THESIS

VARIETAL RECOVERY FROM DROUGHT-INDUCED DORMANCY IN KENTUCKY BLUEGRASS

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY TIMOTHY G. ANSETT ENTITLED VARIETAL RECOVERY FROM DROUGHT-INDUCED DORMANCY IN KENTUCKY BLUEGRASS BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ABSTRACT OF THESIS

VARIETAL RECOVERY FROM DROUGHT-INDUCED DORMANCY IN KENTUCKY BLUEGRASS

The relative drought recovery of 25 Kentucky bluegrass varieties was studied by observing mature plants in the field and greenhouse. Plant food reserves of the varieties were measured on the basis of etiolated growth and were studied relative to drought recovery. The ability of rhizomes of representative varieties to endure desiccation stress and later initiate growth was studied and related to drought recovery.

Although no significant difference between varieties was noted in the field test, A-20 and Common (SD #1) showed the best recovery from drought stress. The varieties were further tested in the greenhouse for recovery from more severe drought conditions. A significant difference between varieties was noted in one greenhouse test in which Primo and Merion showed the best recovery from drought stress. In a second, more severe greenhouse drought test, A-20 exhibited the best recovery from drought stress, yet no significant difference between varieties was found. Furthermore, the studies indicated that plant food reserves do not determine the ability of a variety to recover from drought stress.

Rhizomes of five varieties were tested and shown to possess varying abilities to initiate new growth, both when exposed and unexposed to desiccation stresses. A significant difference between varieties was noted. Also, varieties exhibiting better recovery from drought stress showed greater growth from rhizomes after exposure to desiccation stress than varieties that recovered from drought stress poorly.

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INTRODUCTION

In the past, availability of adequate water to meet the needs in the United States has been taken for granted. For generations, water costs failed to assign a real value to water, charging only for labor and equipment to obtain and transport it.

Throughout the United States it is now recognized that the water supply is not infinite. With the widespread droughts of recent years, significant restrictions on water use have occurred. In the future, population pressures will increase water demands and there will be increased competition for available water.

One of the larger demands for water in the United States is to irrigate Kentucky bluegrass (*Poa pratensis* L.) turf. This can be accounted for since this crop accounts for the largest cultured acreage in North America (38), and in addition Kentucky bluegrass requires approximately one inch of water per week during the growing season (5). In semi-arid and arid regions, the water requirement for Kentucky bluegrass greatly exceeds the amount of natural precipitation received. Thus, supplemental irrigation is required to maintain a quality turf. Even in more humid areas, rainless periods of two or more weeks frequently occur during the growing season (45); thus, supplemental watering is required for high quality Kentucky bluegrass turf. For the four months May, June, July, and August, the amount of supplemental irrigation required ranges from 5.7 inches in Minneapolis, Minnesota to 16.9 inches in San Francisco, California (6).

If low water-use turfgrasses can be identified or developed and used, large amounts of water can be saved. However, the potential to save water is not the only reason for having turfgrasses that require less water. For, as water demands increase, water for turf irrigation will likely be assigned a low priority. In recent years lawnwatering restrictions in Colorado cities have been increasingly utilized to conserve water, and this trend is likely to become more common in even more humid areas. Thus, it is quite important that suitable lawn grasses be identified and/or developed that will require less water and survive without irrigation through extended periods of drought.

Dernoeden (24) studied the relative drought tolerance of 25 varieties of Kentucky bluegrass and determined varieties which were able to remain green and turgid during drought periods. He did not study the ability of these varieties to survive long periods of drought. There are indications that a variety may require only limited water for its maintenance but its ability to survive a long drought may be quite limited. Turgeon (86), in a review of current turf research, suggested that the susceptibility to drought-induced dormancy and the ability to recover from complete dormancy are totally different responses, and, they may vary with cultivar and cultural practices. Funk and Engel (31) note that Delta Kentucky bluegrass recovered well from summer drought stress, but it was one of the first varieties to go dormant in a drought.

The intention of these studies was to determine if cultivars of Kentucky bluegrass possess differing abilities to recover from long periods of drought; if so, to identify factors which control that ability and to determine any relationship between susceptibility to drought-induced dormancy and the ability to recover from that dormancy.

LITERATURE REVIEW

Drought and Soil Moisture

Water deficit in a turf first causes a slowing down of plant growth. If the deficit is prolonged, wilting will occur. A long term, severe drought will cause death of the plant tissue (98).

Water stress resulting from a lack of available soil moisture is termed soil drought. While atmospheric drought occurs when plant water stress exists because the transpiration rate exceeds the absorption rate, despite an adequate supply of soil moisture. Physiological drought results from an internal plant water stress caused by a decreasing ability of the plant roots to absorb water from soil solutions high in salts (5).

Drought is most often correlated with a lack of available soil moisture. The physical properties of soils influence soil water relationships. Not all of the water entering a soil becomes part of the storage reservoir available for plant growth. There are two views in regard to what constitutes available water in the soil (74). The first hypotheses is that soil water is equally available to the plant from field capacity to wilting point. The other is that soil moisture content near the permanent wilting point is not readily available to the plant. The term, readily available moisture, has been used to refer to that soil moisture that is most easily extracted by plants, and is estimated to be about 75 percent of the water between field capacity and permanent wilting point (45).

In relation to plant growth, soil moisture is best described in terms of the amount of water retained and the tightness with which it is held in the soil (79). It is not the total amount of available water present at a given time in a soil that is important as much as the fact that some is available at any given time (76).

It should be noted that the permanent wilting point may not indicate the lower limit of water availability to the plant, but rather the approximate lower limit available (32).

Occurrence of Drought

Soil drought occurs when the moisture content of a soil has been depleted to near the permanent wilting point. Natural precipitation and irrigation increase the amount of soil moisture and reduce the possibility of soil drought. Direct water evaporation from the soil as well as water use by the plant (evapotranspiration) influence the amount of soil moisture and increase soil drought potential. The evapotranspiration rate of a turf is influenced by light intensity and duration, temperature, atmospheric vapor pressure, wind, water absorption rate, and soil moisture tension (5). If, for a prolonged period, the amount of water lost by evapotranspiration exceeds the amount of water entering the soil from natural precipitation and irrigation, soil drought occurs. It is axiomatic that areas receiving limited amounts of natural precipitation are more prone to soil drought than those receiving abundant precipitation.

Atmospheric drought occurs most often when hot, dry winds blow during the growing season (18). Under these conditions, transpiration is so excessive that the plant roots may be unable to absorb enough water, despite an adequate soil moisture content.

Physiological drought occurs in saline soils, when water which is high in salts is applied, or when a fertilizer high in soluble salts is applied at excessive rates (5).

Plant Response to Moisture Stress

The water content of a grass plant is determined by the balance between absorption and transpiration. The plant-water balance remains favorable as long as water absorption is near that of transpiration. When transpiration exceeds water absorption, the water balance is negative. Under this condition an internal plant water stress develops. This internal plant water stress may be a result of reduced absorption (soil or physiological drought), or increased transpiration (atmospheric drought). Considered separately, there seems to be no absolute limit to the safety range of either transpiration or water absorption. The limit of one of these conditions for any plant is itself partly determined by the intensity of the other (98).

The effects of water deficits range from death to less severe morphological and physiological effects upon the turfgrass plant.

Morphological Modifications

Many phases of growth are affected during plant water stress. Depth of rooting of the turfgrass plant increases with moderate soil moisture stress (10,25). Shoot growth is depressed during severe moisture stress, causing an increased root/shoot ratio of grasses (71,84,85).

Tillering decreases as soil moisture decreases from field capacity to permanent wilting percentage (27).

Other morphological modifications as a result of moisture stress include thinner leaves, decreased size and total area of leaves, thicker cuticle and cell walls, smaller intercellular spaces, and smaller xylem cells (5).

Physiological Modifications

A water deficit causes a general reduction in physiological activity. A water loss of 10% will usually induce closure of stomata (44), which reduces transpiration and limits the subsequent plant water loss (42,71).

Under drought stress, photosynthesis is reduced as a result of the limited CO_2 absorption taking place with closed stomatal openings. Also, reduced photosynthetic activity of green tissues is caused by moisture stress (28, 30, 44).

Soluble carbohydrate accumulation occurs during moisture stress as a result of restricted growth and degradation or reduced production of proteins (14,44,46). The net rate of protein synthesis is reduced during water stress (42,70,96). This decrease is protein content may reflect a retardation of protein synthesis or an acceleration of protein degradation (42,70).

Loss of water by the plant stimulates the transformation of sugars to starch, lowering osmotic pressure of the plant (44).

Water stress decreases respiration in seeds and certain mature tissues, but stimulates respiration in actively growing tissues (5).

Moisture Stress and Temperature

Moisture stress is often influenced by and associated with soil and air temperature effects. High temperature may increase plant water loss, by increasing evapotranspiration rates of a turf, and thus cause moisture stress (68). There is evidence that high temperature injury is in many cases a result of heat-induced drought injury (19, 54). Mueller and Weaver (68) found in a study of prairie grasses that there was no loss of plants and only slight injury to leaves at air temperatures up to 135^{o}F when soil moisture was available.

High temperatures can cause a depletion of carbohydrate reserves due to increasing rates of respiration and vegetative growth and depressed photosynthetic rates. Moisture stress may produce a beneficial effect during high temperature periods by inducing dormancy, which stops the depletion of carbohydrate reserves (12,89).

Transpiration is an effective means of outward heat transfer from a turf. The evaporation of water results in cooling of the leaf surface. When moisture stress limits transpiration, the plant leaf temperatures may rise to critical levels (5).

Low soil temperatures can cause turfgrass moisture stress during winter due to soil water being in a frozen, unavailable state for root absorption (5).

Indirect Effects of Moisture Stress

There is evidence that moisture stress causes indirect detrimental effects on turfgrasses. Moisture stress weakens the turf plant, making it more susceptible to pest damage and this makes damage more evident (5,36).

A water stress may increase disease development caused by certain turfgrass pathogens. Symptom development and/or infection by fungi causing diseases such as Fusarium blight and leaf spot can increase with moisture stress (29).

Reduced growth observed as a result of moderate water deficits may, in part, arise from a disturbance in mineral nutrition, as well as direct effect on growth due to water deficit (9). Garwood and Williams (34) found that plant nutrients, particularly nitrogen, are concentrated near the surface of the soil profile under grass, and these would be unavailable to the turf when the upper horizon of the soil is dry. Although the plants may be able to extract water from the deeper and wetter parts of the soil profile, the lack of nutrients in the subsoil may limit growth (9, 33).

Drought Injury

Drought injury is believed to result from metabolic and mechanical effects that accompany tissue dehydration (72).

Metabolic Injury

Physiological responses to moisture stress were discussed earlier and these may cause metabolic injury if drought persists. There are several types of metabolic injury which may occur.

A net loss of carbohydrate reserves occurs if respiration exceeds photosynthesis. Respiration has been shown to increase with slight moisture stress in some species (44). As discussed earlier, moisture stress decreases photosynthetic activity. If moisture stress continues, the supply of carbohydrate reserves will become depleted. This condition can be termed starvation. The starvation effect could be due to an effect on translocation rather than a direct effect on the photosynthetic rate (54).

There is considerable debate in the literature as to whether starvation occurs to a sufficient degree to account for drought injury. The major point of controversy relates to the effect of moisture stress on respiration. Although studies of some species have shown that slight moisture stress increases respiration, at more severe moisture stress, respiration will decrease. The basic question is concerned with the rates of respiration and photosynthesis under (conditions of) moisture stress when injury occurs. Levitt (54) concludes that drought injury usually occurs while the plant still contains large quantities of reserves, so starvation is not likely to be a cause of injury.

Levitt (53) reviewed an experiment of Mothes which indicated protein loss may cause drought injury. Mothes allowed sunflower and tobacco plants to lose water until the lower (but not upper) leaves wilted. If these lower leaves were allowed to regain their turgor, the recovery was only apparent, for they died sooner than on control, unwilted plants. Soluble substances, as well as water, moved from these lower leaves to the upper ones during the onset of wilting. Protein was converted to asparagine or glutamine which were translocated to the younger, upper leaves and resynthesized (there) to proteins. The injury, according to Mothes, is therefore due not only to the water removal, but also to the loss of protein. He suggests that wilting may speed up the aging of leaves by decreasing the ability of the chloroplasts to synthesize proteins.

According to Levitt (54), many investigators have reported an accumulation of the amino acid, proline, as a result of water stress. This accumulation could be the product of protein breakdown, but Levitt concludes that at least some of the proline accumulation is the result of synthesis. He states that proline accumulation may be an indirect result of protein breakdown, by conversion into proline of other amino acids which are primary products of protein breakdown. It is possible that proline accumulation may play a direct role in drought resistance.

The general increase in rate of metabolic breakdown is probably the most universal characteristic of severe water stress and results in damage to and a destruction of the submicroscopic structure of protoplasm (73).

Before the protein deficit is severe enough to injure the plant, products of protein breakdown, possibly NH_3, may accumulate to a sufficient degree to be toxic (54).

Enzyme inactivation and impairment of the nucleic acid system occurring as a result of water stress may reduce protein synthesis, causing a net loss of protein, and thus injury (54).

Mechanical Injury

Since a drought-induced decrease in reserves or in protein content takes a long time at normal growing temperatures, metabolic drought injury must be a relatively slow process. It cannot explain the very rapid kinds of drought injury.

Structural changes in the protoplasm, resulting from mechanical stress induced by the loss of water from the cells, are believed to be a major cause of drought injury (72).

A mechanism of mechanical drought injury has been proposed by Iljin (43,44). According to Iljin, it is not the lack of water in dehydrated tissues that is the cause of death for the protoplasm. Injury is caused rather, by the drying and remoistening processes and the rates of those processes are the critical factors influencing survival. When plant tissue dries, the cells collapse as a result of loss of water. The outward diffusion of water causes the vacuole to shrink and the protoplasm to be pulled inward, while at the same time, the rigid cell wall resists collapse. The protoplasm is subject to inward pull by the vacuole and outward pull by the cell wall. The resulting mechanical disruption of the protoplasm causes death of the plant tissues. Vegetative tissues may survive severe drying if dehydrated slowly, but are subject to injury when remoistened quickly, as the cell wall will expand with the addition of water more rapidly than the protoplasm. When plant tissues have not lost a large amount of moisture and the protoplasm remains semiliquid, vigor may be restored without injuring the protoplasm.

In discussing the relationship between metabolic and mechanical drought injury, it is important to realize that metabolic disturbances which are not severe enough to injure by themselves may increase the effects of mechanical injury (54).

Drought Resistance

Not all plants are injured by extended periods of drought. The ability of a species to grow satisfactorily in areas subject to periodic water deficits has been termed drought resistance (65). Maximov (63) concluded from investigations that the true measure of drought resistance is the ability of the plant to survive exposure to drought without permanent injury.

Classifications of Drought Resistance

Shantz (76) utilized a classification of Kearney and Shantz. They classified plants which grow in regions subject to drought as either drought escaping, drought evading, drought enduring, or drought resisting. Drought escaping plants complete their life cycle during favorable moisture periods, producing seed in a short period of time. Whereas, drought evading plants have a limited amount of growth or use the limited soil moisture efficiently during drought, conserving the moisture, and thus increasing the length of the period of growth. Drought enduring plants grow only during periods of adequate soil moisture. When drought occurs, they go dormant, and initiate growth when moisture conditions are favorable. Drought resistant plants absorb water rapidly when it is available, use that stored water when drought occurs, and lose water very slowly.

According to Klomp (48), Paltridge and Mair found that grasses could be grouped into four arbitrary divisions, based on their relative xerophytism. The amount of water that a plant has lost at the point of permanent wilting, expressed as percentage of its water content when turgid, has been termed the "water balance." The amount of water retained by a plant at permanent wilting, expressed as percentage of its water content when turgid, was termed the "water residium." The water balance plus the water residium equals one hundred. Paltridge and Mair's groupings were as follows (3):

Mesophytes-Plants having a water balance of less than 50%
- True mesophytes-Water balance less than 25%
- Xerophytic mesophytes-Water balance, 25-50%

Xerophytes-Plants having a water balance greater than 50%
- Mesophytic xerophytes-Water balance, 50-75%
- True xerophytes-Water balance greater than 75%

According to Bailey (3), a high water balance should indicate the ability to withstand drought, since a large reduction in the water content could occur before injury to the plant occurred. Consequently, one of the principal features of drought resisting plants is their capacity for enduring a greater water loss (64).

Bailey (3) identified the two factors of drought resistance of grasses as the water balance and the ability of the underground parts of the plant to remain dormant. He found that although _Agropyron ciliare_, _Bromus marginatus_, and _Festuca rubra_ have low water balances, they were still able to withstand drought in a dormant condition.

Cook (20) classifies factors affecting drought resistance as those enabling a plant to either withstand desiccation or prevent desiccation.

Beard (5) provides a detailed scheme of drought resistance classifications for turfgrasses. According to Beard, turfgrasses survive drought through escape, dormancy, an increased water absorption capacity, xeromorphic features which reduce water loss, or drought hardiness. Escape is the ability to germinate, establish, mature, and produce seed within a short time when the soil moisture level is favorable. Dormancy allows a turf to survive drought and initiate growth from drought hardy buds when favorable moisture conditions develop. Water absorption capability is a function of root characteristics. Certain turfgrasses have a greater potential for drought survival because their root system is more efficient in obtaining soil moisture. Some xeromorphic features reduce the water loss by transpiration when drought occurs, enabling the turf to conserve moisture and thus survive. Drought hardiness is the ability of a plant to survive desiccation.

Perhaps the most basic approach to drought resistance is that of Levitt (54). Levitt considers plants to be resistant to drought because they either avoid the development of severe water deficits or tolerate severe deficits without injury.

Drought Avoidance

Through drought avoidance, the plant is able to maintain a favorable moisture balance even under conditions of low soil moisture. Plants are usually drought avoiders due to adaptations which result in increased efficiency in the absorption and/or use of limited water.

Water Absorption. Plants which have root systems efficient in extracting water from the soil may be able to avoid drought stress.

Many investigators have related the drought resistance of a turf to the density and extent of its root system (20,74,95). Factors influencing the ability of a root system to absorb soil moisture include root mass, rooting depth, root number, degree of branching, extent of the root hair zone, and root growth activity (5).

Depth of rooting is often considered the most important factor in the drought resistance of a turf (26, 37). Depth of rooting determines the volume of soil that stores water and that can be drawn on by the plant between rainfall or irrigations (57,103). Short rooted grasses have less soil volume to draw water from and it is thought that drought resistance differences between and within species may be a result of differences in rooting depth (37,103). Hagan (37) observed that common Kentucky bluegrass wilted one week earlier than Merion Kentucky bluegrass. He found that Merion was extracting the soil moisture to a depth of 2.5 feet while the common only to 2 feet.

A deep rooted turf is not necessarily able to avoid drought. It may delay the onset of water stress only until the soil moisture in its root zone is depleted. A deep rooted turf is only able to avoid drought if water is present at the lower soil depths. Some grasses may only have short root systems as an adaptation to capitalize on brief rains in dry climates. The soil is rarely moistened below two feet in drier areas and longer roots would be of no advantage for extracting water from a dry subsoil.

The root to shoot ratio may be an important factor in drought avoidance. A moisture stress limits the growth of shoots more than the growth of roots (84,85). This increases the root to shoot ratio. During moisture stress, the larger root to shoot ratio enables the roots to absorb less water per unit volume of soil, and still avoid drought stress.

No plants are known to extract water from the soil at a rate to maintain normal growth once the soil approaches the permanent wilting point (98). As soil moisture is depleted, roots can extend themselves into moister soil areas (11,97). Differing capabilities of plants to extend roots into moister soil may affect relative drought resistance (97).

Water Use. Plants may also avoid drought by efficient use of limited water.

Plants which have a lower water use rate will enter a drought period with a greater reserve of soil moisture and thus may be able to avoid drought stress for a longer period. Beard (5) found differences in water use rates among 17 Kentucky bluegrass cultivars. Chewings fescue used less water than either Kentucky bluegrass or creeping bentgrass in a study by Welton and Wilson (93). However, there is little evidence that drought resistant plants necessarily have a low water requirement (76).

In initial drought research it was thought that the transpiration rate was an indication of the degree of drought resistance (3,71). However, Maximov (63) was not in agreement with this theory; since, he found that some xerophytes have higher transpiration rates than certain mesophytes. He concluded and it is generally accepted that the rate of transpiration, when water is supplied at non-stress levels, cannot be used for judging the drought resistance of a plant (3,64).

The ability of a species to close its stomates early in the development of moisture stress is a very important drought adaptation. Stomatal closure greatly reduces water loss by reducing transpiration. The closing of stomates also decreases photosynthetic activity, by preventing CO_2 from entering the leaves. Consequently, plants which close stomates very early in water stress may have reduced vigor as a result of lessened photosynthesis. To overcome this, some drought adapted plants open their stomates for CO_2 assimilation at night, when danger of water loss is at a minimum.

Some drought resistant plants may not close their stomates early in water stress (63). The low rate of cuticular transpiration of some drought resistant plants allows them to keep their stomates open longer and still avoid drought stress. Once stomates of these plants do close, the leaf surface cuticle reduces the transpiration rate to a small fraction of stomatal transpiration (54). To reduce cuticular transpiration, the cuticle should be thick, dense, and composed of materials impervious to water.

Another way that plants avoid water stress is by reducing their exposed leaf area. They may do this by shedding some leaves (54, 97,101). More important in this study is the ability of Kentucky bluegrass to reduce leaf surface area by folding its leaves. The reduction in leaf area exposed to the atmosphere decreases the water loss rate. According to Dernoeden (24), there is controversy in regard to the usefulness of leaf folding. In some species, rolling or folding of leaves may not occur before the moisture stress is sufficient to cause injury.

Drought Tolerance

The drought-avoiding plant is not subject to the moisture stress of its environment. But, not all plants possess the ability to avoid drought. And drought-avoiders may at some point in a drought be unable to avoid moisture stress. Drought survival then depends on the ability of the plant cell to endure critical water stress, which is termed drought tolerance.

Drought tolerant tissues usually have a small cell size with a small vacuole. Cells having a large proportion of protoplasm and a small vacuole are least disturbed by desiccation and are thus protected against injury (44).

Cell shape affects tolerance also, as long, narrow cells are subjected to only minimal contraction (5).

Drought tolerance of turfgrasses varies with stage of development (5). Seeds are drought tolerant due to the protoplasm being in a resting state. Buds are also drought tolerant, due to being devoid of vacuoles (44). As seeds and buds develop and mature, vacuoles are formed and drought tolerance decreases (44). Slower growing tissues are also thought to be more drought tolerant (5,101).

Drought tolerant species are thought to have a high cell sap concentration and high osmotic pressure (5,54,62). High osmotic pressures increase the ability of cells to hold water, lessening the degree of cell contraction, and increasing drought tolerance (5,44).

Drought tolerance has sometimes been attributed to the presence of special substances which protect the protoplasm against dehydration (43). Accumulations of colloidal carbohydrates have been associated with this (46,62).

It is known that carbohydrate reserves are an important factor in the response of grasses to stress (35,46,47,58,88,92,104). However, carbohydrate reserves may play another role. Kentucky bluegrass commonly endures drought by stopping growth and becoming dormant during periods of stress. Buds in the crown and rhizomes are extremely drought tolerant and initiate growth when soil moisture becomes favorable (23,52,98). Rhizomes serve as storage organs for carbohydrate reserves. The reserves are needed for regrowth from dormancy (26,59,84,87). If reserves are low, grasses may not be able to recover from dormancy (107).

Measurement of Drought Resistance

Many methods of measuring drought resistance have been used in the past. The methods used range from direct observation of plants during drought in the field to measurement of characteristics thought to be related to drought tolerance. Field performance continues to be the standard by which researchers rate tolerance, regardless of the evaluation procedure used (100). Results of drought tolerance tests of grasses using artificial drought chambers have shown varying degrees of correlation with field survival (100).

Despite many efforts, isolation of a specific characteristic as a measurement of drought resistance has not been reported (100).

The way in which drought resistance is defined affects the methods used for measurement. Burton (17) defined drought tolerance for the southeastern United States as the ability to remain green and grow under periods of moisture stress. Wright (100) defines drought tolerant grasses for the semi-arid and arid Southwest as those which are able to establish, develop, and maintain themselves through drought periods by efficient and economical use of moisture. It is important to determine whether drought avoidance or drought tolerance components of resistance are being measured. Some methods measure avoidance and not tolerance, others the opposite. Still other methods may be used to measure factors involved in both. If yield or water use during moisture stress is used as a measurement of drought resistance, drought avoidance is the main factor being evaluated. When survival of a prolonged drought is used as a measurement, drought tolerance is the main factor involved. Grasses may possess a high degree of avoidance, yet little tolerance, or the opposite may be true.

Direct Methods. Direct measurements of drought resistance include yield under moisture stress and survival during prolonged drought periods.

Many investigators (56,68,99,100) have conducted investigations determining the survival of seedlings during drought periods. Seedling drought resistance is of great importance in the establishment of perennial grass stands (68,75). Seedling drought resistance also enables testing of much larger populations than could be attempted with mature plants (100). However, measurements of seedling drought resistance may not indicate the degree of drought resistance of the mature plant. Sharma (77) noted that germination at low water potential may not be taken as an index of drought tolerance in mature plants.

Some drought resistance valuations are just observations of grasses which were exposed to moisture stress under natural conditions. Morrow and Reeves collected many selections of grasses and planted and evaluated them for drought resistance in areas of Texas (2). Natural precipitation was the only moisture the grasses received and selections thriving were considered drought resistant. Using similar methods, Knowles (50) established drought tolerance experiments in areas of western Canada.

Much drought research has also been done using artificial drought chambers to simulate drought stress. Carroll (19) rated the drought tolerance of grass species on the basis of degree of injury occurring when the moisture of grass soil plugs was allowed to drop below the permanent wilting point. In another study, Carroll (18) investigated atmospheric drought tolerance of grasses by artificially exposing grass plugs to low relative humidity and wind. Schultz and Hayes (75) noted agreement of results in artificial drought trials and field drought tests.

Indirect Methods. Indirect determinations of drought resistance include measurements of transpiration rate, water balance, and rooting characteristics. These factors are believed to be involved in drought resistance. However, specific direct relationships have not yet been identified between these factors and drought resistance in field observations.

Burton et al (17) found that root yields of 8 grasses were not correlated with a drought tolerant index derived from yield and drought injury symptoms. However, depth of root penetration did explain differences in susceptibility to drought injury.

Cook (20) extensively studied the rooting characteristics of selections of *Bromus inermis*. He concluded that total axial length of roots is one of the best single measures for evaluating the root system for drought resistance.

The water balance of grasses has been used to determine drought resistance by several investigators (3,48).

Transpiration intensity (3), water use rate (17), and osmotic pressure (54) have also been related to drought resistance.

Bailey (3) studied drought resistance resulting from the ability of underground parts to remain dormant. After subjecting three western grasses to drought conditions for approximately one year, he concluded that the ability to survive drought by dormancy is of great importance.

Ratnam (71) used rhizomes of several southern grasses in his study of drought resistant grasses. He desiccated the rhizomes in open air and also in an atmosphere of 75 percent relative humidity. Rhizomes were removed from the desiccating conditions at different times and their ability to sprout was measured. Ratnam concluded that the ability of the rhizomes to sprout after being subjected to desiccation stress was a major factor in the overall drought resistance of grasses.

Cordukes (21) was able to evaluate the extent of drought injury to turfgrass species by electrolytic and ninhydrin methods.

According to Corleto and Laude (22), drought resistance evaluations may often be determined too early after release from stress. The evaluation of response to stress should include both measurement of immediate injury and appraisal of the plant's ability to resume satisfactory growth. It was suggested that measurements be taken for at least four weeks after termination of stress.

Factors Influencing Drought Resistance

Conditions under which turf is grown affect its drought resistance. Environmental factors influencing drought resistance includes availability of moisture, temperature, and amount of shading.

Cultural factors influencing drought resistance of a turf include mowing, fertilization, and irrigation practices.

Drought resistance may be influenced in several ways. The factors of drought resistance which are influenced include the water use rate, the absorption potential, and the level of carbohydrate reserves. Water-use and absorption factors relate to drought avoidance, while the level of carbohydrate reserves affects drought tolerance as well.

Water-Use Rate. The water use rate of a turf is greatly affected by environmental factors. Water use increases with increased light intensity, increased temperatures, and reduced relative humidities (4, 37).

Cultural factors affecting the water use rate include mowing frequency and height, nitrogen fertilization practices, irrigation practices, and amount of traffic.

Water use is increased as the mowing height is raised (4, 66, 82, 94) and a frequently mowed turf will use less moisture (82).

Nitrogen fertilization increases the total water use (61, 82) but reduces the water required per unit of dry matter produced (5, 82).

Increased water application rates and reduced irrigation frequencies reduce the amount of water used by turfgrasses (4, 61). Turfs subjected to intense traffic also have an increased water use rate (5).

Water Absorption. Water absorption is affected by environmental and cultural factors which influence rooting of the turf plant. Reduced light intensities in shaded areas limit the depth of rooting due to reduced photosynthesis (5). The optimum soil temperature range for root growth of Kentucky bluegrass is 50 to 65^{o}F (5). At non-optimum temperatures the reduction in root growth may affect the plant's ability to absorb water. Grasses will usually produce a deeper root system in coarse textured soils than in one that is fine textured.

Low mowing heights also contribute to reduced depth of rooting by reducing photosynthetic leaf area, limiting carbohydrates available for root growth (12,49,60,104).

Frequent irrigation limits gas exchange in the soil, resulting in sparser and shallower rooting (60,74,81). Effective rooting depth has been found to decrease as soil moisture increases (10,25). Root systems developed under relatively dry soil conditions may be capable of extracting a greater amount of soil water on a root unit volume basis than those developed under moist conditions (78). However, if the soil becomes too dry, root growth is retarded and may not occur.

Excessive nitrogen fertilization during periods of grass root formation will limit root development (74). The nitrogen stimulates top growth; thus using reserve carbohydrates at the expense of root growth. Excessive use of nitrogen will increase the shoot:root ratio of grasses (39,80,103).

Compacted soil resulting from heavy traffic restrict root development by limiting the oxygen required for root growth (26,55, 81).

Plant Reserves. High temperatures result in depletion of carbohydrate reserves in Kentucky bluegrass (58,89,105,106). Non-structural carbohydrate levels were lowest at the temperature producing the greatest top growth in terms of dry matter (106).

Short daylengths and low light intensities favor utilization of carbohydrate reserves in turfgrasses (15,91).

Frequent clipping reduces the carbohydrate reserves of grasses as the reserves are utilized for renewing leaf growth (39,83,87,92). Height of clipping also influences plant reserves. Grasses maintained at low mowing heights have reduced reserves as a result of lessened photosynthetic leaf area (1,92).

Nitrogen fertilization stimulates top growth of grasses leading to a reduction in carbohydrate reserves (35,40,47,88,92).

When soil moisture is the major factor limiting growth, an increase in soil moisture may limit the amount of carbohydrate reserves (13,14,40). Consequently, restricting irrigation to the plant until absolutely necessary will maintain a higher level of reserves.

Previous Drought Research with Kentucky Bluegrass

Kentucky bluegrass has been included in several experiments testing the drought resistance of grasses.

Klomp (48), using the water-residuum method described earlier, classified Kentucky bluegrass as a true xerophyte. This indicated that the grass would wilt only after losing at least 75 percent of its water content.

Mueller (67) measured rhizome production of some grasses and other prairie plants and found that among 23 species the rhizome production of Kentucky bluegrass was second to Western wheatgrass.

Weaver and Albertson (90) in a survey of plant species surviving the great drought in the plains found that Kentucky bluegrass had been substantially reduced from its former cover of about 5 percent.

Knowles (50) found that Kentucky bluegrass lacked hardiness and was not suitable for use in the open plains area of Western Canada without supplemental irrigation.

In listings comparing the drought resistance of turfgrasses, Kentucky bluegrass is commonly rated intermediate (5, 102).

Varietal Drought Research

Beard studied comparative water use rates of 17 Kentucky bluegrass cultivars and classified them as follows (69):

Very Low	Low	Intermediate	High	Very High
Prato	Pennstar	Merion	A-34	Sodco
Cougar	Park	Galaxy	Newport	Sydsport
Delta	Nugget	Monopoly	Fylking	
Kenblue	Windsor	Baron		

In other studies (7,8), Beard found Cougar and Pennstar to possess the best capability to recover from drought in tests of 8 varieties.

Dernoeden (23,24) classified 25 varieties on the basis of resistance to wilting at low, medium, and high soil moisture levels. His ranking of the 25 varieties at low soil moisture levels is shown in Appendix Table 1.

FIELD STUDY

The literature suggests that a reliable test for drought resistance of turfgrass is to grow it under droughty field conditions (23,24). The objective of this study was to determine the relative rates of recovery from drought-induced dormancy of 25 varieties of Kentucky bluegrass under field conditions.

In this study dormancy was induced by restricting irrigation. Dormancy was induced easily under the semi-arid conditions of Fort Collins, Colorado, as average annual precipitation for the area is only about 15 inches (38 cm).

Varieties and blends of Kentucky bluegrass utilized in this study were planted in 1971 at the W. D. Holley Plant Environmental Research Center adjacent to the Colorado State University campus in Fort Collins. The thirty varieties and blends in this study were replicated three times. The 90 plots were arranged in a randomized complete block design and each measured 10' x 10' (3 meters x 3 meters). Each plot was maintained at two different cutting heights, 3/4" (19 mm) and 1 1/2" (38 mm), prior to 1977. In 1977 the entire area of each plot was cut at 1 1/2" (38 mm).

Materials and Methods

Starting August 20, 1977, irrigation was withheld from the plots for a period of 27 days. At the end of this period, all plots were in a dormant condition. Leaves of all varieties were brown and severely wilted. The weather data for Fort Collins during the test period is summarized in Appendix Table 2. Natural precipitation occurring during the drought period (August 20-September 16) amounted to 0.26 inches (6.6 mm).

For the purpose of soil water determination, three cores of soil, measuring approximately 4" x 4" (10 cm x 10 cm) were removed from the plot area on September 16. The soil core samples were weighed at that time. At a later date the soil cores were oven dried at 105°C (221°F) for 72 hours and reweighed. The moisture content of the soil at the end of the drought period was determined to be 9.3 percent. Dernoeden (24) had calculated a moisture tension curve for this soil and had determined its 15 bar percentage to be approximately 15 percent soil moisture. On September 16, the plots were irrigated for 2 1/2 hours. The area was subsequently watered for 45 minute periods at 2-3 day intervals.

Visual observations of each plot were made on September 19 and every 2-3 days following until October 6. The observations were used as the basis for evaluating the recovery of each of the plots. Recovery was indicated by the presence of non-wilted growing leaf tissue. Recovery ratings were made on the basis of density as well as overall quality. Density ratings estimated the percentage of the plot area covered with non-wilted leaf tissue. Overall quality ratings estimated the color, texture, density, and uniformity of each plot.

Plots were evaluated on a 0-10 scale, with 10 representing the maximum rating, indicating 100% density or highest quality.

The plots were mowed once during the rating period, on September 26. Although ratings were taken of the 15 plots devoted to blends of Kentucky bluegrass, those ratings were not used in the data analysis. This was due to the probable dominance of those plots by one of the varieties in the blend six years after planting.

It was intended that the data would be statistically analyzed based on the randomized complete block design of the plots. Unfortunately, it was discovered that the radius of one sprinkler head not actually in the test plot area overlapped the corner plots. Therefore, 16 of the 75 plots had received limited irrigation during the drought period. Data on those plots could not be used in this statistical design analysis. Analysis of variance was done using a completely randomized design method. Density and overall quality ratings from dates 9, 18, and 20 days after the drought period were analyzed.

Two commercial sources of South Dakota Common were utilized. The varieties are designated Common (SD #1) and Common (SD #2).

Results and Discussion

Rankings of the varieties based on density and overall quality ratings from 20 days after the drought period ended are given in Tables 1 and 2. F ratios of the ratings indicated no significant difference between varieties. It seems appropriate to comment on the lack of statistical significance obtained from the field ratings. Using a completely randomized design, no variation is attributed to block effects. This creates a more conservative test of significance. Also, the problem seems to be that of visual ratings in general. Differences observed in the field may not have been fully discriminated using visual ratings.

Regardless, varieties which were rated 7.5 or above on the 0 to 10 scale after 20 days had recovered well from the drought period. In comparison with Kentucky bluegrass not experiencing the drought, only slight differences were observed. In the case of A-20, rated 8.0 for both density and overall quality, no difference was detectable.

Varieties rated below 6.5 showed obvious drought effects. Their reduced densities would allow for invasion of undesirable turf weeds, as well as cut down on the wear they could tolerate without further injury.

A-20 and Common (SD #1) exhibited the best recovery from the drought period. A-20 had ranked intermediate and Common (SD #1)

Table 1. Comparison of density ratings of the field study varieties after a 20 day recovery period, no statistical significance. Ratings on a 0 to 10 scale with 10 representing optimum density.

Rank	Variety	Mean
1	A-20	8.00
2	Melle	7.83
3	S-21 Common (SD #1)	7.75
4	Fylking Common (SD #2) Nugget Sodco Arboretum Code 95	7.50
5	Delta	7.33
6	Primo Geary Newport Park Kenblue	7.25
7	Pennstar	7.16
8	Prato Windsor Ill-38-17 Baron	7.00
9	Adelphi Merion	6.75
10	Sydsport	6.50
11	A-34	6.25

Table 2. Comparison of overall quality ratings of the field study varieties after a 20 day recovery period, no statistical significance. Ratings on a 0 to 10 scale with 10 representing optimum overall quality.

Rank	Variety	Mean
1	A-20	8.00
2	Common (SD #1)	7.75
3	S-21 Common (SD #2) Code 95	7.50
4	Melle	7.33
5	Nugget Kenblue	7.25
6	Delta Sodco	7.16
7	Pennstar Fylking Geary Park Arboretum	7.00
8	Baron	6.83
9	Primo Newport Ill-38-17 Merion	6.75
10	Prato Windsor	6.66
11	Adelphi	6.50
12	Sydsport	6.25
13	A-34	6.00

was ranked below average among the varieties in Dernoeden's study of drought resistance. S-21, Melle, Common (SD #2) and Code 95 also showed good recovery from drought.

The varieties ranked highest in Dernoeden's study, Arboretum and Merion, were not among the best varieties at recovery from drought in this experiment. Arboretum was ranked intermediate and Merion was considerably below average in recovery.

A-34 and Sydsport exhibited the poorest recovery from drought. A-34 also ranked low in Dernoeden's study while Sydsport was intermediate.

Conclusion

It was noted, without significant verification, that certain Kentucky bluegrass varieties recover from drought better than others. Varieties ranking best in this study should be considered in areas where irrigation is not always possible. This study also showed evidence that the ability to recover from drought and the ability to avoid drought-induced dormancy are governed by different factors, as rankings from this study differ considerably from those of Dernoeden.

GREENHOUSE STUDY

Testing regrowth after exposure to different periods of drought was not feasible in field tests. Since only one set of variety plots was available, recovery from the initial test would have to be uniform for all varieties before a new test could be started. Consequently, a greenhouse study was undertaken using plugs from the test plot area.

This greenhouse study is also representative of a major turf problem in Colorado, that of winter drought. Turf areas in eastern Colorado are commonly devoid of snow cover during the winter months. The combination of dry winds and low soil moisture often lead to desiccation injury. Many turf areas have failed to resume growth in the spring of the last two winters due to this problem.

The plugs used in this study had been irrigated regularly for three weeks prior to removal. They were in an active state of growth at the time of sampling.

Materials and Methods

On October 9, 1977, 4 sets of 75 plugs each were removed from the variety plot area. Each set contained 1 (one) plug from each of the 75 variety plots. All plugs were intended to be 4'' x 4'' (10 cm x 10 cm). In some cases, a 4 inch depth was not possible to obtain, so the deepest possible intact plug was taken. It should be noted that the plugs which were less than 4 inches deep had a limited number of roots in the non-intact section of the plugs. Therefore, the effective soil moisture reservoir of those plugs was virtually unaffected by the smaller soil volume. Each plug was weighed after removal. In addition, five more plugs were removed and weighed, and later oven dried and weighed to determine soil moisture content. At the time soil plugs were removed, moisture content of the soil was 21.7 percent. The 4 sets of plugs were each placed in galvanized metal pans measuring 34" x 22" x 3/4" (86 cm x 56 cm x 2 cm). The sets were designated as follows:

Set A - Control, no drought stress

Set B - 7 day drought stress

Set C - 14 day drought stress

Set D - 21 day drought stress

Watering of the plugs, when desired, was accomplished by filling the pan with water, capillarity moving the water throughout the plug.

For reporting purposes, the date the plugs were taken will be called day 0 and the other dates will be referenced to that date.

From day 0 through day 7, only Set A was watered. On day 7, 5 plugs each of Sets B, C, and D were weighed and soil moisture content was calculated to be 10.2 percent.

On day 8, ratings of all plugs were taken based on the following 1-5 stress scale:

1 - Greater than 95% leaf tissue wilted

2 - Greater than 50% leaf tissue wilted

3 - Greater than 25% leaf tissue wilted

4 - Less than 25% leaf tissue wilted

5 - No signs of wilted leaf tissue

All plugs in Set A were rated 5. Plugs in the remaining sets averaged a rating of 1.8. Watering of Set B also started on day 8.

On day 9, the plugs in Set B showed considerable regrowth. A pattern of regrowth was also evident. Plugs protected from the drying atmosphere of the air by other plugs showed the best regrowth. Because of this it was decided to discard Set B plugs and to spread plugs from Sets C and D further apart and place guard rows around the outside plugs.

On day 14, 10 plugs each from exposed and protected sections (prior to day 9) were weighed. The moisture content of the exposed plugs did not differ appreciably from that of the protected plugs. Soil moisture was calculated to be 3.1 percent. Also, all plugs in Sets C and D were given a rating of 1. The plugs from Set A were again all rated 5.

<u>Set C Recovery</u>

Beginning on day 15, plugs of Set C were watered daily and observed for regrowth. Regrowth was first evident on day 20, when 35 of the 75 plugs had some visible green leaf tissue. Ratings of the plugs were then taken on 1-2 day intervals based on the following regrowth scale:

0 - No growth

1 - < 5% regrowth

2 - 5-20% regrowth

3 - 20-30% regrowth

4 - 30-40% regrowth

5 - 40-50% regrowth

6 - 50-60% regrowth

7 - 60-70% regrowth

8 - 70-80% regrowth

9 - 80-90% regrowth

10 - > 90% regrowth

Final visual ratings were taken for Set C on day 50. These ratings represented recovery following a 14 day drought period and a subsequent 35 day recovery period. Counts of live tillers from each plug were made on day 51.

Set D Recovery

On day 21, 10 plugs each were weighed and soil moisture was determined to be 3.3 percent. Each of the plugs was rated 1 on the stress scale at that time. All Set A plugs again rated 5. Beginning day 22, the plugs were watered and observed for regrowth.

Initial regrowth was observed in 1 (one) plug on day 28 and ratings were then made at 1-2 day intervals based on the 0-10 regrowth scale.

Final visual ratings were taken on day 64. These ratings represented recovery following a 21 day drought period and a subsequent 42 day recovery period. Counts of live tillers were also made on day 64.

Results and Discussion

Set C

F-ratios for both the final visual ratings and the live tiller counts revealed a significant difference between varieties, Appendix Table 6. In Figure 1, the varieties are ranked on the basis of visual percent regrowth ratings from a 14 day drought after a 35 day recovery period. Means of the varieties are represented in an LSD graph. When the bars of an LSD graph overlap, no significance occurs. Figure 2 is an LSD graph of the mean live tiller counts of the varieties taken the same day.

Rankings of both the visual percent regrowth ratings and live tiller counts were similar. Varieties ranking high in visual percent regrowth ratings also ranked high in live tiller counts.

Primo and Merion showed the best recovery according to the visual percent regrowth ratings. Each received a mean rating of 4.0 indicating 30 to 40 percent regrowth of the plugs. Primo and

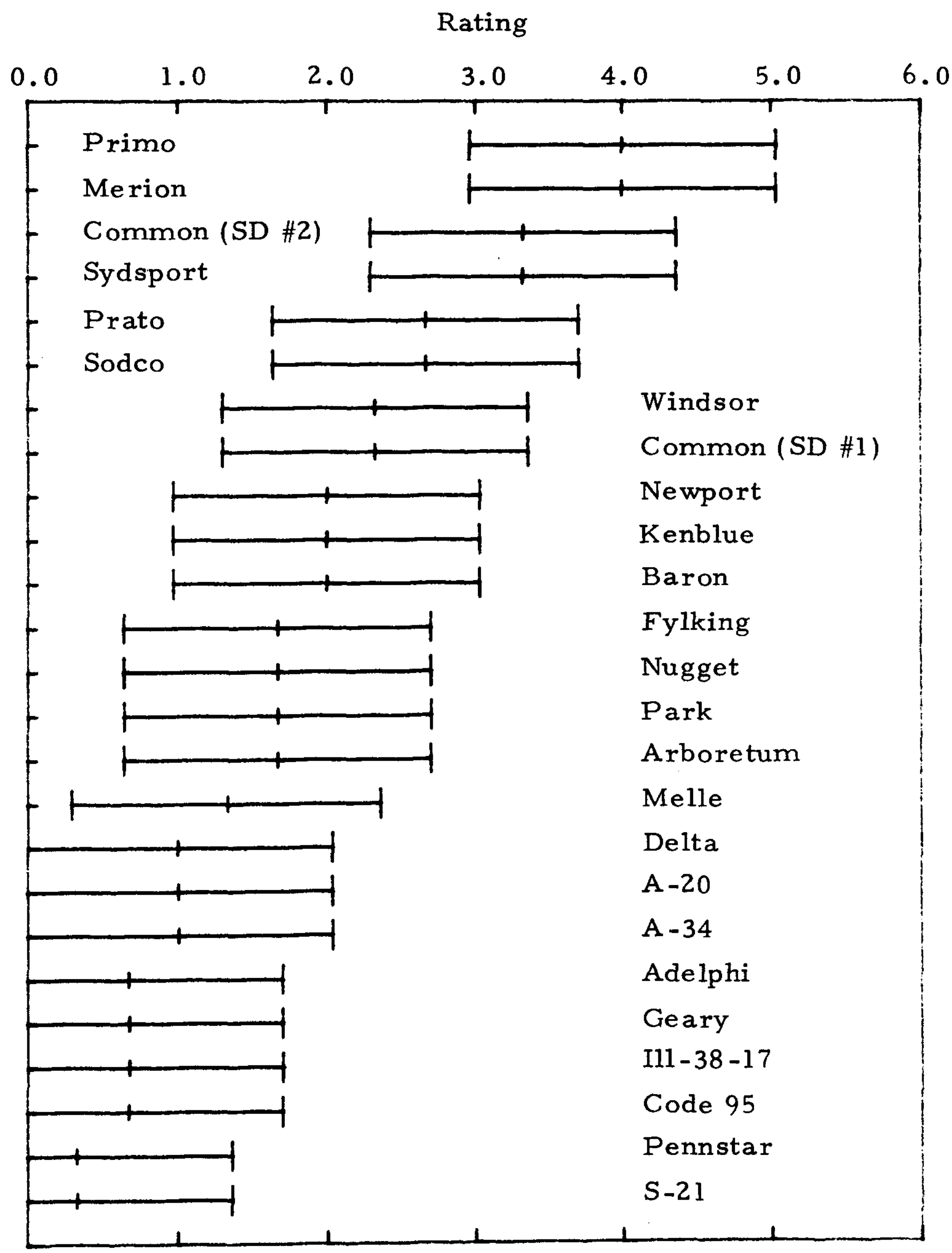

Figure 1. Depicts LSD separation of varieties after a 14 day drought and 35 day recovery period, based on visual regrowth ratings. LSD (5%) bars are 2.06 units long. Ratings based on 0 to 10 scale with 10 representing greater than 90% regrowth.

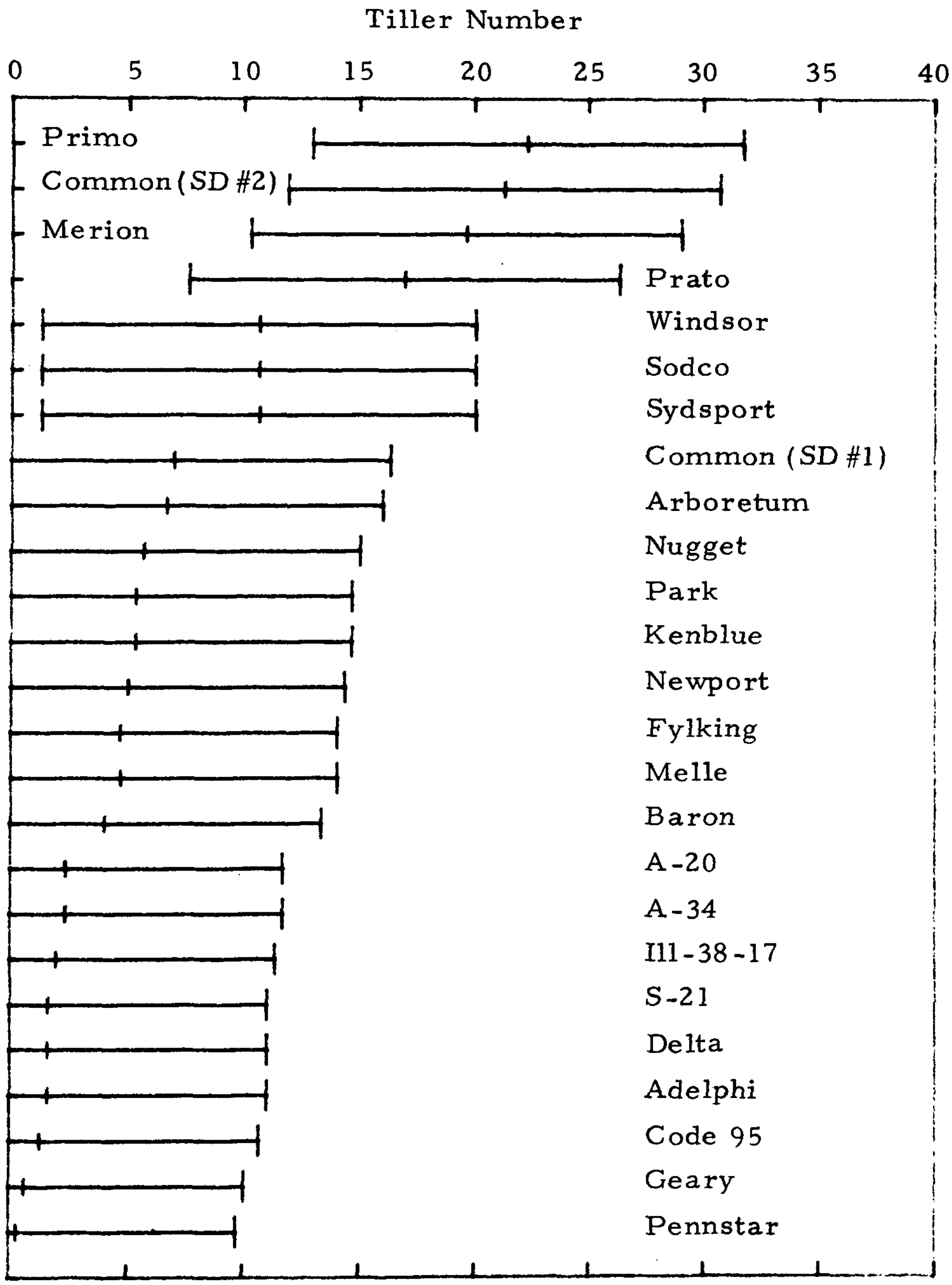

Figure 2. Depicts LSD separation of varieties after a 14 day drought and 35 day recovery period, based on live tiller counts. LSD (5%) bars are 18.74 units long.

Common (SD #2) had the highest mean counts of live tillers of 22.33 and 21.33 live tillers respectively. Considering both estimates of recovery, then Primo, Merion, and Common (SD #2) were the best performers in this study. Pennstar, Geary, and S-21 were varieties which performed poorly.

The ranking of the varieties in this 14 day greenhouse drought study varies considerably from the ranking of varieties in the field study. Primo and Merion, the best performers in the greenhouse, were both below average in the field test. And A-20, top ranked in the field, was below average in performance in the greenhouse.

The difference in results may be explained by the degree of drought experienced in each test. The greenhouse experiment involved a more severe drought stress than the field test. This was due to the soil plugs in the greenhouse being exposed to the air while the soil in the field test was unexposed and protected by the plant cover. Less moisture was lost by soil in the field test. Specifically, soil moisture contents of the field soil and the greenhouse plugs at the end of their drought periods were 9.3 percent and 3.1 percent respectively.

The less severe drought in the field test may have allowed some varieties to avoid much of the drought stress. Although all varieties in the field were dormant after the 27 day drought period, some varieties may not have gone into dormancy until perhaps as late as the 15th to 20th day. Unfortunately, no data was taken on the time of initiating dormancy. Varieties going dormant late in the drought period had been dormant for a shorter period when irrigation was resumed. As a result, they would be expected to resume growth sooner and at a more rapid rate. As the greenhouse stress was more severe, these same varieties were unable to avoid the stress, were dormant longer, and their performance suffered.

Set D

The drought stress of 21 days which the Set D plugs experienced was even more severe than that of Set C plugs. The moisture content of the plugs was virtually the same after 21 days as after 14 days. But the varieties had been exposed to the stress for an additional seven days. The stress was so severe that 10 of the 25 varieties showed no regrowth at all after a 42 day recovery period. The lack of statistical significance in this test can be attributed partly to this as well as to much variability within varieties.

The recovery rankings based on visual percent regrowth ratings and live tiller counts are shown in Appendix Tables 3 and 4. A-20 showed the best recovery with a 1.67 mean visual regrowth rating and a mean live tiller count of 9.0. Much of A-20's recovery could be attributed to regrowth from rhizome buds. Most of the regrowth of the entire Set D was from rhizome buds.

Conclusion

This study revealed Kentucky bluegrass varieties which were able to endure and recover from severe moisture stress. Primo and Merion are varieties which will recover the fastest. These varieties should be considered for use when it is desirable to have a quality turf area at certain times throughout the year, yet withhold water from the area at other times. Merion and Primo will produce a high quality turf when irrigated, but will endure severe drought periods, with limited loss of quality after irrigation is resumed. These varieties may also show reduced desiccation during severe winter drought. This study also indicates that certain varieties that performed well in the field, such as S-21, may not produce the same results when exposed to more severe drought stress.

PLANT RESERVES STUDY

Plant reserves may be a critical factor determining whether Kentucky bluegrass will recover from drought-induced dormancy. Varietal differences in recovery from drought-induced dormancy might be attributed to differences in plant reserves. Varieties entering a drought period with greater reserves, or those able to avoid depleting reserves below critical levels, may be able to recover from drought faster and more completely.

Many methods have been used to calculated plant reserves. An etiolated growth method was used in this study. As photosynthesis is prevented, any growth produced must be related to the stored quantities of carbohydrates and other energy-producing materials which the plant may use for recovery. This method of measuring food reserves has been used successfully in the past and has advantages over chemical isolation techniques (16,41). Most notably, the question of whether or not the measured reserves are available for regrowth is eliminated as regrowth is used to measure the reserves.

Materials and Methods

On December 3, 1977, 4 plugs were removed from each of 25 Kentucky bluegrass variety plots. The plugs measured approximately 2 inches (5 cm) in diameter and were 2 inches (5 cm) deep. In a few cases an intact 2 inch deep plug could not be removed so the deepest plug possible was obtained. In such cases the roots and other storage organs had not penetrated the 2 inch depth. Consequently, the lessened soil volumes should not effect results. The plugs were each clipped to the soil surface level and then placed in a styrofoam cup labeled for identification. The plugs were then watered and placed in an environmental control chamber arranged in a randomized complete block design of four blocks. The chamber was set at a constant temperature of 75^{o}F (24^{o}C) and when closed was without light. The chamber was opened to water the plugs every 1-2 days to keep them moist.

After two weeks in the chamber, the plugs were removed and clipped at the soil surface, clippings were placed in paper bags marked for identification and the plugs were placed back in the chamber.

Five additional clippings at two week intervals were made followed by a final clipping one week later. A total of 7 clippings were made with the final clipping being on March 4, 1978, 13 weeks after the plugs were first placed in the chamber.

The clippings were oven dried at 70^{o}C (158^{o}F) for 24 hours and then weighed. The dry weight was used as an indication of food reserves. The weights from each of the clipping dates as well as the cumulative clipping weights were statistically analyzed.

Results and Discussion

Clipping dates, mean dry weights per clipping, and percentage of total dry weight per clipping are shown in Table 3.

Statistical analysis of total plant food reserves, based on the total dry weight of all clippings, revealed no significant difference between varieties. Ranking of the varieties based on total food reserves is shown in Table 4. Common (SD #1), Delta, and Windsor had the greatest total food reserves, and Melle and Nugget the least. For all varieties, mean total food reserves was 146.85 milligrams. The first clipping accounted for the most reserves, with a mean for all varieties of 123.63 mg. Statistical analysis of the first clipping reserves also indicated no significant difference between varieties. Ranking of the varieties based on the first clipping is shown in Appendix Table 5. Total food reserves or food reserves depleted in the initial two weeks of etiolated growth may not be a positive factor in the influence of plant reserves on drought resistance. The pattern of reserve depletion during etiolated growth may be representative of reserve depletion during drought stress. It is important that a variety not deplete its reserves too quickly when exposed to drought stress as reserves are needed to recover from drought. Varieties having greater total reserves, yet depleting them in the first two week period, may on the basis of food reserves be poorly adapted to recover from drought.

Table 3. Clipping numbers, dates, means (for all varieties), and percent of total dry weight for each clipping.

Clipping #	Date	Mean (mg)	Percent of Total
start	December 3, 1977		
1	December 17	123.63	84.19
2	December 31	18.28	12.45
3	January 14, 1978	3.19	2.17
4	January 28	0.92	0.63
5	February 11	0.47	0.32
6	February 25	0.28	0.19
7	March 4	0.08	0.05
Total		146.85	100.00

Table 4. Comparison of the total plant reserves of the varieties based on dry weight of 13 weeks of etiolated growth, no statistical significance.

Rank	Variety	Mean (mg)
1	Common (SD #1)	187.40
2	Delta	186.98
3	Windsor	179.60
4	Adelphi	170.88
5	Fylking	170.23
6	A-20	168.98
7	Sydsport	162.95
8	Primo	160.48
9	Baron	157.85
10	Merion	153.30
11	Ill-38-17	152.95
12	Park	148.18
13	Arboretum	147.00
14	Geary	146.35
15	S-21	141.65
16	Common (SD #2)	137.28
17	A-34	137.15
18	Pennstar	135.50
19	Prato	134.18
20	Kenblue	131.00
21	Code 95	129.20
22	Newport	128.15
23	Sodco	124.75
24	Melle	96.95
25	Nugget	82.32

To identify the varieties which had the most reserves remaining after the initial two week depletion, the first clipping dry weights were subtracted from the total dry weights. Statistical analysis revealed a significant difference between varieties, Appendix Table 6. Figure 3 shows the means of the varieties for total reserves minus first clipping in an LSD graph. S-21, Delta, and Merion showed the highest amount of reserves with 42.90, 41.23, and 37.80 mg respectively. This indicated that these varieties should have more reserves available for regrowth following a two week depletion period than the other varieties. According to this, these varieties should have performed well in the greenhouse 14 day drought test. Although Merion performed well in that test (Figures 1 and 2), S-21 and Delta were both below average. S-21 did perform well in the field test (Tables 1 and 2), and Delta was average, but Merion performed poorly. Sydsport and Common (SD #2) showed the least amount of reserves remaining yet these varieties were among the better performers in the greenhouse test. Lack of correlation between the amount of reserves remaining after the initial two week depletion period and performance in the greenhouse test indicates that total reserves remaining after two weeks of depletion may not be a good estimate of regrowth (from drought) potential.

The possibility that a certain minimum amount of reserves was required for regrowth (from drought) was explored. Percentage of

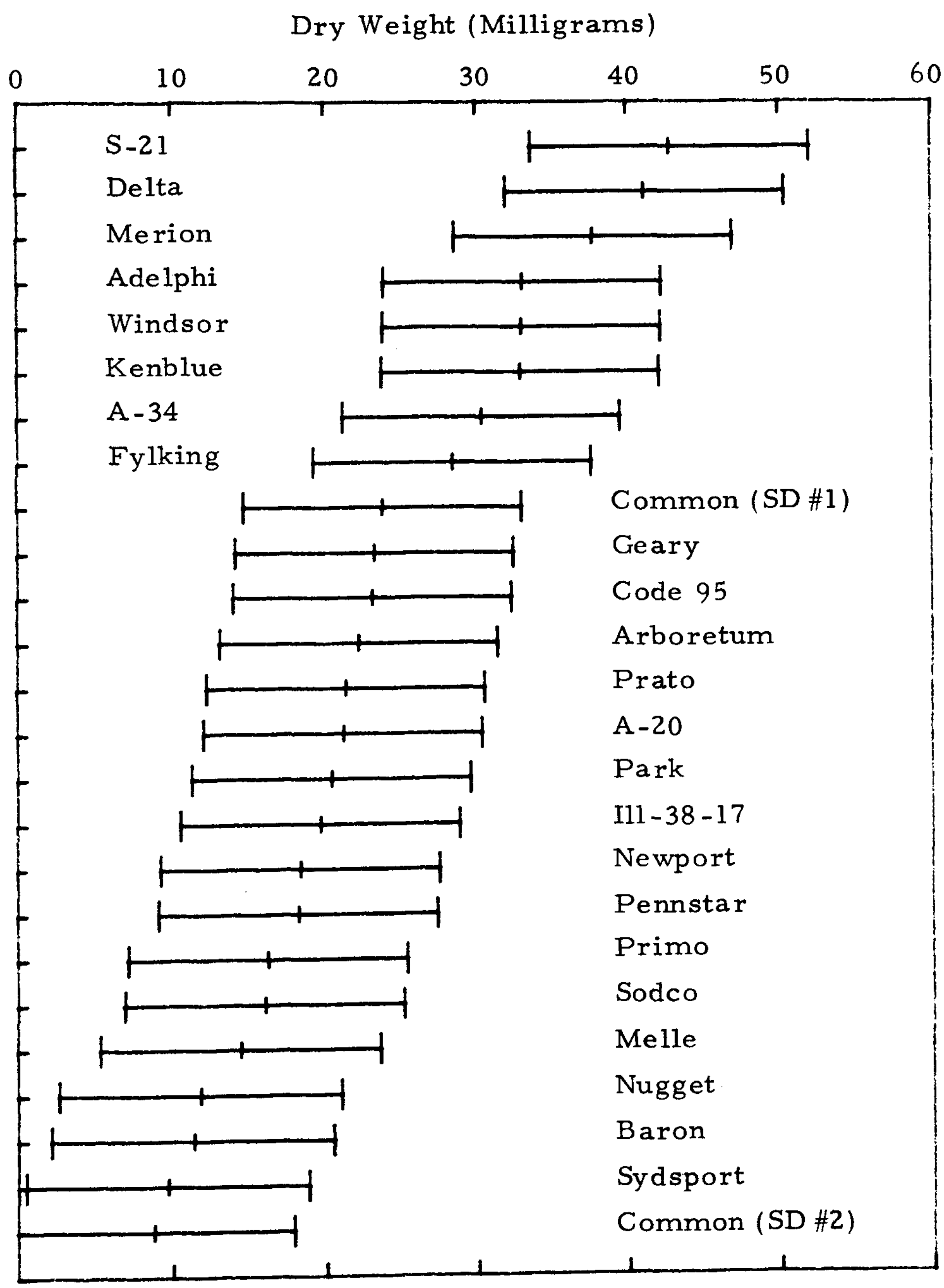

Figure 3. Depicts LSD separation of plant reserves, total reserves minus first clipping. LSD (5%) bars are 18.32 units long.

total reserves remaining after two weeks of depletion was calculated for each variety and appears in Table 5. Varieties had between 6.0 and 30.3 percent of their total reserves remaining after two weeks of reserve depletion. Varieties showing the largest percentage of total reserves remaining were not to a great extent the same varieties performing well in the field and greenhouse recovery from drought tests.

Statistical analysis of the dry weights of the second, third, and fourth clippings indicated significant difference between varieties, Appendix Table 6. Means of the varieties for these clippings are expressed in LSD graphs in Appendix Figures 1, 2, and 3. Lack of correlation between varieties showing greater reserves in these clippings and those varieties performing well in the recovery from drought tests was noted in these instances also.

Conclusion

Based on an etiolated growth measurement of reserves, a lack of correlation between recovery from drought tests and total plant reserves was noted. Although a significant difference between varieties was found for reserves remaining after two weeks of depletion, no correlation with recovery from drought tests was observed. A significant difference between varieties was also found for reserves removed on the 2nd, 3rd, and 4th clipping dates, but again no

Table 5. Comparison of the percentage of total reserves remaining after a two week depletion period.

Rank	Variety	Percent
1	S-21	30.3
2	Kenblue	25.2
3	Merion	24.7
4	A-34	22.2
5	Delta	22.0
6	Adelphi	19.4
7	Windsor	18.4
8	Code 95	18.0
9	Fylking	16.7
10	Prato Geary	16.0
11	Arboretum	15.1
12	Melle	15.0
13	Nugget Newport	14.4
14	Park	13.8
15	Pennstar	13.5
16	Ill-38-17	12.9
17	Common (SD #1) Sodco	12.8
18	A-20	12.6
19	Primo	10.1
20	Baron	7.2
21	Common (SD #2)	6.4
22	Sydsport	6.0

correlation with performance in the recovery from drought tests was evident. Varieties were shown to deplete their reserves at varying rates during etiolated growth. With further study, this factor may be found to be important in recovery from drought.

RHIZOME STUDY

The ability of the underground parts of grasses to remain dormant during periods of drought is a major factor determining drought resistance. Dormant underground parts, such as the rhizomes of Kentucky bluegrass, are able to initiate new growth when favorable moisture conditions develop. This regrowth is initiated from the buds at the nodes of rhizomes.

Differences between Kentucky bluegrass varieties in recovery from drought-induced dormancy may be caused by variation in rhizome characteristics. A variety with a large number of rhizomes may be able to recover from dormancy much faster than one with few rhizomes. Perhaps more important is the ability of a rhizome bud to retain its viability during prolonged drought. Buds of one variety may possess a greater tolerance to drought than other varieties. To test this hypothesis, an experiment exposing rhizome buds to different desiccation stresses for varying time intervals was conducted. Similar experiments with other grasses have been conducted by Mueller (67) and Ratnam (71).

The five varieties selected for use in this experiment were chosen as they represented both extremes of drought resistance in previous experiments.

Materials and Methods

On March 17 and 18, 1978, pieces of sod were removed from five Kentucky bluegrass variety plots at the W. D. Holley Plant Environmental Research Center. The pieces were washed free of soil and rhizomes were removed. At that time any rhizome appearing to be dead was discarded. The rhizomes were then sectioned into pieces containing a single node and measuring 1/8 to 1/4 inch in length.

Dehydration stresses of three intensities and three durations were used in this experiment. The 3 intensities used were 95, 90 and 84 percent relative humidity. The 95, 90 and 84 percent relative humidities were maintained using different saturated salt solutions in three sealed desiccators at a constant temperature of 20 ^{o}C (68 ^{o}F). The salt solutions used as well as the corresponding water potentials of the three relative humidities were as follows (51):

Solid Phase	Temp ^{o}C	RH	ψ (Bars)
$NaHPO_4 \cdot 7\ H_2O$	20	95%	- 67.58
$ZnSO_4 \cdot 7\ H_2O$	20	90%	-138.83
KBr	20	84%	-229.73

The three desiccators were placed in a growth chamber to maintain constant temperature. Desiccation periods used in the experiment were 24, 48 and 96 hours.

The rhizome pieces of each variety were randomly separated into 13 groups. These groups represent one group for each relative humidity for each duration time plus one group which was to be immediately tested for regrowth. The rhizome pieces were put in containers which allowed for air circulation and then placed into the desiccators. The number of rhizome pieces in each container, depending on variety, ranged from 22 to 30. Each of the 3 desiccators held 16 containers suspended over the saturated salt solution on a wire grid. There was one container of each variety for each duration time plus one container with rhizome pieces which was used to estimate tissue water loss.

When the other containers were placed in the desiccators, the rhizome pieces from one container for each of the varieties were tested for regrowth. The regrowth test for this experiment consisted of placing the rhizome pieces on a moist filter paper over 1/8 inch of silica sand in a petri dish and by observing bud break. The petri dishes were kept in a growth chamber at 70°F (21°C) with 13 hour daylength and were watered daily. Counts of the rhizome pieces showing regrowth were made at 5 day intervals.

After 24, 48, and 96 hours the same procedure was followed. One container of each variety from each of the desiccators was removed and tested for regrowth. Counts of rhizome pieces showing growth were made after 5, 10, 15, and 20 days. Final counts were made on April 27, which amounted to regrowth periods of 38, 37, and 35 days for the 24, 48, and 96 hour stress periods respectively. At that time, no new growth from rhizome pieces had been observed for three days. Chi-square analysis of the final counts of rhizome pieces showing growth was used to analyze results.

The containers holding rhizome pieces used to estimate tissue water loss were weighed before being placed in the desiccators and after 24, 48, 72, and 96 hours. The rhizome pieces were later oven dried and weighed.

Results and Discussion

Tissue water loss during the experiment at the 95, 90, and 84 percent relative humidities was calculated and is shown in Table 6.

Percentage of rhizome pieces showing growth and chi-square values for the relative humidities, durations, and varieties are shown in Table 7. Significant differences between relative humidities, exposure times, and varieties were found.

Relative Humidities

Analysis of overall relative humidity effects in the experiment showed significant differences between exposure to the 95, 90, and 84 percent relative humidities (Table 7a). Considering all time periods, 63.4 percent of the rhizome pieces from the 95 percent relative humidity stress grew. This compared with 54.1 percent

Table 6. Percent water content of rhizome pieces exposed to three relative humidities at four time intervals.

Relative Humidity	Oven-Dry Weight	Percent Water of Tissue				
		Initial	After 24 Hours	After 48 Hours	After 72 Hours	After 96 Hours
95%	60.0 mg	80.2	71.6	65.5	62.2	60.1
90%	48.7 mg	81.9	49.7	40.9	40.4	38.9
84%	48.6 mg	78.9	25.2	18.2	13.8	14.7

Table 7. Effects of relative humidity, exposure time, and variety on regrowth of rhizome pieces of Kentucky bluegrass. Chi-square values (1%* and 0.1%**) are listed.

a. Relative Humidity:	Percent of Rhizome Regrowth 95%	90%	84%	Chi-Square
overall	63.4	54.1	47.2	18.68**
24 hr. exposure	64.6	63.9	55.5	2.64
48 hr. exposure	64.4	59.3	43.2	10.71*
96 hr. exposure	61.3	39.2	42.7	14.62**
96 hrs-90% RH vs. 84% RH	-	39.2	42.7	0.13
95% RH vs. no stress (71.1%)	63.4	-	-	2.74

b. Exposure Time:	24 hrs	48 hrs	96 hrs	Chi-Square
overall	61.3	55.6	47.9	12.67*
95% RH	64.6	64.4	61.3	0.20
90% RH	63.9	59.3	39.2	16.97**
84% RH	55.5	43.2	42.7	5.03

c. Variety:	A-34	Pennstar	Sydsport	Merion	Baron	Chi-Square
overall	55.4	41.3	59.1	73.4	46.5	52.15**
no stress	92.0	50.0	73.9	81.8	63.2	16.96*
severe stress	41.0	23.8	45.1	66.7	35.7	38.45**

from the 90 percent relative humidity stress and only 47.2 percent from the 84 percent relative humidity stress.

For the 24 hour exposure period there was no significant difference between relative humidities. Differences in percentage of rhizome pieces showing growth did not vary greatly between the relative humidities for the first 24 hour exposure period.

The 48 hour exposure period had significant difference between exposure to different relative humidities. The 95 percent relative humidity had 64.4 percent of rhizome pieces that grew, 90 percent relative humidity had 59.3 percent show growth, while the 84 percent relative humidity had only 43.2 percent which grew.

Significant difference was also shown between relative humidities for the 96 hour exposure period. However, calculation of a further chi-square showed no significant difference (Table 7a) between the 90 percent relative humidity and the 84 percent relative humidity. This indicates that the water content of tissue reached after 96 hours in the 90 percent relative humidity (38.9%, Table 6) injures as much as the water content (14.7%) reached after 96 hours in the 84 percent relative humidity.

A chi-square was also calculated to test for significant differences for growth between the rhizome pieces exposed to the 95 percent relative humidity stress and the rhizome pieces that were tested for growth without exposure to any stress. The regrowth of rhizome pieces exposed to 95 percent relative humidity was not significantly different (Table 7a) from regrowth of rhizome pieces not exposed to any stress.

Length of Exposure

Analysis of the overall exposure time effects showed significant differences between the 24, 48, and 96 hour periods (Table 7b). Considering all relative humidities, the percent of rhizome pieces showing growth was 61.3 for the 24 hour stress period, 55.6 for the 48 hour period, and 47.9 for the 96 hour exposure.

Time of exposure had no effect on the 95 percent relative humidity stress. There was no significant change in the percent of rhizomes showing growth when the duration of the 95 percent relative humidity stress was increased from 24 to 96 hours. This indicates the rhizome pieces may lose moisture down to 60 percent water content (Table 6) without affecting their growth potential.

Significant differences between the length of exposure were found for the 90 percent relative humidity stress. Percent of rhizome pieces showing growth was 63.9 after the 24 hour stress, 59.3 after the 48 hour stress, and 39.2 after the 96 hour stress.

No significant differences between exposure times was found for the 84 percent relative humidity stress. Although it was noted that the percent of rhizome pieces showing growth was greater for the 24 hour stress, there was essentially no difference in growth between the 48 and 96 hour stresses. This indicated no significant reduction in growth of rhizome pieces occurred when water content dropped from 18.2 percent to 14.7 percent.

The stresses which resulted in substantial reductions in the percent of rhizome pieces showing growth were 90 percent relative humidity for 96 hours and 84 percent relative humidity for 48 and 96 hours.

Varietal Effects

Significant difference between varieties was indicated by counts for each relative humidity and time of exposure (Table 7c). Percent of rhizome pieces showing growth in this overall analysis ranged from 41.3 percent for Pennstar to 73.4 percent for Merion. Ranking of the varieties is shown in Table 8a.

Analysis of the numbers of rhizome pieces not exposed to any stress and showing regrowth also indicated significant difference between varieties. Ranking of the varieties on this basis is shown in Table 8b. Percent of rhizome pieces showing regrowth ranged from 50.0 percent for Pennstar to 92.0 percent for A-34.

A-34 rhizome pieces showed the largest drop in growth when exposed to stress, going from 92.0 percent under no stress to 55.4 percent when stressed.

As discussed earlier, significant reduction in the regrowth of rhizomes occurred in only three of the stresses. Analysis of

Table 8. Ranking of varieties based on percentage of rhizome pieces showing growth over all exposure times and relative humidities, after no exposure to stress, and after exposure to severe stress. Chi-square values (1%* and 0.1%**) are listed.

Rank	Variety	Percent
a. All exposure times and relative humidities (Chi-square = 52.15**)		
1	Merion	73.4
2	Sydsport	59.1
3	A-34	55.4
4	Baron	46.5
5	Pennstar	41.3
b. No exposure to stress (Chi-square = 16.96*)		
1	A-34	92.0
2	Merion	81.8
3	Sydsport	73.9
4	Baron	63.2
5	Pennstar	50.0
c. Exposure to severe stress (Chi-square = 38.45**)		
1	Merion	66.7
2	Sydsport	45.1
3	A-34	41.0
4	Baron	35.7
5	Pennstar	23.8

rhizome pieces of the varieties showing growth for those stresses was done. Significant difference between varieties was again indicated. Ranking of the varieties for the most severe stresses is shown in Table 8c. Merion performed the best with 66.7 percent of its rhizome pieces showing growth and Pennstar the worst with only 23.7 percent showing growth.

Conclusion

The stresses of 90 percent relative humidity for 96 hours and 84 percent relative humidity for 48 and 96 hours were the only ones resulting in substantial reduction of the percentage of rhizome pieces showing growth. These stresses reduced water content of tissue to 38.0, 18.2, and 14.7 percent respectively. Water content of tissue after 48 hours at the 90 percent relative humidity was 40.9 percent, yet little reduction in the growth of the rhizome pieces occurred. Tissue water content was reduced only slightly to 38.9 percent with 48 hours of additional exposure to 90 percent relative humidity, yet significant reduction in regrowth of rhizome pieces occurred. It can be concluded that a stress reducing tissue water content to approximately 40 percent for a period of 48 hours will reduce the growth potential of rhizomes. There was not a significant reduction in percentage of rhizome pieces showing growth when the length of exposure to the 84 percent relative humidity was increased from 48 to 96 hours.

Some rhizome pieces had a water content reduction to 18 percent for a period of 48 hours yet retained their ability to grow from nodes.

The rhizomes of different varieties vary in their ability to grow from nodes both when stressed and unstressed. Desiccation stresses on rhizomes affect the growth potential of rhizomes, depending on variety. A-34, with a high percentage of rhizome pieces showing growth when unstressed, showed substantially reduced regrowth when stressed. While Merion, although not showing as much growth from rhizome pieces as A-34 when unstressed, showed considerably more growth than A-34 when both were under stress.

Under severe stress Merion showed a much higher percentage (66.7) of rhizome regrowth than the four other varieties. Merion may have performed well due to its good reserves status as shown in the reserve study. The ranking of varieties for rhizome regrowth after severe stress is similar to the regrowth ranking (Figure 1) of the Set C greenhouse experiment. Merion performed best of the five varieties also used in the rhizome study in that experiment. Pennstar, worst performer in the rhizome study, also performed poorly in the greenhouse study. These links indicate that growth from rhizomes may be a major factor affecting varietal differences in recovery from drought.

SUMMARY AND CONCLUSIONS

Varieties recovering well from drought stress in the field did not necessarily perform well in the greenhouse. Conversely, varieties performing well in the greenhouse test may have shown poor recovery in the field. Regardless, the best overall recovery from drought stress was exhibited by A-20, Kenblue, Merion, Sydsport, S-21 and Common (SD #2). All these varieties also ranked among the better performers in Dernoeden's study of drought resistance (24). This indicates that varieties may possess an overall ability in regards to drought resistance generally.

The varieties showing best overall recovery from drought had greatly different amounts of plant food reserves. For that reason, plant food reserves were not considered a major factor affecting drought recovery in this study. However, under certain conditions, the fact that some varieties were found to deplete their reserves faster than others may influence drought recovery.

The best growth from rhizomes after exposure to desiccation stress was exhibited by Merion and Sydsport, varieties which also showed among the best overall drought recovery. Pennstar, which had shown poor overall drought recovery, also exhibited limited growth from rhizomes exposed to desiccation stress. This indicates that drought recovery may be dependent on growth from rhizomes.

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APPENDIX

LIST OF APPENDIX TABLES

LIST OF APPENDIX FIGURES

Appendix Table 1. Ranking of Kentucky bluegrass varieties on the basis of resistance to wilting at low (8.86 - 10.86%) soil moisture. From Dernoeden, 1976 (24).

Rank	Variety	Rank	Variety
1	Arboretum	14	Sodco
2	Merion	15	Nugget
3	Common (SD #2)	16	Windsor
4	Code 95	17	Newport
5	Kenblue	18	Pennstar
6	Geary	19	Adelphi
7	Delta	20	Common (SD #1)
8	Baron	21	Park
9	S-21	22	Fylking
10	Melle	23	Primo
11	A-20	24	Ill-38-17
12	Sydsport	25	A-34
13	Prato		

Appendix Table 2. Climatological data for Fort Collins, Colorado (1977) derived from the National Oceanic and Atmospheric Administration, The Environmental Data Service, Asheville, North Carolina.

	Temperature							Precipitation
	Avg. Max.	Avg. Min.	Avg.	Highest	Date	Lowest	Date	Total
Field Drought Period (Aug. 20 - Sept. 15)	82.0	53.0	67.5	94	6	43	10	0.26 in.
Field Recovery Period (Sept. 16 - Oct. 6)	73.0	44.4	58.7	84	24,28	36	1,3	0.00 in.

Appendix Table 3. Comparison of visual ratings of the greenhouse study varieties after a 21 day drought and 42 day recovery period, no statistical significance. Ratings on a 0 to 10 scale with 10 representing greater than 90% regrowth.

Rank	Variety	Mean
1	A-20	1.67
2	Kenblue Sydsport	1.33
3	S-21	1.00
4	Common (SD #2) Ill-38-17 Baron	0.67
5	Fylking Primo Delta Park Melle Arboretum Merion	0.33
6	Pennstar Adelphi Prato Windsor Common (SD #1) Nugget Geary Newport Sodco Code 95 A-34	0.00

Appendix Table 4. Comparison of the live tiller counts of the greenhouse study varieties after a 21 day drought and 42 day recovery period, <u>no statistical significance</u>.

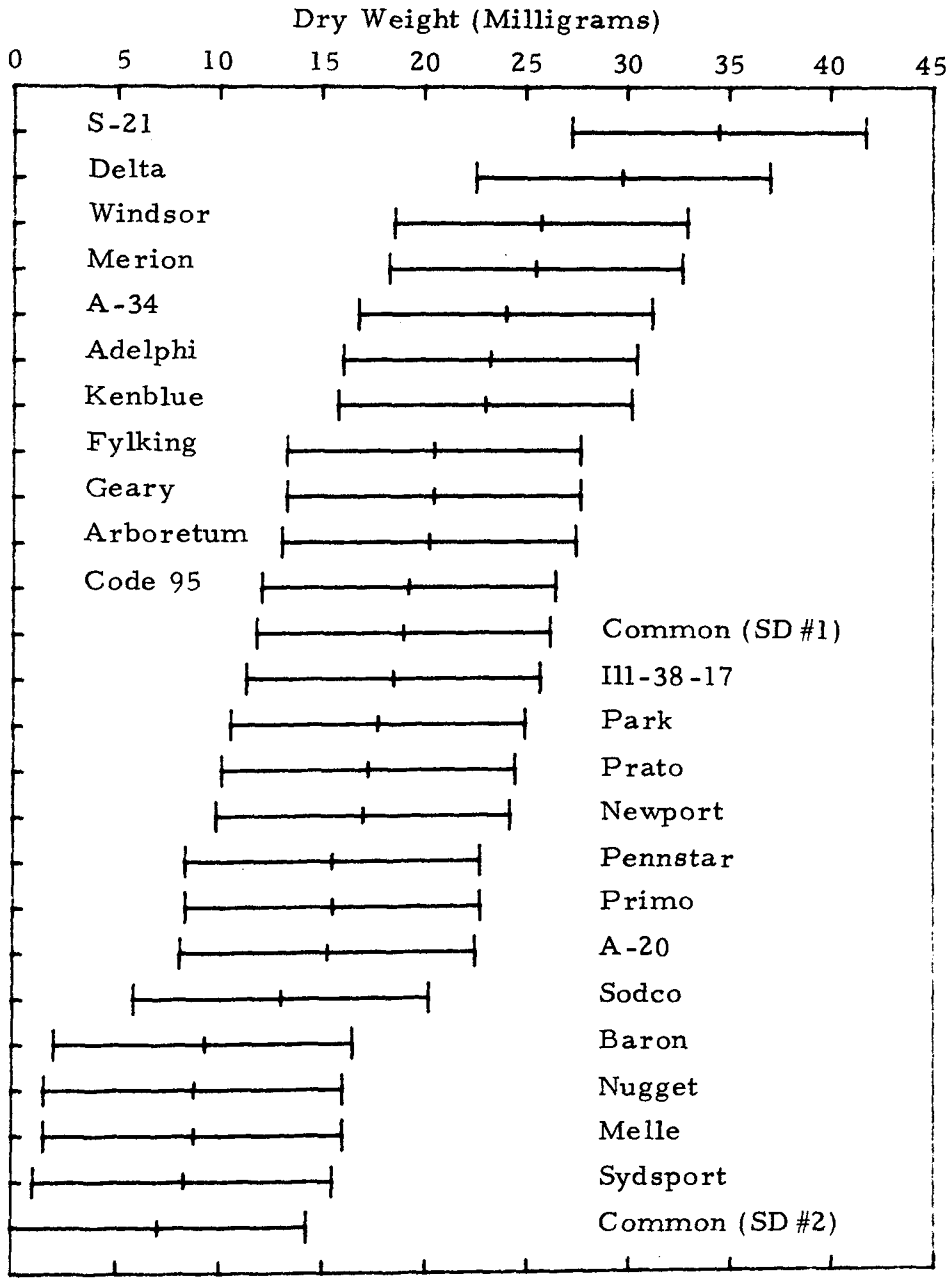
Rank	Variety	Mean
1	A-20	9.00
2	Kenblue	4.00
3	Sydsport	3.00
4	S-21 Baron	1.33
5	Common (SD #2) Delta Ill-38-17 Arboretum	0.67
6	Fylking Primo Park Melle Merion	0.33
7	Pennstar Adelphi Prato Windsor Common (SD #1) Nugget Geary Newport Sodco Code 95 A-34	0.00

Appendix Table 5. Comparison of the plant reserves of the varieties depleted in the initial two weeks of etiolated growth, no statistical significance.

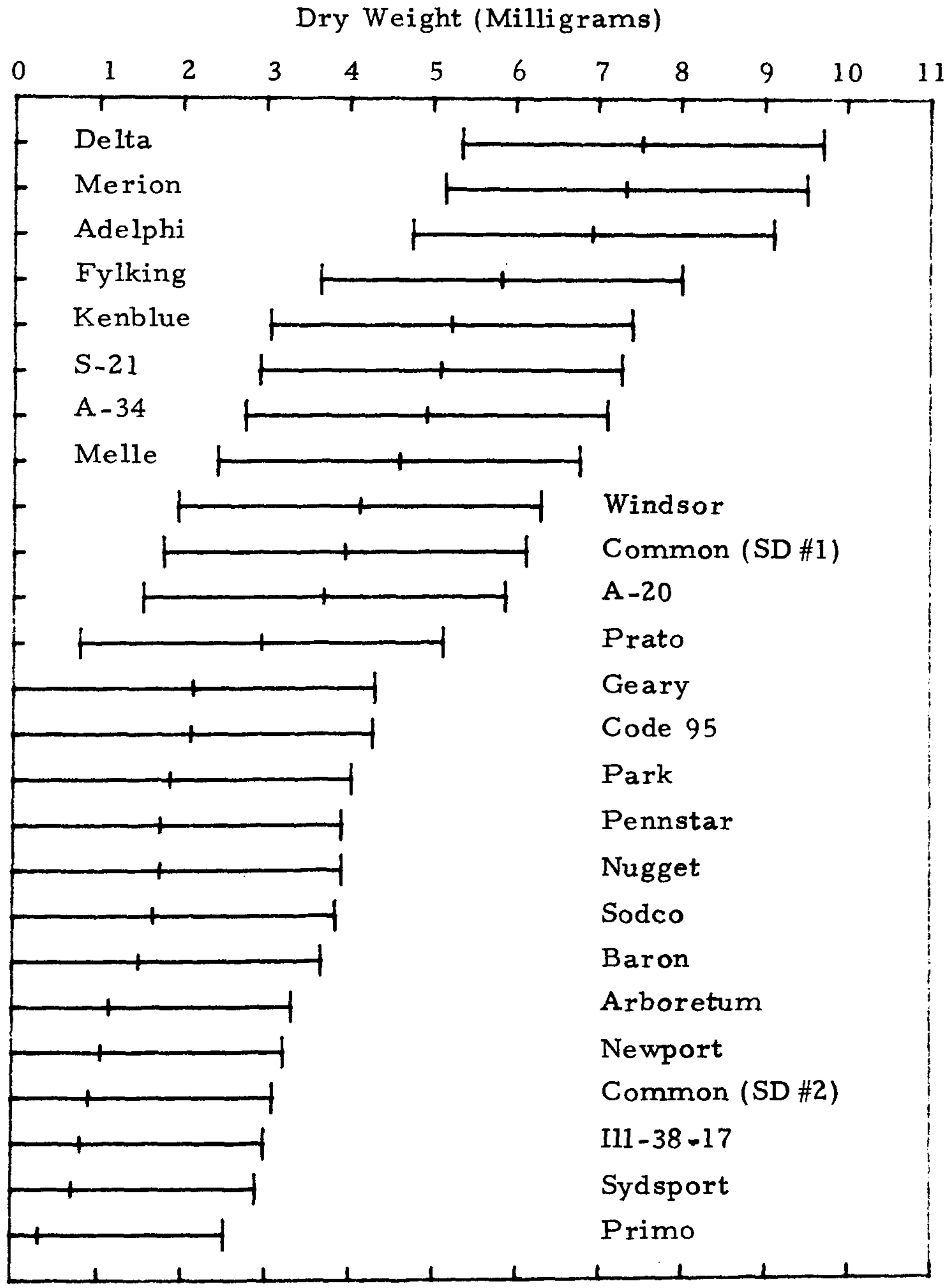
Rank	Variety	Mean (mg)
1	Common (SD #1)	163.50
2	Sydsport	153.25
3	A-20	147.75
4	Windsor Baron	146.50
5	Delta	145.75
6	Primo	144.25
7	Fylking	141.75
8	Adelphi	137.75
9	Ill-38-17	133.25
10	Common (SD #2)	128.50
11	Park	127.75
12	Arboretum	124.75
13	Geary	123.00
14	Pennstar	117.25
15	Merion	115.50
16	Prato	112.75
17	Newport	109.75
18	Sodco	108.75
19	A-34	106.75
20	Code 95	106.00
21	S-21	98.75
22	Kenblue	98.00
23	Melle	82.50
24	Nugget	70.50

Appendix Table 6. Statistically significant data using the analysis of variance. The F-ratio, degrees of freedom, sums of squares and mean squares for significant data (5% and 1%*) are listed.

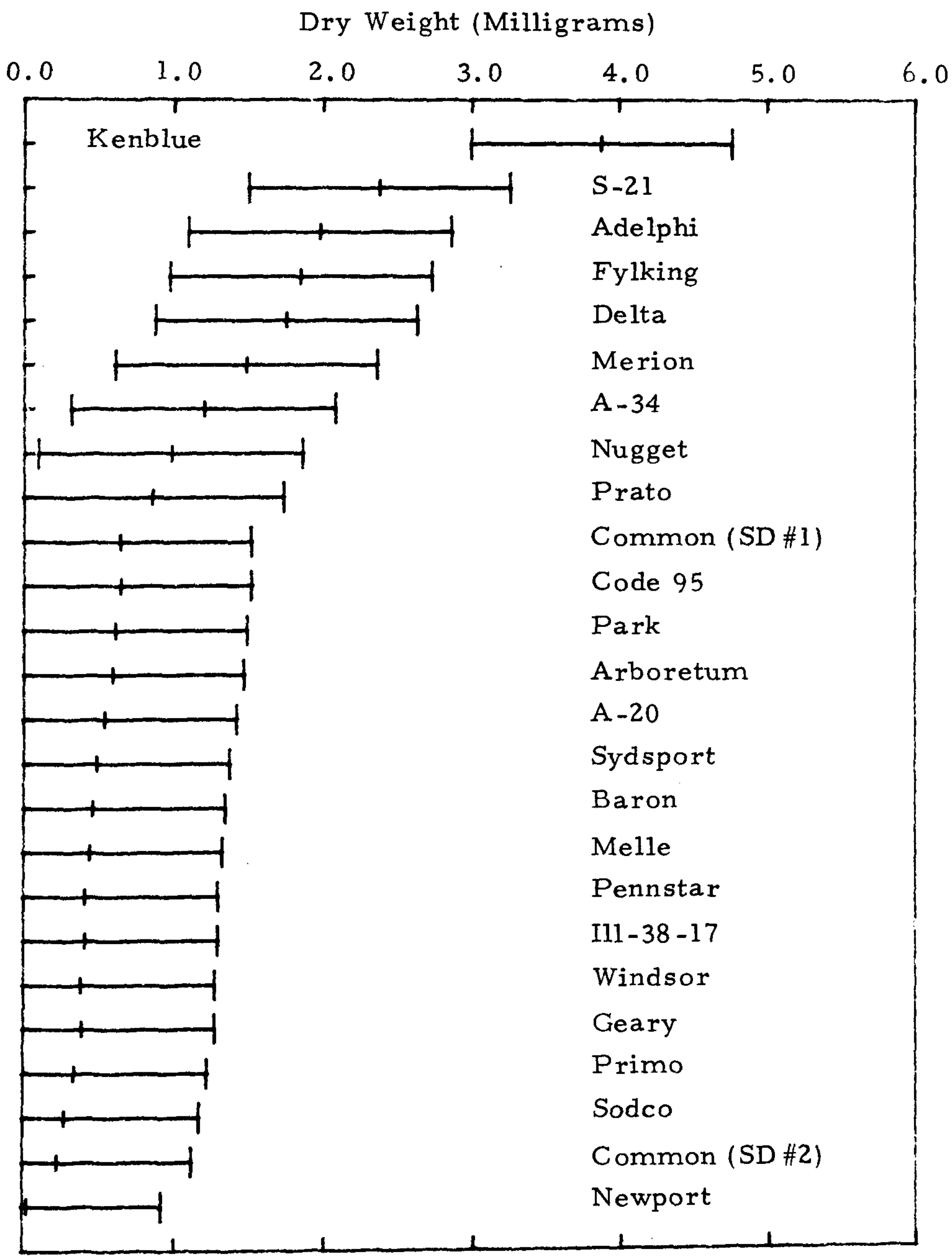
	df	SS	MS	F ratio
Greenhouse Study				
Set C visual rating	24	84.67	3.43	2.23*
Set C live tiller counts	24	3129.65	130.40	1.89
Reserves Study				
Second clipping	24	4576.16	190.67	1.82
Third clipping	24	477.71	19.90	2.08*
Fourth clipping	24	73.26	3.05	1.95
Total reserves minus first clipping	24	8846.08	368.59	2.17*



Appendix Figure 1. Depicts LSD separation of plant reserves, second clipping. LSD (5%) bars are 14.42 units long.



Appendix Figure 2. Depicts LSD separation of plant reserves, third clipping. LSD (5%) bars are 4.36 units long.



Appendix Figure 3. Depicts LSD separation of plant reserves, fourth clipping. LSD (5%) bars are 1.76 units long.

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