SEEDLING STUDY

Methods and Materials

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

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

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

All flats were saturated with water at the beginning of each drought trial. After 24 hours of draining and evapotranspiration the
soil was considered to be at field capacity. At that time all flats were weighed to the nearest gram. Several days elapsed without further irrigation. When the grass appeared to be near the permanent wilting point the blades of grass were tightly folded, cascaded and had a blue-gray color. At that time all flats were rated on a scale similar to that used in the field study. After rating, the flats were reweighed. The soil at this time was assumed to be at a moisture tension comparable to the approximate permanent wilting point, as judged by the wilted appearance of the turf.

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

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

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Daytime high temperature</td>
<td>70 - 75°F</td>
</tr>
<tr>
<td>Nighttime low temperature</td>
<td>65 - 68°F</td>
</tr>
<tr>
<td>Daytime relative humidity</td>
<td>61%</td>
</tr>
<tr>
<td>Nighttime relative humidity</td>
<td>76%</td>
</tr>
</tbody>
</table>

**Trial 1: Results and Discussion**

Results of the initial trial are shown in Figure 8. Adelphi, Fylking and Park exhibited the best tolerance to drought of the nine varieties tested. Pennstar, Windsor and Vantage were intermediate
Figure 8. Depicts LSD separation of seedling varieties, Trial 1. LSD (5% level) bars are 0.98 units long.
in tolerance and Merion, S. D. Common and Newport had shown least
tolerance to drought.

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

An anomaly was revealed when the performance of the seedlings
and mature plants were compared, Table 2. Those varieties which
performed well under drought stress in the field study did not do so
as seedlings. Adelphi, which ranked highest in tolerance as a
seedling, performed poorly in the field study. Merion, conversely,
ranked third in the field study but poorly in the seedling investigation.
This information implies that drought tolerance is directly related to
rate of rhizome and secondary root development and maturity.
Merion was slow to emerge and had not produced a dense stand one
month after emergence. It is speculated that if these seedlings were
transplanted into the field that Merion would, in time, surpass the
other varieties in its ability to tolerate drought. Therefore, it
Table 2. Comparison of 9 mature and seedling Kentucky bluegrass varieties.

<table>
<thead>
<tr>
<th>Variety</th>
<th>Mature Plants Field Study</th>
<th>Seedlings Greenhouse Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adelphi</td>
<td>Lower Third</td>
<td>Upper Third</td>
</tr>
<tr>
<td>Fylking</td>
<td>Lower Third</td>
<td>Upper Third</td>
</tr>
<tr>
<td>Park</td>
<td>Lower Third</td>
<td>Upper Third</td>
</tr>
<tr>
<td>Pennstar</td>
<td>Lower Third</td>
<td>Middle Third</td>
</tr>
<tr>
<td>Windsor</td>
<td>Lower Third</td>
<td>Middle Third</td>
</tr>
<tr>
<td>Vantage</td>
<td>Not Tested</td>
<td>Middle Third</td>
</tr>
<tr>
<td>Merion</td>
<td>Upper Third</td>
<td>Lower Third</td>
</tr>
<tr>
<td>South Dakota Common</td>
<td>Upper Third</td>
<td>Lower Third</td>
</tr>
<tr>
<td>Newport</td>
<td>Lower Third</td>
<td>Lower Third</td>
</tr>
</tbody>
</table>
appears that drought tolerance of established turf cannot be determined by observing seedling grasses, as established by the criterion used in this study.

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

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

An inspection of the roots had shown that those varieties which had appreciable recovery, also had developed rhizomes. It would seem logical that varieties which produce rhizomes early in development would be more tolerant of drought.
**Trial 2:**

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

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

**Conclusion**

The inconsistency of the data accumulated during the nine month seedling investigation is difficult to explain. Undoubtedly, varietal drought tolerance is a dynamic process, changing as the plants mature. The shortening and gradual lengthening of days, fluctuations in the greenhouse environment which differ from outdoor environmental changes are other variables which probably affected the performance of the seedlings. Also, the artificiality of the greenhouse, its shadows, fans, cool and warm spots, placement of heat pipes, et cetera are other sources that influence results.
Table 3. Seedlings ranked according to percent recovery from severe drought, a 0.10 value equals one plant. Data not significantly different.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Variety</th>
<th>% Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Adelphi</td>
<td>15.50</td>
</tr>
<tr>
<td>2</td>
<td>South Dakota Common</td>
<td>15.00</td>
</tr>
<tr>
<td>3</td>
<td>Windsor</td>
<td>5.10</td>
</tr>
<tr>
<td>4</td>
<td>Park</td>
<td>3.80</td>
</tr>
<tr>
<td>5</td>
<td>Merion</td>
<td>1.50</td>
</tr>
<tr>
<td>6</td>
<td>Newport</td>
<td>0.50</td>
</tr>
<tr>
<td>7</td>
<td>Pennstar</td>
<td>0.03</td>
</tr>
<tr>
<td>8</td>
<td>Fylking</td>
<td>0.03</td>
</tr>
<tr>
<td>9</td>
<td>Vantage</td>
<td>0.00</td>
</tr>
</tbody>
</table>
Figure 9. Depicts LSD separation of seedling varieties, Trial 2. LSD (5% level) bars are 0.88 units long.
Although this investigation does have its incongruities, several important insights into drought tolerance were evident. It can be concluded that drought tolerance is not a parameter that can be selected for when grass plants are in the seedling stage. Determining drought tolerance among seedlings, however, may be possible if rate of rhizome and root development were used as a criterion. Also, it has been substantiated that drought tolerance of Kentucky bluegrass is a function of maturity.
GREENHOUSE STUDY

Methods and Materials

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

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

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

Beneath 30 plugs gypsum blocks were inserted at a depth of 8 cm. These blocks were to be utilized in monitoring soil tension during experimentation. Calibration of the gypsum blocks revealed
inconsistencies existed between meter readings and percent moisture in the soil. Also, the gypsum blocks were normally not sensitive enough for making measurements at the extremely droughty conditions that were induced.

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

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

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

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

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

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

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

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

The high moisture range approximates the lowest level at which most Kentucky bluegrasses should be maintained without any permanent injury. The ranking of the varieties in Figure 10 does not indicate which varieties tolerate the greatest soil tensions. Delta, which is ranked third at this range, could not persist at the low moisture level. Therefore, the varieties Code 95 and Merion are ranked low, but they exhibit superior tolerance in very dry soils. Warren's A-20 and A-34, Delta, and Arboretum performed significantly better at 9.5 to 11.5 percent soil moisture than Prato, Windsor, S-21, and Pennstar as shown in Figure 10. Soil moisture tension ranged from 28 to 36 bars at the 9.5 to 11.5 percent soil moisture level, Appendix Figure 1.
Figure 10. Depicts LSD separation of varieties at the 9.5 to 11.5% moisture level. LSD (5% level) bars are 0.56 units long.
Only 12 of the 25 varieties tested were able to tolerate soil moisture levels of 8.8 to 9.9 percent (35 to 42 bars), long enough for sufficient data to be accumulated as shown in Figure 11. Thus, these 12 varieties were considered more drought tolerant, under greenhouse conditions than the 13 varieties that did not persist. Varieties maintained at these high tensions incurred 15 to 20 percent injury. Injury was localized in the center of the sod. These center plants grow more swiftly, thus they probably did not possess an adequate storage of carbohydrate for recovery. Warren's A-34, Code 95, and Nugget exhibited the best tolerance to drought, Figure 11. Warren's A-34 and Nugget ranked poorly in the field study. Warren's A-34 and Nugget are shade tolerant grasses, and this physiological adaptation was undoubtedly favored by the greenhouse environment. It should also be noted that these varieties were slow growing as shown in Figure 19. Adaptation to less light and slow growth rates may have resulted in a greater root to shoot ratio and subsequent increase of stored carbohydrate and less hydrated tissue. Such an adaptation may enable these varieties to resist drought under greenhouse conditions in the winter. Fylking, a poor shade performer, and Sydsport were shown to be the least tolerant of drought of the 12 varieties.

The third category represented the lowest moisture level a variety could tolerate before above ground shoots die and buds enter into dormancy as shown in Figure 12. Figure 12 shows that varieties
Figure 11. Depicts LSD separation of the varieties at the 8.8 to 9.9% moisture level. LSD (5% level) bars are 0.56 units long.
Figure 12. Depicts LSD separation of varieties at the lower limits (pre-permanent wilting point). LSD (1% level) bars are 0.73 units long.
such as Geary, Melle, Warren's A-34, Park, S.D. Common #1 and Code 95 tolerated the lowest limits of soil moisture. Excellent turf varieties such as Baron, Merion, Fylking, Warren's A-20 and Sydsport also ranked high whereas Adelphi, Delta and Windsor were varieties that ranked poorly.

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

Conclusion

This greenhouse experiment did produce results which conflicted with the field experiments; however, basic trends were reinforced. Varieties such as Code 95, Geary and Merion had shown good tolerance to drought in both studies. The supportive data for the drought tolerance of these three varieties strengthens field study findings. It may be concluded that these varieties are among the most conservative of water of the many varieties of Kentucky blue-grasses on the market. More experimentation will be necessary to substantiate the drought tolerance of Warren's A-34 and Nugget as applied to environmental conditions imposed by this study. Pennstar and Windsor performed poorly in both greenhouse and field studies.
and should not be considered where maximum water conservation is desired. It was also shown that Kentucky bluegrass can maintain optimum greenness and turgidity at lower soil moisture levels than is normally employed by turfgrass managers.