PHYSICAL CHARACTERISTICS OF KENTUCKY BLUEGRASS TURF

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Physical Characteristics of Kentucky Bluegrass Turf

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This study was initiated to gain a better understanding of the effects exerted by several external factors on selected physical characteristics of Kentucky bluegrass (*Poa pratensis* L.), and to develop and evaluate some techniques for their measurement under turfgrass conditions. Techniques were developed for the measurement of the number of seeds per kg, stand density, seedling stand height, leaf angle, leaf-fold angle, and leaf width and length. Four factors examined were cutting height (1.3 and 2.5 cm), the presence and absence of preventative fungicide treatment, Kentucky bluegrass variety (Warren's A-34, Baron, Bonnie-blue, Newport, and Pennstar), and seeding rate (65, 194, 388, and 1033 pure-live seeds per dm²). The effect of other factors, such as stand age, leaf age, and the interrelationships of the physical dimensions, was also examined. The physical characteristics studied were the number of seeds per kg, field survival, seedling stand height, rate of ground coverage, leaf angle, sheath width, leaf lengths, percent leaves cut, leaves per tiller, percent loose 'unattached' tillers per sample plug, leaf-fold angle, and the folded and unfolded leaf widths.

A theoretical model was developed to predict the leaf area index (LAI) of a turf stand, given tiller densities and cutting heights within the range of the data. Further, this information was used in a computer simulator for an estima-
ABSTRACT

tation of the light at the bottom of a turf stand, given the mean leaf angle and the LAI.

To measure the leaf angle of bluegrass to the nearest degree and blade widths and lengths to an increment of 0.05 mm, a technique was developed utilizing an ordinary (transparency) overhead projector, a mirror, and a protractor screen, which enlarged the image of the plant parts by 10 to 20 times. This technique provided good precision for width and length measurements with 92 - 97% repeatability, and 32 - 97% for angular measurements.

For sampling turf population densities, the Noer Soil Profile-Sampler (inner dimension of 13 x 76 mm) was compared to three other popular sampling tools (35, 51, and 102 mm round). Samples of the Noer tool were representative of the population density when the loose, 'unattached' tillers per sample plug were included. Because the counting process was less tedious and the plugs were returned to the plots with minimum disturbance of the samples and plots, the Noer tool had an advantage over the other sampling tools.

With an increase in cutting height there was found to be a decrease in the tiller density after one year's growth (350 tillers/dm² at 1.3 cm vs. 250 at 2.5 cm), more loose tillers per sample plug, and longer leaves -- a 50 - 75% length increase with a 100% height increase.

With the application of fungicide, there was no effect on the field survival rate or tiller density in the first
year. Significantly more brown leaves attached to the tillers were associated with fungicide application.

In the first year of growth, seeding rate had, perhaps, a more dramatic effect on the variables examined than the other factors tested. The seedling stand height, rate of ground-cover increase, and leaf angle were found to be positively related to the seeding rate. On the other hand, the field survival, percent loose tillers per sample plug, percent leaves with cut ends, green leaves per tiller, sheath width, leaf width, and budleaf length were negatively related with seeding rate.

Under the conditions of this test, the five varieties were characterized as follows. Warren's A-34 had the most seeds per kg, greatest field survival, highest tiller density throughout the test, fastest rate of ground coverage, fewest green leaves per tiller, narrowest leaf angle and leaf blades of the varieties examined. Baron possessed the fewest loose tillers per sample plug, most brown leaves per tiller, and widest sheath width. Bonnieblue had the most green leaves per tiller, and widest sheath width (equal to Baron). Newport was characterized as having the lowest tiller density over the duration of the experiment. Pennstar had the least number of seeds per kg, lowest field survival, most loose tillers per sample plug, widest leaf angle, and narrowest sheath width of the five varieties.
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PHYSICAL CHARACTERISTICS OF KENTUCKY BLUEGRASS TURF

Introduction

Prior to 1960, the homeowner or turf manager had little choice in selecting the proper Kentucky bluegrass (Poa pratensis L.) variety for the job. At the time, Merion was the only alternative to several common-type Kentucky bluegrasses. During the 1960's, many successful breeding programs yielded a number of new Kentucky bluegrass varieties, and by 1968, there were more than 38 recognized Kentucky bluegrass varieties on the market (4). The breeders and seed companies involved in these new varieties, as well as some government agencies, then became interested in finding methods which could separate one variety from the others. Several research projects were begun using biochemical, physiological, and morphological means of quickly and reliably providing varietal separation. Although some of these studies were deemed successful in differentiating bluegrass varieties, most found that other factors such as seedlot and environment confounded the differences. One result of these studies on the morphological and physical differences among bluegrass varieties was an increased awareness of the many factors that influence a bluegrass plant of a given genotype. In some instances the behavior of the bluegrass plant grown under turfgrass conditions was found to deviate from the behavior of bluegrass grown in pasture studies by such classic Kentucky bluegrass researchers as Etter (19) and Evans (20,21,22).
During the 1970's an increasing number of improved bluegrasses were released. The use of intercrossing of established varieties to form new varieties provided a new and extremely perplexing problem for the researcher working on varietal identification. The differences between varieties became quite subtle compared to the influence of the many environmental and management factors which affect the bluegrass plant.

This study was in no way an attempt at varietal identification. The major emphasis of this work was on the development and evaluation of techniques which could be utilized for the study of bluegrass physical characteristics under turfgrass conditions. The effects of some of the factors affecting bluegrass physical characteristics were then examined using the techniques developed.
Entity of Bluegrass

Prior to studying the characteristics of a bluegrass stand, the basic unit of Kentucky bluegrass must be established. Some researchers (25,74) use the bluegrass 'plant' as their basic unit of study. A bluegrass plant, as they use the term, consists of a primary shoot with associated lateral tillers. Many of the early studies of Kentucky bluegrass were based on the bluegrass 'plant' because such work was done in pastures where separate plants can easily be discerned. However, with the dense stands of modern cultivated turfgrasses, the identity of the 'plant' becomes obscure.

Although the grass plant is botanically an assemblage of shoots, most researchers recognize the tiller as the basic unit of grasses (42). To assess the independence of the tillers of a grass plant, Williams studied the movement of carbohydrate in timothy. By exposing the primary shoot to radio-labeled carbon-dioxide and observing its translocation as carbohydrate to associated tillers, he showed that the relationship of a perennial grass shoot and its tillers is quite unlike that of an annual such as corn.

Though at what stage such free interchange [among tillers] stops is as yet undetermined; it may be related to the stage of differentiation of the vascular strands. This may be a real difference between the annual cereal [which freely transports at least until ears appear] and the perennial grass. Buds and small tillers import [carbohydrates] from older shoots, but large till-
ers do not import from other shoots or export to other large ones (75).

Other authors subdivide the bluegrass tiller into phytomers (9,p.32;19,21,26,31,34,48). The phytomer can best be understood by a look at the origin of this term.

The Phytonic Theory, originated in 1841 by Gaudichaud (26), was explained by Eames (18) as,

The shoot consists of 'units of growth' that are renewed by a type of terminal 'budding.' The make-up of these units has been variously defined:

a) as an internode with its attached leaf;
b) a leaf with a root -- the internode being the base of the leaf;
c) a segment of the stem, limited by nodes, with or without a leaf;
d) a leaf primordium with its base incorporated in the axis -- a root, as a part of the phyton, is lacking in angiosperms.

In 1879, Gray objected to the name Phyton because in Greek it means "plant." He changed the name to Phytomer, which means "plant-part" (26). With the inception of the root-and-shoot theory, which is universally accepted today, the concept of a plant consisting of a series of structural units has become antiquated (18). Of the many theories explaining plant structure proposed in the nineteenth century, Bower (11) finds none to have a basis in primitive plant embryology as they should if these segments of plants were of fundamental nature. Eames (18) concurs; his findings indicate no anatomical basis for subdivision of a plant into segments as in the Phyton Theory.
Even though, for convenience sake, the tiller is often expressed in artificial segments, the use of the term 'phytomere' in modern scientific literature is both inaccurate and misleading to the newcomer.

In this study of the physical characteristics of bluegrass, the terms 'plant' and 'tiller' are used synonymously as the basic unit of Kentucky bluegrass turf.

**Seeding Rate**

In determining seeding rate, one of the most accurate methods is to calculate from a desired stand density to the appropriate weight of seed per unit area. This calculation requires knowledge of

a) the desired stand density,

b) the number of seeds per unit weight,

c) the purity and germination (percent pure live seed), and

d) the field survival.

The percent pure live seed and field survival will be covered in a later section.

Until the 1960's, most calculations of seeding rate done in this manner were based upon published figures for cleaned, common Kentucky bluegrass seed. Kentucky bluegrass, as reported in early seed texts, had 4,800,000 seeds per kg (2,200,000 seeds per lb) (3,73).
When determining seeding rates for a ryegrass-bluegrass mixture study, Keckley (34) found that the three varieties of bluegrass he used ranged from 2,700,000 seeds per kg (1,240,000 seeds per lb) for Pennstar to 4,700,000 seeds per kg (2,150,000 seeds per lb) for Merion. In a more thorough study of seed weights, Christians and Wilkinson (14) found that Kentucky bluegrass ranged from 1,876,000 seeds per kg (852,000 seeds per lb) for Birka, to 4,600,000 seeds per kg (2,100,000 seeds per lb) for Merion. This decrease in the number of seeds per unit weight from the earlier to the later references, may be attributable to better seed production techniques as well as improved bluegrass varieties.

Madison (47) observed the population changes of bluegrass stands seeded at various rates, and found that rates producing 280 - 400 seedlings per dm² (2600 - 3720 seedlings per ft²) were relatively stable in density while maturing. Lage and Roberts (40) discovered that densities similar to those used by Madison eventually decreased to mature densities of approximately 155 tillers per dm² (1400 tillers per ft²). Madison (47) did not feel that seedling densities should be equal to the mature densities because the quickest maturing turf starts with slightly fewer than the eventual number of tillers per unit area, and attains its mature density by growth and tillering. He concluded that bluegrass planted at 490 - 980 g per 100 m² (1 - 2 lbs per 1000 ft²) produced a higher quality and earlier playable turf than the
higher seeding rates of 1950 - 3900 g per 100 m$^2$ (4 - 8 lbs per 1000 ft$^2$). Similar results were found by Longley (45) twenty-five years earlier, although Longley found the lower rate of 650 g per 100 m$^2$ (1.3 lbs per 1000 ft$^2$) to yield a poorer stand of turf. As a minimum, to ensure establishment and good competition against weeds, Musser and Perkins (51) recommended a rate of 110 - 220 seedlings per dm$^2$ (1000 - 2000 seedlings per ft$^2$).

Many early experiments on bluegrass seeding rates did not take into account the percent pure live seed and varietal differences in seed weight. These studies (40,45,47) as a result cannot be experimentally reproduced.

Field Survival

As mentioned earlier, the field survival is important in the calculation of proper seeding rates. Field survival can be defined as the number of seedlings which emerge compared to the number of pure-live seeds (PLS) planted. Another term frequently encountered in dealing with field survival is the 'field mortality.' The field mortality is the percentage of viable seeds planted which do not emerge to form seedlings. Typical field mortality rates vary from 25 to 50 percent (51). The field mortality, as well as the overall seedling vigor, is dependent upon several factors:

a) seed size (36,51,68,72),
b) volume of endosperm in a seed (12),
c) species and cultivar (5,34,36,55),
d) soil physical characteristics and environment (27,51),
e) use of seed-treatment fungicides (24),
f) inherent weakness in seed which shows up as excessively low germination in laboratory tests (51).

As a rule, larger seeds possess greater seedling vigor and result in greater field survival (36,68,72). This effect of greater seedling vigor is not correlated with the seed's embryo size. However, the volume of the endosperm has a considerable effect on seedling growth rates and emergence (12). In the initial growth and establishment of a stand, seeds with good germination generally show increased initial growth and tillering (60). As the plants grow, the influence of seed size becomes progressively less pronounced (68).

Different species, as well as different cultivars within species, often differ in seedling vigor, field survival, and germination rate (5,34,36,55). For example, Baron Kentucky bluegrass is commonly noted for its excellent seedling vigor (5). Keckley (34) found that the field survival of the three bluegrass varieties tested varied from 25 percent in Merion to 34 percent in Pennstar, when planted alone. Parks (55) also found cultivar differences in field survival as well as germination rate. Eight days after planting, he noted that 3 percent of the Merion seeds had
germinated, compared to 16 percent of the common Kentucky bluegrass seeds. After 22 days, 53 percent of the Merion seeds had germinated, and 66 percent of the common.

Many physical and environmental characteristics may influence field survival. A crust on the seedbed surface may offer a minimum number of "safe-sites" for germination and as a result, the number of seedlings emerging will increase to a limit and level-off with increasing seeding rate. However, on a seedbed with a rough surface, the number of seedlings emerging is a linear function of the seeding rate with little or no sign of leveling-off (27).

Fungicidal seed treatment may also be beneficial in enhancing field survival rates. Forbes and Ferguson (24) found that the use of Arasan (Thiram) fungicide as a seed treatment resulted in increased Kentucky bluegrass seedling emergence percentages in a greenhouse study.

Tiller Density and Competition

In turfgrass management, tiller density is regarded as a major factor in sward quality. Many management practices may affect the tiller density in addition to the obvious influence of planting rate. Nutrient supply (47), cultivar, cutting height and frequency (33), and the season of year (64) all have a direct effect on the tiller density. Increased densities put greater stress on individual grass plants. Further, high densities produce changes in the
physical and physiological characteristics of the plants within the stand resulting from severe interplant competition. As a result of severe competition, plants respond with extreme plasticity in size and form. The primary effect of increased density is to reduce the plant to a miniature size (17, pp. 17-18). Further, as density increases, less tillering of a plant occurs (25, 59). Many other responses occur in plant populations as a result of increased density, and their generalized effects were summarized by Risser (61) and Yoda, Kira, Ogawa, and Hozum (78):

a) Individuals show a plastic response as they adjust to share limiting resources,
b) there is an increase in mortality,
c) differences become exaggerated within the population, and a hierarchy of exploitation is encouraged (61),
d) The chance of a seed producing a mature plant declines with increasing density,
e) there is a maximum population size and densities above this maximum cannot be achieved,
f) the densities of overcrowded populations converge with the passage of time irrespective of the differences in initial density,
g) the converging density is closely correlated with plant size (78).

Higher plant densities do not automatically infer increased amounts of foliar vegetation. In fact, the total quantity of foliage has an asymptotic relationship with increasing density: the quantity of foliage will increase to a certain maximum and 'level-off' with increasing plant density. This seems to indicate certain self-regulating devices operating within a population in regard to foliage quantity and plant density (30).
"Competition occurs when each of two or more organisms seeks the measure it wants of any particular factor or thing and when the immediate supply of the factor or thing is below the combined demand of the organisms (17, p. 3)." When plants compete, they are competing for either materials or energy: water, light, nutrients, oxygen, or carbon-dioxide (15, p. 163). With the exception of plants which form bulbs or tubers, competition for space never occurs. Crowding is a regular feature in a plant community, its effect causes the competition for energy or materials. Many authors use the term 'competition for space' as a convenient catch-all for other forms of competition, when in fact they do not wish to explore the real factors for which competition is occurring. Donald (17, p. 6) feels that, "the loose use of this term [competition for space], whether wittingly or otherwise, could be discontinued to advantage."

**Leaf Angle**

Several researchers have noted differences in leaf angle among Kentucky bluegrass cultivars (10, 53, 62, 74). The angle of the leaf is commonly measured from the budleaf axis (assumed to be vertical) to a subtending leaf. Since a wide leaf angle significantly correlates with a low growth habit (10), cultivars with wide leaf angles can be expected to tolerate lower cutting heights and still maintain a large portion of their leaf area (9, p. 11).
Of the previous investigations of bluegrass leaf angle, most researchers measure the leaf angle with an ordinary protractor. Nittler (53) measured the angle formed between the "second leaf" (assumed to be the first leaf subtending the budleaf) and the "stem" of several seedling bluegrass varieties. He found that Newport Kentucky bluegrass had the widest average angle (34 degrees) and Beaumont had the most acute angle (13 degrees) of the varieties tested.

A problem in studying leaf angle of seedlings or in spaced plantings (10,53,74) is that the physical characteristics of bluegrass under these conditions do not correlate with those of bluegrass grown under dense, turfgrass conditions (1). Further, unclipped, spaced plants cannot be used as reliable criterion for the behavior of plants under mowed conditions (38). In addition, variations noted in spaced plantings often are obscured or disappear in solid stands (13). In a study of bluegrass leaf angle under turfgrass conditions, Sheffer (62) examined differences among cultivars. The level of precision evident in this study probably resulted from the use of only 3 tillers per plot and a measurement increment of 10 degrees. He found the first and third leaves subtending the budleaf to be unusable in good cultivar separation. Further, the inclusion of the first and third leaf angles actually decreased the accuracy obtained by use of the second leaf alone.
Many environmental factors have been shown to influence leaf angle. Under short days the shoots of Kentucky bluegrass are strongly decumbent, whereas under long days the shoots grow upright (20,22,58). Other grasses such as orchardgrass (66), bermudagrass, panicum, and corn (41) have been shown to exhibit similar behavior. Beard (9, p.191) observed that under an 8-hour photoperiod the leaf angle of bluegrass was 34 degrees (from the budleaf), while under a 16-hour photoperiod 15 degrees was noted.

Leaf angle has also been shown to vary with light intensity (9, p.191;41,74). The leaf angle becomes narrow under weak light and wide in full sun. Merion Kentucky bluegrass in full sun has a leaf angle of 25 degrees from the budleaf, compared to a leaf angle of 15 degrees in 60 percent shade (9,p.191). Wilkinson and Beard (74) observed a steady decrease in the leaf angle when light intensity was decreased from 32,100 lux (leaf angle of 75 degrees from budleaf) to 2,700 lux (20 degrees).

In addition to photoperiod and light intensity, the nutrient supply and cutting practices also influence the growth habit (28) and presumably the leaf angle.

Seldom do such physical variations occur without a direct benefit to the plant. In the summer when the sun is high in the sky, foliage that is erect (a narrow leaf angle) has the greatest sunlit foliage area. From late fall to early spring when the sunlight frequently originates from
below 30 degrees from the horizon, foliage with a near horizontal leaf has the greatest sunlit foliage area (70). Another advantage of upright foliage in the summer, is that a vertical foliage orientation is, "a means of minimizing heat load under strong irradiance but at the same time providing sufficient illumination to saturate the leaf's photosynthetic apparatus for much of the day (44, p.358)."

From a management standpoint, upright leaves have also been shown to retain less foliar-applied pesticide than horizontal leaves, although this may be partially counteracted if the pesticide residue collects in the leaf axils (2).

A further discussion of leaf angle and light competition follows in the section on stand structure and light relations.

Stand Structure and Light Relations

In a grass stand where nutrients and water are supplied in ample quantities, the growth rate will be dependent upon the temperature, light, and genetic composition. Because temperature conditions are not limited in quantity, light becomes the sole limiting factor for which there is competition in a stand of a certain genetic composition (16,79, pp.191-192). In the initial stages of stand development after planting, light is usually available in greater quantities than needed. A great deal of the light penetrates
through the canopy to the ground, and a definite light-saturation point occurs (50). As plants grow and develop more leaves, a greater proportion of the incident light is intercepted by the canopy, eventually leading to severe competition for light among the plants as well as among leaves on a plant (17. pp.83-85;79, p.210). As the stand reaches maturity, the lower leaves are forced to import carbohydrates from other plant parts or die, and an equilibrium between leaf emergence and leaf death is established (9, p.188;79, p.210). In addition to being shaded by the upper leaves, the older leaves experience a physiological decline in their photosynthetic capability with age, even if shading is not occurring (32). To further compound the light deficiency occurring in lower parts of the canopy, horizontal leaves located at the top of the stand intercept more light then would be intercepted by vertical leaves. These upper leaves are thereby light saturated and are wasting light energy which could be utilized by the lower leaves (56). This results in a large portion of the light being intercepted in the uppermost few centimeters of the plant canopy (76).

Contrasting views on light competition in shaded stands of grasses exists among researchers. Bean (8) feels that decreasing the light intensity will also decrease the growth rate and tiller production, thereby decreasing competition. However, because leaves are able to adapt their photosynthetic apparatus to be more efficient at low light intensity-
ties, Donald (17, pp. 83-85) feels that plants grown in shade compete for light as acutely as those grown in full sun.

Another effect of light competition is its influence on tiller production. By using wheat plants grown in separate tubes so the roots could be exposed to non-limiting amounts of nutrients and water, Puckridge (59) varied the spacing (plant density) between the plants to demonstrate that at high densities a minimum number of tillers are produced. Shading of the lower and basal regions of a tiller has been shown to depress the tillering rate over that of an overall shading (49).

When measuring the relative efficiency of photosynthesis per unit of incoming sunlight, Pendleton, Smith, Winter, and Johnson (57) found that the efficiency of sunlight utilization steadily increased as the leaf angle decreased. Kriedeman, Neales, and Ashton (39) found the rate of photosynthesis of a leaf to be proportional to the cosine of the angle of incidence of directional illumination. For example, when the sun is at the zenith, the photosynthesis rate was minimum with upright leaves, increasing to full potential with prostrate leaves. The rate of photosynthesis and the efficiency of photosynthesis should not be confused. As a leaf becomes more upright, the efficiency of photosynthesis increases since light saturation is lessened, however illumination per unit leaf area is lower resulting in a lower photosynthetic rate.
An interesting relationship exists regarding light utilization between leaf area and leaf angle. The quantity of sunlit foliage is dependent upon the total leaf area, the leaf angle, and the angle of illumination (70). When leaves are upright, an exceedingly high leaf area is required to intercept 95 percent of the incoming light. As the leaf angle widens, a smaller leaf area is necessary for 95 percent interception (56). Yield, or net photosynthesis, and leaf angle have been found to have either a negative or no correlation at low leaf areas (plant densities). As the leaf area increases, upright leaves result in increased photosynthetic rate and dry matter accumulation for a stand (29, 46, 56, 77). Loomis and Williams (46) concluded that, "the hypothesis that erect leaves should confer tolerance to crowding is widely accepted."

Leaf Dimensions

Environmental factors and external stresses which affect the growth of a grass plant often influence its leaf blade dimensions. Perhaps the strongest influence on leaf dimensions is imposed by interplant competition resulting from high tiller densities. For example, there is a highly significant negative correlation of leaf width with tiller density of grass (6).

In addition to the tiller density, the leaf width has been shown to vary with the cultivar (10), where taller
growing cultivars tend to have narrower leaves (52). Conversely, cultivars with wide leaf angles tend to have wide leaf widths (10).

Light also has a profound effect on leaf dimensions. As the light intensity increases, both the leaf angle and leaf width increase (74). In addition to light intensity, the photoperiod influences leaf dimensions (66). Beard (9,p. 185) has observed that both leaf length and leaf width increase with increasing daylength.

The leaf dimensions also vary with the number of leaves per tiller. Although there is a significant positive correlation of leaf number with leaf length, no relationship exists between the number of leaves per tiller and leaf width (52).

When cut in cross section, the blade of Kentucky bluegrass shows a characteristic 'vee' shape. The angle of this 'vee,' hereafter referred to as the leaf-fold angle, varies with the turgor pressure of the plant. An inward folding of the leaf is noted (narrower leaf-fold angle) when turgor pressure drops during drought conditions (71).
In light of the foregoing information on some physical characteristics of Kentucky bluegrass, the following experimental objectives were formulated:

1) to determine the influence exerted by cutting height, fungicide application, bluegrass variety, and tiller density induced by seeding rate, on several physical characteristics of the Kentucky bluegrass plant grown under turfgrass conditions,

2) to develop and evaluate techniques for the measurement of bluegrass plant dimensions and stand density,

3) to examine the factors affecting bluegrass leaf angle, including,
   a) the effect of leaf age on leaf angle,
   b) which leaf provides the greatest angular differences among the seeding rates and varieties tested,
   c) whether the first and third leaf angles confound the use of the second leaf angle alone (see Sheffer (62)),
   d) if leaf angle #1 may yield seeding rate and varietal differences with the influence of the budleaf removed,

4) to evaluate the influence of stand age on several physical characteristics,
5) to examine the distribution of observations of several physical characteristic variables to determine if they are influenced by unaccounted factors,

6) to test the hypothesis by Winter and Ohlrogge (77) that populations with high LAI's (or population densities) tend to be mutually exclusive with those having wide leaf angles, under turfgrass conditions,

7) to estimate whether light is a limiting factor in very dense turf stands, where fertility, disease, and water are not limiting,

8) to test the hypothesis by Madison (47) that disease is the primary limiting factor in densely planted turf stands, and,

9) to provide recommendations for proper seeding rates of Kentucky bluegrass under a variety of conditions.
Design of Experiment

Factors. Since the height of cut has an obvious effect on the dimensions of a bluegrass plant, it was therefore advantageous to include it as a factor in the experiment. A low height of cut would subject the plants to a maximum stress, thereby inducing maximum differences in plant form under other factors. Two cutting heights were used: 1.3 cm (1/2 in) and 2.5 cm (1 in). These heights are characteristic of intensely managed turfgrass as that of a golf course fairway.

Casual field observation have revealed that fungicides seem to alter the appearance of a stand long after application. This change of appearance, whether from a change in plant form or tiller density, was examined by a fungicide treatment variable.

In addition to cutting height, a factor with, perhaps, equal or greater influence on plant form is that of tiller density. Different tiller densities were induced by various seeding rates. To avoid the error resulting from differences in seed weight, purity, and germination, planting rates were calculated on the basis of pure-live seed (PLS) count per unit area. Hence, all varieties could be established at theoretically equal seedling densities. A rate of 194 PLS per dm² (1800 PLS per ft²) was selected as a near optimum seeding rate, which roughly corresponded to 0.9 kg
of seed per 100 m$^2$ (1.8 lbs per 1000 ft$^2$). Rates of 65, 388, and 1033 PLS per dm$^2$ (600, 3600, and 9600 PLS per ft$^2$) were also used. The highest rate was of particular interest for demonstrating the effects of extreme density on plant dimensions and competition.

Since little is known of many of the physical characteristics of the improved bluegrasses, a variety factor was included. Newport was used for comparison to an older bluegrass. Warren's A-34, Baron, Bonnieblue, Newport, and Pennstar were the five varieties, selected on the basis of color, texture, growth habit, density, and high rate of apomixis.

Experimental design. Practical considerations often necessitate the use of certain experimental designs. To enable the cutting heights to be in large, easily mowed blocks, a split-plot design was required. The cutting height factor constituted the main plots. Further subdivision into a split-split-plot design made block application of fungicides possible. The fungicide factor constituted the sub-plots. The convenience of arrangement into main, sub-, and sub-sub-plots required the sacrificing of some precision in the cutting height and fungicide factors. This, however, was acceptable because

a) to some extent, the influence of these factors was already known,
b) the planting rate and variety factors were of primary concern (the cutting height and fungicide factors were included to broaden the scope of inference of the experiment),

c) by sacrificing precision in the cutting height and fungicide factors, an increase in precision resulted for the variety and rate factors.

Because of the large number of error degrees of freedom available through replicate x treatment interaction, only two replications of the experiment were required.

During analysis in all sections of this research, the 5% level of significance was used unless expressly noted otherwise.

**Pure Live Seeds per Kilogram**

The following formula was used in calculation of the seed required for each plot, given the three measured parameters of each variety.

\[
\text{Seed per plot (g)} = \frac{\text{(desired PLS/dm}^2\text{)(area of plot in dm}^2\text{)}}{\text{(no. seeds/gram)(% germin.)(% purity)}}
\]

A referee testing of the percent purity and germination for each of the five varieties was done at The Bureau of Plant Industry, Seed Laboratory, in Harrisburg, Pa.

To determine the number of seeds per kilogram, six samples of 1000 seeds each from each variety were counted using
an Agricultural Specialty Company Model 2080 seed-counting machine, and weighed to the nearest milligram. These weights per 1000 seeds were then converted to seeds per kilogram.

To assess differences in the number of seeds per kilogram among the varieties used, a completely randomized design analysis of variance was used. Duncan's multiple range test was utilized for mean separation. For comparison of the measured number of seeds per kilogram to an earlier established figure, a t-test was run on each variety against the published value of 4,800,000 seeds per kg (3,73).

Establishment

Prior to establishment of this test, hereafter referred to as the bluegrass seeding rates test, at the Penn State Joseph Valentine Turfgrass Research Center, the Hagerstown silt loam soil at the plot site was sampled to a depth of 5 - 8 cm and tested at the Penn State Soil Testing Laboratory. The results indicated a pH of 7.7, and a need for phosphorus and potassium. A rate of 6.7 kg per 100 m² (13.8 lbs per 1000 ft²) of 0-25-25 fertilizer was applied to the plot area per the soil test recommendation, and incorporated by rototillage. The area was then raked, dragged smooth, watered, and firmed with a cultipacker. A starter fertilizer of 0.7 kg N per 100 m² (1.5 lbs N per 1000 ft²) from 16-24-8 fertilizer was applied and surface raked. The nitrogen source
was sulfur-coated urea, with approximately half of the nitrogen water insoluble. The area had been fallow for several years and no soil fumigation or pre-plant herbicides were used.

The seed required for each plot was calculated for the desired rate and variety, and weighed. Those plots receiving fungicide treatment also received a seed treatment. Equal quantities of fungicide were added to the seed designated for the fungicide plots, at an equivalent rate to provide 61 g per 100 m² of Actidione-Thiram (2 oz per 1000 ft²), plus 122 g per 100 m² of Tersan SP (4 oz per 1000 ft²) in a 1.2 by 1.8 m (4 by 6 ft) plot. In addition, 25 g of autoclaved bluegrass seed was added to the seed of the 65, 194, and 388 PLS per dm² rates to serve as diluent for a more uniform seed application. The fungicide, diluent, and seed were thoroughly mixed prior to seeding each plot.

On May 12, 1977, the 160 plots were hand-seeded with shaker jars within the confines of a plot box to curtail wind effects. The 0.3 m (1 ft) borders between individual plots were seeded to Pennfine ryegrass, to enable easy recognition of individual bluegrass plots at a later time. The perimeter of the plot area was seeded to Kentucky bluegrass cultivar K-150A. The seedbed was then lightly raked, rolled, and Soil-Gard mulch, at a rate of 6 liters per 100 m² (1.5 gal per 1000 ft²), was applied to ensure minimum seed movement. After allowing this to dry, the area was
The seedbed was kept moist by irrigation for about three weeks until the seedlings were in the 2 - 3 leaf stage. During hot weather, irrigation was minimized to avoid damping-off.

**Maintenance**

Throughout the summer, the plots were irrigated when needed to prevent moisture stress and competition for water. Similarly, fertilizer was applied (Appendix 2) whenever the turf became off-color, to minimize competition for nutrients. The fungicide plots were sprayed at approximately two-week intervals, or as dictated by specific disease problems. All of the fungicides, except the last spraying of the season, were contact-protectant types (Appendix 1).

One month after planting, the plots were mowed for the first time to a height of 2.5 cm (1 in). Throughout the first growing season, the area was mowed thrice weekly using a walk-behind power, reel mower. Clippings were removed to provide less litter in the turf, thus facilitating easier identification and removal of tillers. During the three weeks following the first mowing, the height of cut was gradually lowered to 1.3 cm (1/2 in) on half the plot area. After the first season, the area was clipped thrice weekly with a triplex mower and the clippings were not removed.
Since soil fumigation and pre-plant herbicides were not used, many broad-leaf weeds emerged with the stand. At two weeks after planting, bromoxynil was sprayed at 1.4 g a.i. per 100 m² (1/8 lb a.i. per acre) in 3.6 liters of water (38 gal per acre) as recommended by Shelly (63). Although the majority of the weeds were controlled, some tough-to-control weeds remained. A week later, a double rate of bromoxynil was applied. The control of the remaining weeds was complete and was safely achieved sooner than possible with phenoxyl-herbicides.

The grassy weeds were annual bluegrass (*Poa annua* L.), crabgrass (*Digitaria ischaemum* (Schreb.) Muhl.), and Pennfine ryegrass (*Lolium perenne* L., var. Pennfine) that washed from surrounding borders. The crabgrass was successfully hand-rogued; however, roguing of the ryegrass was almost futile. Later in the season, in plots with low bluegrass seeding rates, the ryegrass began to overtake the bluegrass. This dilemma was overcome when most of the ryegrass in the plot area was winter-killed during the first winter. Although roguing of the *P. annua* was not attempted, an application of benefin (2.5G formulation) in mid-August of 1977, at 25 g a.i. per 100 m² helped prevent the fall germination of *P. annua*. To prevent germination of crabgrass after the first season, siduron was applied at a rate of 120 g a.i. per 100 m² on May 25, 1978.
**Percent Ground Cover**

Throughout the growing season after planting the bluegrass seeding rates test, visual estimates of the percent of ground covered by green foliage were recorded at regular intervals. The plots were rated 26 times throughout the season from 10 days after planting, the first day seedling emergence was noted, until 131 days after planting, when most of the plots had complete foliage cover. The changes in percent ground cover with time were of interest more from a demonstrative standpoint than an analytical one. Graphs drawn from the data provide sufficient information on ground cover changes over time with varieties and seeding rates. The difference in ground cover over time, the slope of the ground-cover curve, and transformed slope were calculated for 5 selected time intervals for the varieties and seeding rates. The transformed slope was calculated in the same manner as van der Plank's (69) compound interest infection rate (r-value). Since a disease progress curve and a percent ground cover curve are related both in appearance and theory, this transformation was used to show the rate of change in ground cover, taking into account differences in initial coverage plus the non-linearity of the curve. The meaning of the r-value will be discussed in greater detail in the results section.
Population Counts

At four intervals during the course of the experiment, tiller density counts were made using two techniques. As well as providing information on the changes in plant density with time over rates, varieties, cutting heights, and fungicide, plus determination of field survival, these density readings were useful as references when physical characteristics were measured throughout the season.

The May 25, 1977, tiller count (13 days after planting) employed a different technique than the subsequent counts. A wire grid with 2.5-cm squares was constructed and laid upon each plot. Two close-up, black-and-white, print photographs, each containing at least 20 grid squares, were taken at two randomly selected areas within each plot. After development, the photographs were examined under magnification and ten squares were selected at random from the two photographs of each plot. The number of blades per square was counted and recorded. Since blades rather than tillers were counted, it was important to know what proportion of the population possessed more than one blade per tiller. From 10 to 70 tillers were randomly selected from each of the 20 plots representing all rate and variety combinations. The percentage of tillers with more than one blade (including the budleaf) was recorded and evaluated.

Subsequent counts on July 22, 1977, November 2, 1977, and May 22, 1978, were direct tiller counts. A Noer Soil
Profile-Sampler with an inner dimension of 13 x 76 mm (0.5 x 3.0 in) was used for obtaining population samples. Three plugs were taken at random from each plot. Before counting, a standard for a minimum acceptable tiller was established: a green or half-green tiller possessing a sheath, budleaf, and one attached leaf. During counting, any ryegrass or annual bluegrass in the sample was discounted.

Preliminary analysis of the data indicated a heterogeneity of cell variance, where the variance increased with the mean, which is commonly encountered with enumeration data. A significant Bartlett’s test for homogeneity of variances (65, pp. 347-349) confirmed this. Figure 1 shows a computer-generated histogram of the raw data, that indicated a distribution which departs from normality. Therefore, a square-root transformation was performed on all data prior to analysis, and the means were retransformed (squared) following mean separation. For calculation of field survival from the May 25, 1977, count, retransformed means were compared to the PLS seeded rates, and a percent field survival of the pure live seed was calculated.

Sampling tool evaluation. Because of the small sampling size of the 13 x 76 mm (0.5 x 3 in) profile-sampler tool, and the absence of references of its previous use for this purpose in the literature, a brief evaluation was performed against several other popular sampling tools. An 850 cm² area of Merion Kentucky bluegrass turf, clipped at 2.5
Figure 1. Computer-generated histogram of untransformed blade counts, converted to blades per square decimeter, demonstrating an abnormal distribution curve, measured two weeks after planting.
cm, was cut and removed, and two of each of the following size plugs were removed from within it:

- 35 mm (1 3/8 in) round
- 13 x 76 mm (0.5 x 3 in) rectangular
- 51 mm (2 in) round
- 102 mm (4 in) round

For each of the plugs, the loose and the intact tillers were counted separately. Then, all of the tillers within the 850 cm² area were totalled.

Since this evaluation was not intended as a critical test of the various sizes but merely to see if the 13 x 76 mm samples were yielding representative results, a simple analysis was made consisting of the percent deviation, standard error, and coefficient of variation for intact, and the sum of loose and intact, tillers per dm² equivalent.

**Loose vs. intact tillers.** The plugs produced by the 13 x 76 mm sampling tool contained a number of loose, 'unattached' tillers. Since a loose tiller was one which was leaning into the sampled area, an analysis of the percent loose tillers would presumably indicate which factors contribute to nonvertical tiller orientation.

The loose tillers per plug were counted in the fungicide-check plots of one replicate using all variety x seeding rate x cutting height combinations during the 12-month tiller density count. These counts were then converted to the percentage of loose tillers per plug and were analyzed.
as a factorial design with the sampling error used as the error term. Duncan's multiple range test was used for mean separation.

Density preference ratings. During the six- and twelve-month population counts, the plots were visually rated for an overall density estimate of the stand. The purpose of this rating was to group the plots into three categories on the basis of their overall density appearance at the time of rating and to relate these rating categories to the initial planting rates and the actual tiller densities at the time of rating. The plots were rated as, (a) too thick, (b) acceptable, or, (c) too thin, in regard to their overall visual density appearance.

Leaf Angle Measurement

To gain an accurate understanding of how the leaf angle changes under the influence of cutting height, fungicide treatment, seeding rate, and variety, it was desired to measure the first, second, and third leaf angles to an increment of 1 degree. Leaf angles were measured from the sheath-budleaf axis which, for the purposes of this experiment, was assumed to exhibit vertical orientation. Field observation has shown that this supposition is not always true, especially at low tiller densities. Two measurements were made on each leaf, to remove the influence of leaf curvature and tapering. The internal angle was measured at the
leaf crotch, at the junction of the adaxial leaf surface with the adjacent surface of the sheath or budleaf. The external angle was measured from the abaxial leaf surface to the opposite side of the sheath-budleaf axis (Figure 2-a). Since few angles were anticipated in excess of 90 degrees, such angles when encountered were recorded as 90 degrees. Unfortunately, more of these very wide angles were encountered than expected, and the practice of recording them as 90 degrees proved disadvantageous.

**Angle measurement technique.** Measurement of the influence of the aforementioned factors on leaf angle was done on August 15 - 24, 1977. A 5-cm diameter plug was randomly sampled from each plot in a manner so as to avoid crushing the tillers and changing the actual leaf angles. The plug was transported, on a tray containing water to prevent loss of turgor and possible change in leaf angle, to a workroom adjacent to the plots. Five tillers were randomly selected and removed from each plug with tweezers. To enlarge the image of the tiller to a size suitable for easy measurement to the nearest degree, an ordinary overhead (transparency) projector was used. Each tiller was inserted into a metal paper-clasp mounted on the projector so that the plane of its leaves was parallel to and about 1 cm above the projector surface. This elevation was necessary to facilitate readjustments of some tillers with leaves skewed from the normal leaf plane, so that the leaf being measured was par-
Figure 2. Measurement of internal and external leaf angles from the budleaf axis and the sheath axis demonstrating the removal of leaf-curvature effect.
allel to the projector surface. Approximately 4 meters from
the projector a mirror was mounted on a stand at a 45 degree
angle, to reflect the tiller image onto a horizontal table
surface, as shown in Figure 3. A specially designed pro-
tractor was used as the screen for the projection. This
protractor had a white surface (about 0.6 m square) with a
plexiglass needle freely rotatable about a central point.
The projected leaf angle image was measured on the upper
half of the protractor and its angle in degrees was read on
the lower half. Especially at the higher cutting height,
curved leaves were encountered, making it necessary to
obtain an angle reading as close as possible to the sheath
(see Figure 2-b). The budleaf length, sheath width, fre-
quency of leaf-cut, number of brown, half-brown, and green
leaves per tiller, and tiller size rating were recorded con-
currently for examination of their interrelationships with
leaf angle. Specifics of their measurement will be covered
in following sections.

A split-split plot design analysis of variance (7) fol-
lowed by Duncan's multiple range mean separation test (65)
was performed on the data. Kramer's adjustment (37) was
used with Duncan's mean separations of unequal numbers, when
needed on these and subsequent analyses herein. An analysis
was run for each angle, for a composite of all three angles,
by seeding rate, and with a \((1 - \cos(\text{angle}))\) transfor-
mation for an estimate of relative photosynthesis rate, as
described by Kriedeman, Neales, and Ashton (39).
Figure 3. Diagram of apparatus used for measurement of leaf angle.
Normality and tiller origin. As a means of determining whether leaf angle is under the influence of other unacounted factors (tiller age and origin, for example), a normality test was undertaken to determine if the population was unimodal (normally distributed) or multimodal (indicating the possible influence of tiller origin, etc.). On June 30, 1977, 196 tillers were randomly selected and removed from the K-150A bluegrass border area at the 2.5 cm height of cut, and measured using the technique previously outlined. Because, as mentioned earlier, observations over 90 degrees were recorded as 90 degrees, these values were not included in the normality determination to avoid misinterpretation resulting from an accumulation of observations at 90 degrees. Three tests of fit to a normal distribution were used:

a) Chi-square goodness-of-fit test to a normal distribution (65, p. 349-350),
b) Fisher's G-statistics for symmetry (G1) and normality (G2) (23, pp. 52-54),
c) Kolmogorov-Smirnov test for goodness of fit to a normal distribution (54, pp. 471-472).

Stand age. As a comparison of an older, established bluegrass stand with the 2-month-old stand used in normality testing, twenty tillers were randomly removed on July 20, 1977, from a 1972 planting of K-150A bluegrass also reel cut at 2.5 cm. An unpaired t-test for unequal numbers was performed between the variables in the two age groups.
Technique precision determination. To assess the precision of the leaf angle measurement technique and locate sources of error, a precision determination was run on July 15, 1977. Ten tillers were removed from the K-150A border at the 2.5 cm height of cut in the manner previously described. Each of the 10 tillers was mounted on the projector and its leaf angles, budleaf length, and sheath width were measured. The mounting and measuring was then repeated two more times using the same 10 tillers. Using the tillers as 10 levels of a factor, a one-way analysis of variance was performed on the data. A coefficient of variation (CV) and standard error (SE) were calculated for both tillers and measurements. The mean, the $r^2$ (representing the fraction of total variation attributable to differences among tillers), and an F-test of whether the differences among tillers were significantly greater than the differences among measurements, were calculated. The data of the 10 tillers were then divided into two groups of 5 each, depending upon their ease or difficulty of measurement, and reanalyzed as just described.

Leaf and Sheath Characteristics

Experience has indicated that other factors may contribute to the 'thickness' of a turf stand besides just tiller density. Such factors are undoubtedly expressed as differences in leaf and sheath dimensions. The study of
these characteristics may also yield information on the leaf area index (LAI) of bluegrass and the amount of area occupied by a bluegrass plant. Tiller density was concurrently measured whenever each of these characteristics was measured to observe their interaction.

A split-split plot design analysis of variance and Duncan's multiple range test were used to analyze the results of the following characteristics, unless noted otherwise.

**Budleaf length.** Budleaf length was primarily of interest because of its influence on the angle of the first leaf. It was hypothesized that as a new budleaf emerges from the sheath and elongates, the angle of the first leaf widens from zero to its mature width. A non-linear regression analysis was performed on the effect of budleaf length on the first leaf angle, which was concurrently measured.

Using the same projection technique as used with leaf angle measurement, it was possible to measure the extension of the budleaf above the crotch of the first leaf to the nearest 0.1 mm. Because some budleaves were cut and some uncut, a source of error was anticipated. Further, because the measuring process required several days to complete, and the turf was mowed every other day, a note was made as to whether the turf was clipped the day of measurement or the day before, for a subsequent analysis using an unpaired t-test.
Sheath width. Whenever the leaf angle was measured, the sheath width was also recorded. In this study, the sheath area of bluegrass refers to the vertical axis of the shoot which supports the leaf blades. Using the projection technique, the sheath width was measured in the same plane as the leaves, at the crotch of the second leaf. Magnification allowed measurement to the nearest 0.1 mm.

Leaves per tiller. During the August 1977, leaf angle measurement, the number of leaves per tiller was counted. The leaves, excluding the budleaf, were classified into three groups:

a) green leaves -- fully or mostly green,

b) half-brown leaves -- greater than 50% brown, but some detectable green, and

c) brown leaves -- intact, undecomposed brown leaves clinging to the tiller.

Percent leaves cut. When recording the number of leaves per tiller or leaf length, a note was made of whether each leaf was cut. If the budleaf, first, second, or third leaf was cut, a '1' was recorded; a '0' was recorded if the leaf was uncut. Thus, the resulting mean of each leaf indicated the fraction of the leaves in a stand with cut ends. Data were analyzed by leaf, as well as a composite of all four leaves.

Leaf width. On November 16 - 18, 1977, a 5-cm diameter plug was randomly sampled from each plot in a manner so as
to avoid crushing and kept cool and moist until measurement. In an adjacent workroom, 20 - 30 leaves were bulk-clipped from each plug with scissors and scattered upon the projector surface. Grassy-weed blades present were identified and discarded. The projector provided a 20X magnification of the leaf image, which was reflected from a mirror and measured on a horizontal screen about 5 meters away. On the screen, 20 leaf widths were measured where the blade image crossed fixed lines on the screen. With actual measurement to the nearest mm, the magnification resulted in a measurement increment of 0.05 mm. The leaves were measured with their leaf fold intact, and the width measured reflects the area available for sunlight interception or, in other words, the width observed when looking down at a stand of grass.

Leaf-fold angle. Following the above width measurement, a preliminary investigation of leaf-fold angle of bluegrass was undertaken. Five leaves were randomly selected from a 5-cm diameter plug obtained from A-34, Baron, Bonnieblue, Newport, and Pennstar at the 1.3-cm cutting height, 194 PLS/dm² (1800 PLS/ft²) rate, and no fungicide application. The five leaves were placed side-by-side on the projector surface in an inverted-vee position. The widths were measured using the same technique described above. The folded width was measured within a minute after placing the blades on the projector to avoid leaf-fold angle changes resulting from the heat generated by the projector.
A weight consisting of three microscope slides was then placed upon the blades to compress and remove their leaf-fold angle. The leaf widths were again measured. Using the formula below, the leaf-fold angle was calculated from the two width measurements.

\[
\text{Leaf-fold Angle} = 180^\circ - 2 \times \arccos\left(\frac{\text{Uncompressed width}}{\text{Compressed width}}\right)
\]

A one-way analysis of variance and Duncan's multiple range test were used to analyze the data.

Using the same technique, a more extensive investigation of bluegrass leaf-fold angle was undertaken on June 1, 1978. Because of the time-consuming nature of this procedure, the fungicide-spray plots were omitted from measurement. Prior to, and during, measurement, the plot area was kept moist, and any sign of wilt was prevented with irrigation. One 5-cm plug was randomly sampled from each plot in a manner so as to avoid crushing of the plants, and 5 plugs at a time were placed in a bucket, containing 2 cm of water, for subsequent measurement. At the projector in an adjacent workroom, the leaves were bulk-clipped with scissors from the plug and 5 leaves were randomly selected and carefully placed in an inverted-vee position on the projector surface. After the folded width was measured, three microscope slides were placed atop the blades and a compressed width was measured. The leaf-fold angle was calcu-
lated per leaf as previously described. A split-plot analysis of variance (omitting the fungicide factor) and Duncan's multiple range test were used for data analysis.

**Leaf length.** Concurrent with the examination of leaf-fold angle, and using the same plugs, the leaf lengths were measured on June 1, 1978. Five tillers were randomly removed from each plug before the leaves were clipped for leaf-fold angle measurement. Each tiller was then placed on the projector surface and the budleaf, first, second, and third leaves were measured from the leaf crotch to the tip with a magnified increment of 0.1 mm. Concurrently, a record was made of whether each leaf was cut.

For the three mowings prior to leaf-length measurement, the plot area was clipped with a hand mower, which was carefully set for the two cutting heights. Then each day of measurement, the area was mowed.

A split-plot analysis of variance (omitting the fungicide factor) and Duncan's multiple range test were used for data analysis.

**Seedling stand height.** On May 25, 1977, two weeks after planting the seeding rates test, the height of the seedlings was measured. On the same day, the 'photograph' seedling count was taken and serves as a basis of reference. The height of the seedlings was measured with a simple device consisting of a plastic metric ruler with a movable indicator. The indicator was a 5.0 x 5.5 cm cellophane
sheet weighing 0.480 g with a slit in the center where the ruler fit. To measure seedling height, the end of the ruler was placed in the stand on the soil surface and the movable cellophane square was allowed to drop onto the top of the canopy where a reading in mm was taken. Forty plots were used, consisting of two sets of the twenty rate by variety combinations. Ten measurements were taken per plot, with a total of 20 observations per rate x variety combination. The data were analyzed using rates and varieties as two factors in a factorial analysis of variance, followed by Dun-can's multiple range test.