>19</td>
<td>Depicts LSD separation of leaf growth rates</td>
<td>97</td>
</tr>
</tbody>
</table>
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.
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°C, 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 adaptation 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 CO₂, 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 boundary 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 phenomena 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 apertures which limits CO₂ 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.

<table>
<thead>
<tr>
<th></th>
<th>30 day seedlings</th>
<th>60 day seedlings</th>
<th>sod</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hrs.</td>
<td>10</td>
<td>16</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>16</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>20</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>3.2*</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>8.0</td>
<td>7.0</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>1.0</td>
<td>5.0</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>1.0</td>
<td></td>
<td>1.0</td>
</tr>
</tbody>
</table>

* 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 (Cynodon 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°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 $\text{CO}_2$ 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.

Pellett 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 hardness 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 antitranspirant 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°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.