Engineering Properties and Maintenance of Golf Putting Greens

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Phase Two: Evaluation of Existing Greens

Introduction

The objective of the first phase of this research project was to apply engineering principles to the study of strength and stability in sand-textured root zones used for golf putting greens. In the second phase of this project, the primary objective is to evaluate existing golf putting greens and correlate their performance to basic engineering properties of soils and laboratory data. Load testing of established and newly constructed putting greens has allowed us to observe variations between greens and their relation to the engineering properties of the sand-textured root zones. The data generated from these field tests correlates with field data and provides a detailed picture of the properties necessary for stable golf putting greens.

Project Background

Literature Review

Bishop (1948) tested a full range of cohesionless soils, ranging from sands to gravels and sandy gravels, in shear box tests. Only two samples are of interest here, brasted sand which is a well graded sand of the Folkeston bed ($C_u = 2.5$) and Ham River sand which is a uniform sieved fraction from the Thames Valley gravels ($C_u = 1.3$). It was observed that in the plot of porosity versus friction angle, the curves of two samples were almost parallel. Due to lack of limiting porosities, the effect of C_u is not clear. Chen (1948) investigated the strength characteristics of cohesionless soils by using triaxial compression tests. He concluded that the friction angle of cohesionless soils increases with increasing uniformity coefficient.

Koerner (1970) studied the effect of gradation on the strength of cohesionless soils using three single mineral particles (quartz, feldspar and calcite). Gradation was evaluated by varying uniformity coefficient (C_u) from 1.25 to 5. The conclusions from his study suggest that C_u has little effect on the strength of cohesionless soils.

Zelsko et al. (1975) performed triaxial tests using sand materials mainly consisting of quartz grains and the range of C_u values is between 1.2 and 2.0. The similar conclusion with Koerner's study was made that improved gradations have a minor or no influence on ϕ.

In review, the results of sieve analysis for cohesionless soils are presented as grain-size distribution curves. The diameter in the grain-size distribution curve corresponding to 10 % finer is defined as the effective size D_{10} ; 60 % finer is D_{60} . Then, the uniformity coefficient C_u is given as : $C_u = D_{60} / D_{10}$. A higher value of C_u indicates the soil sample is well-graded. Previous studies provide conflicting results as to whether or not C_u has any impact on the strength of cohesionless soils.

Laboratory Testing

In order to ensure consistency of the variables that we dealt with in the laboratory, six sands were produced rather than selecting market sands. These sands were made from a commonly available construction sand (MDOT 2NS) which has a wide range of particle sizes. Three different gradations of sands were designed, a coarse, intermediate and fine. Each of these three classifications was again divided into a high coefficient of uniformity (C_u) and a low coefficient of uniformity (C_u). As Figure 1 shows, all six of these test sands were designed to meet the USGA guidelines for golf putting greens.

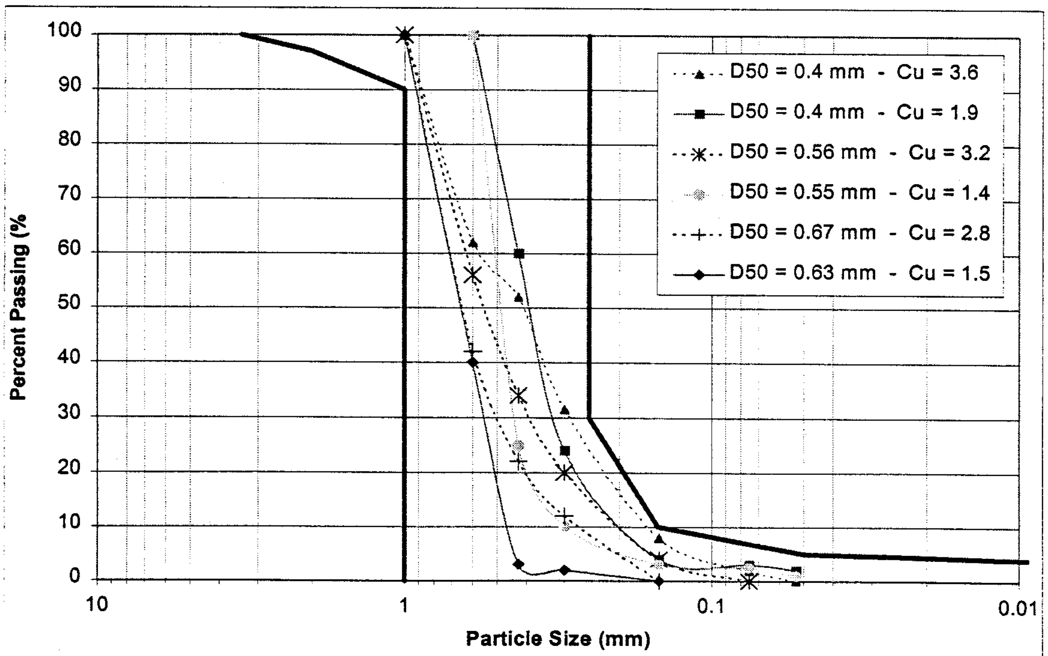

Figure 1: Laboratory Sands Meeting USGA Specifications

A direct measure of a soil's strength against failure under surface compressive load is its bearing capacity. This can be directly tested in the lab with the Modified California

Bearing Ratio (CBR) testing device (ASTM 1883). This device has a small plunger which is forced into a sample volume of sand. A load cell is attached to the plunger and records the force being used to push down on the soil sample. The depth the plunger has punctured into the soil can then be measured to determine the amount of force necessary to cause failure within a soil. Figure 2 indicates the pressure as a function of piston displacement. The peak of the test graph designates the ultimate pressure, which the soil can withstand before it fails. The bearing capacity test was run approximately 290 times on the sand samples under all types of conditions.

The bearing capacity tests also show the benefits of sands with a high coefficient of uniformity (C_u). As the graph shows, the well-graded sands were capable of withstanding an ultimate pressure on the order of 45 psi. The poorly graded sands under the same conditions could only withstand pressures up to 25 psi. This is below the tire pressure found in some golf course maintenance vehicles and indicates that a golf putting green may suffer deformation during normal servicing. It should be reiterated that although these sands display such a wide variety between their ultimate bearing capacities, they all fall within USGA gradation specifications and would be considered acceptable sands for golf putting green construction.

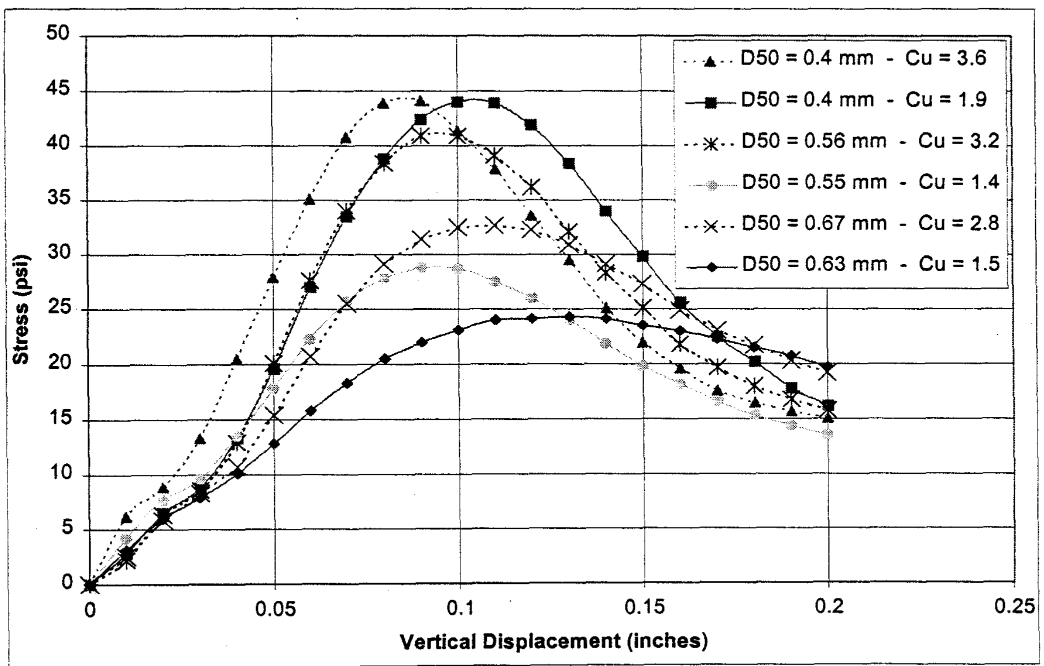

Figure 2: Bearing Capacity of Sands Meeting USGA Specifications

Field Testing

Field CBR Device

The field CBR device in Figure 3 is designed to model the California Bearing Ratio (CBR) testing device. The CBR device can be attached to a three-point hitch or loading bucket of most tractors. The device has a plunger which is forced into the ground. A load cell measures the force on the plunger directly. This force is recorded with the corresponding vertical displacement of the plunger into the ground, measured by a dial gauge on a reference beam.

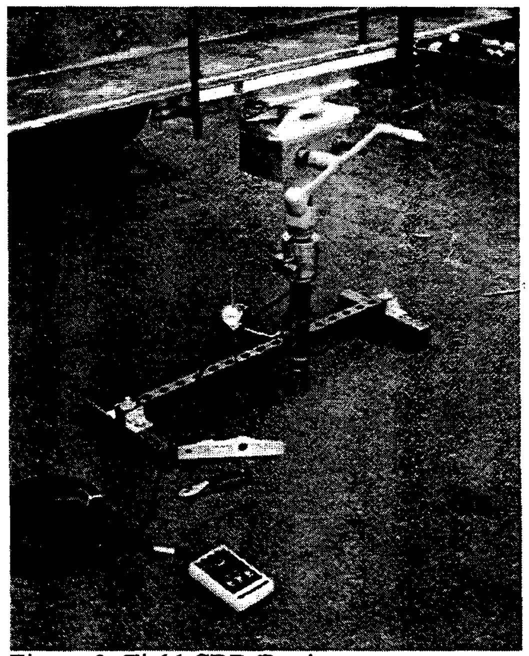

Figure 3: Field CBR Device

The force on the load piston measured by the load cell is divided by the area of the load piston gives us the stress on the surface of the putting green. This calculation is performed for every increment of vertical displacement. Force is recorded at every 0.01 inch of displacement for consistency. The stress at each 0.01 inch of displacement is plotted versus the vertical displacement as shown in Figure 4. The initial part of the curve, labeled A, is the stress on the thatch layer. It is obvious from the graph and common sense that the thatch offers little resistance to deformation. The portion of the graph labeled B is the stress on the underlying sand-based root zone. The underlying sand can take significantly more stress with less deformation than the overlying thatch as shown on this graph.

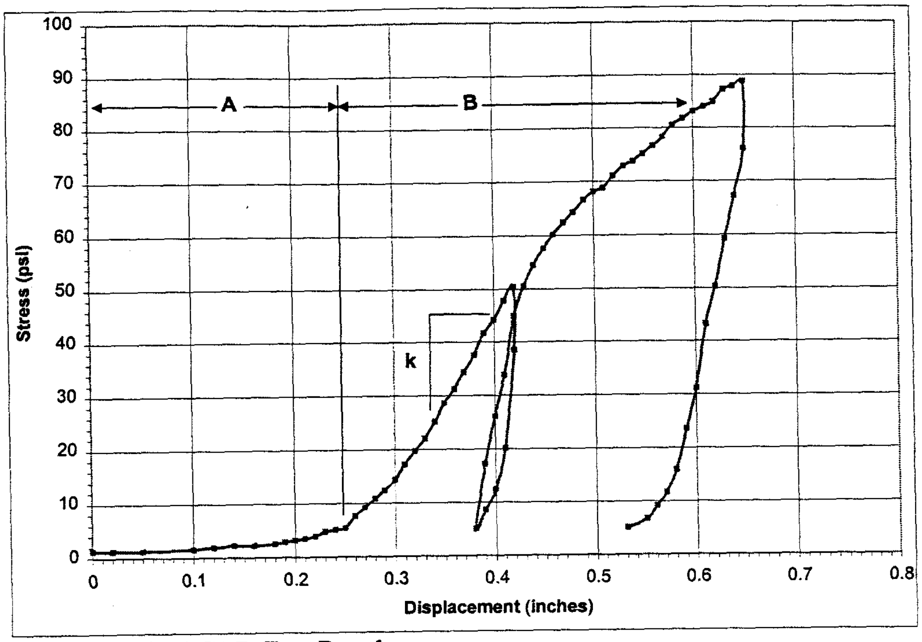

Figure 4: Field CBR Test Results

The slope of a line drawn tangent to the curve, k_s, is the stiffness of the green and is referred to in geotechinical engineering as the modulus of subgrade reaction. For example, a green with k_s of 100 pounds per square inch per inch would be displaced 0.10 inches under a load of 10 psi.

As the putting green is loaded and then unloaded, some consolidation of the thatch and sand occurs. In the example in Figure 4, the sand and thatch consolidated approximately 0.20 inches when subjected to a 50 pounds per square inch load. When reloaded, the stress – displacement curve will follow the same line back to 50 pounds per square inch stress since the thatch and sand have already 'felt' that stress. Beyond 50 pounds per square inch, the thatch and sand experience new, higher stresses, and will continue to consolidate until the sand begins to fail. Engineers often refer to the load and reload curve as an elastic rebound curve.

Modulus of Subgrade Reaction

The modulus of subgrade reaction was first introduced into applied mechanics by Winkler in 1867 and used by Zimmerman in 1888 to describe the response of railroad ballast under the load of individual railroad ties. The Winkler Model is described by the following relationship.

$$k_s = P/y$$

Where P is the stress on the subgrade (in our case, the putting green) and y is the vertical displacement measured under the load. The value of k_s depends on the elastic properties of the subgrade and on the dimensions of the area acted upon by the subgrade reaction. The value of k_s for loading areas less than 30 inches in diameter are considered to be constant and therefore work for our study. The modulus of subgrade reaction is similar to a spring constant and therefore, the golf putting green and soil can be modeled as a series of springs of infinite horizontal extent.

Typically, geotechnical engineers study soils at their failure conditions, governed by local shear strength (ϕ) and by general shear failure under a loaded area. Engineers use a factor of safety and limit the allowable load to a third or a quarter of the ultimate bearing capacity to be conservative in their design. Although we are interested in what soil properties contribute to increased bearing capacity, in this case we are more concerned about the behavior of the soil and golf putting green before failure. An advantage to modeling the golf putting green as a series of springs is that we can study the stiffness of the springs before a failure condition has been reached. Those greens with higher k_s have a higher stiffness and deflect less under a given load.

In phase one of this study, it was shown that ultimate bearing capacity increases with larger coefficient of uniformity and a decrease in the median and/or effective grain size. Initial testing also suggests that an increase in the coefficient of uniformity coincide with an increase in the stiffness of the soil. Figure 5 shows an increase with k_s with an increase in C_u. This may be in fact due to further interlocking of grains as the smaller grains fill the void space between the larger grains, increasing inter-particle friction which leads to higher ϕ and k_s. Figure 6 shows the stiffness of a number of sands as a function of median grain size. Although a linear regression line shows a moderate increase of stiffness with smaller median grain sizes, more data is necessary to confirm or invalidate this trend.

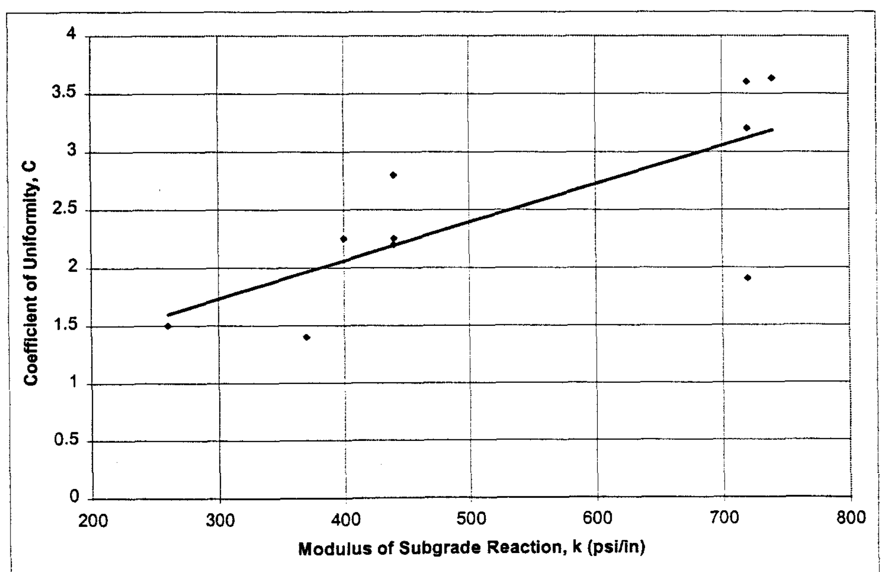

Figure 5: Coefficient of Uniformity and Modulus of Subgrade Reaction

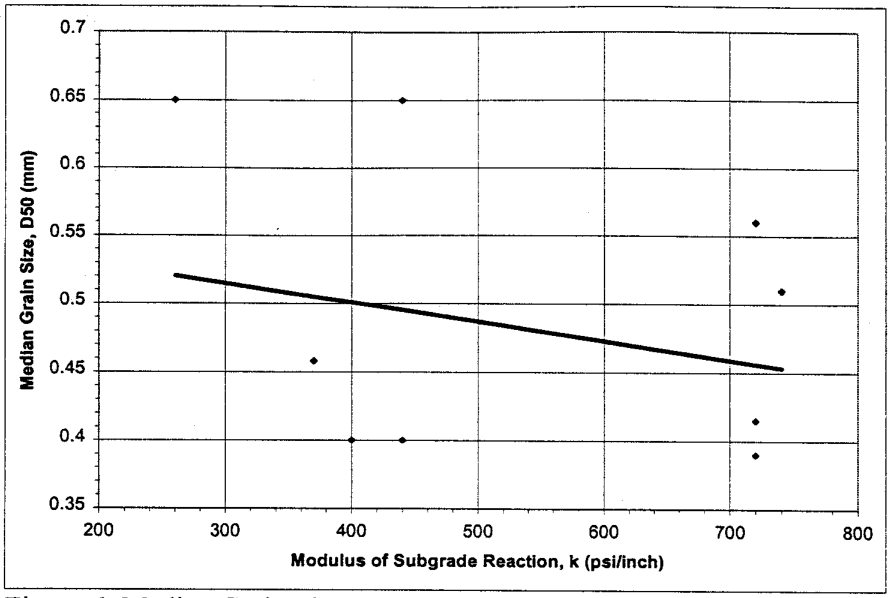

Figure 6: Median Grain Size and Modulus of Subgrade Reaction

A problem associated with testing existing golf putting greens to evaluate the stiffness of the sand root-zone is separating the contributing strength of the root system. Referring to Figure 7, it is clear that the same soil tested in the field with an established root system has significant reserve strength over the same sand tested with no turf. Regardless of where we evaluate the modulus of subgrade reaction in Figure 7, it is consistently greater than that of the sand measured in the laboratory. This suggests that the root system add strength and stiffness to the elastic and plastic properties of the root-zone sand. This additional strength and stiffness is most likely due to the tensile strength of the root system that reduces local shear failure within the root-zone sand.

When possible, golf putting greens have been tested several months after an initial test to evaluate the effect of growing season time on the stiffness characteristics of the putting green. Figure 8 shows a good example of two field tests separated by approximately three months. The slopes of the tangent lines are essentially parallel for both k_s and k_s'. This is typical of other field tests separated by the same time period and suggests that growing period have no effect on green stiffness, at least over a three-month period. Field tests were performed on a newly constructed putting green at the Hancock Turf Research Center at MSU before it was seeded and two months afterwards. The two-month old root system added significant stiffness of the root-zone sand as shown in Figure 9. This location should give us further insight into the effect of time on the stiffness contributed by the root structure.

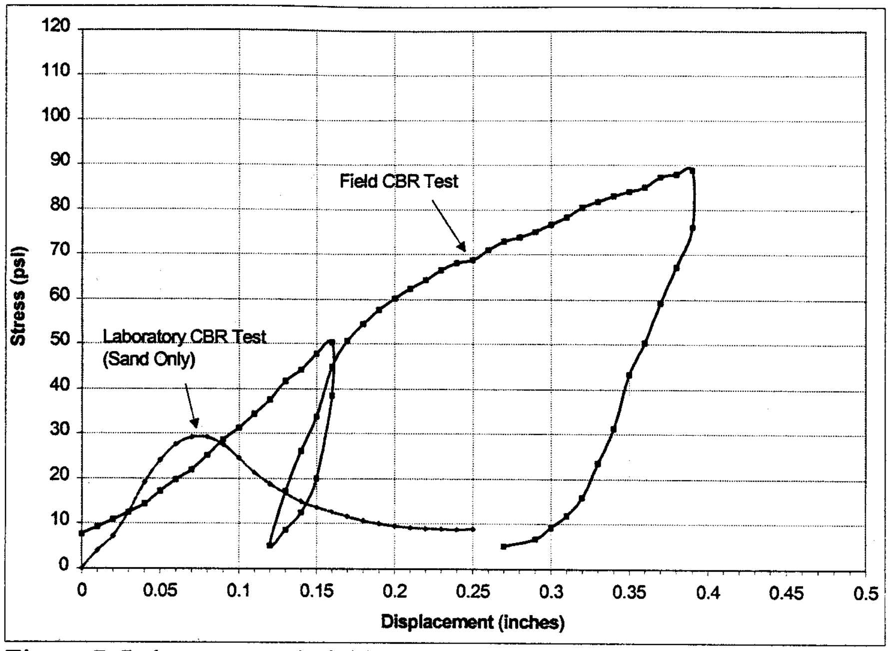

Figure 7: Laboratory and Field CBR Tests

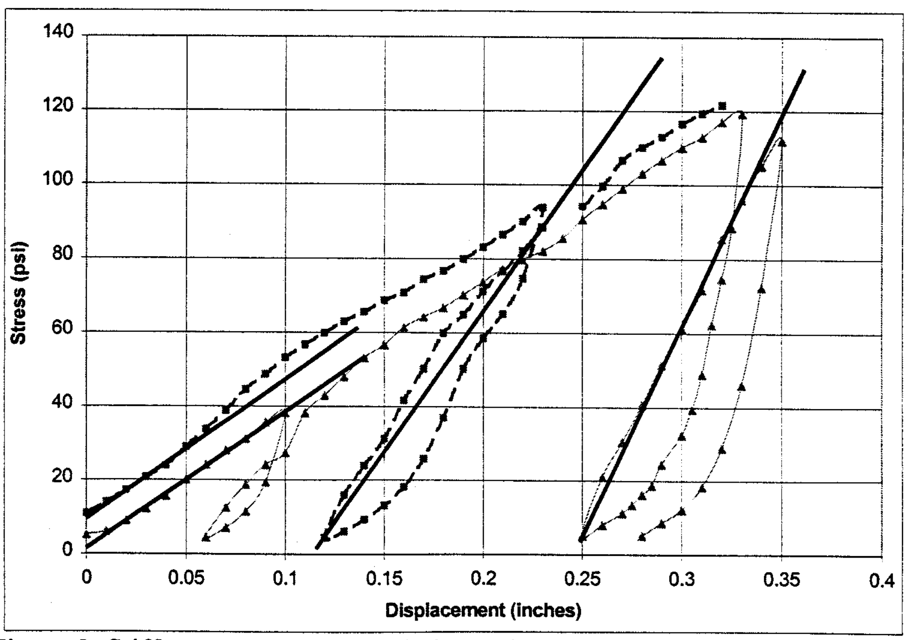

Figure 8: Stiffness as a Function of Time. Three Month Time Between Tests on Same Green

Findings

Initial findings suggest that golf putting greens can be modeled as an elastic spring that has some stiffness, k_s.. The stiffness, or modulus of subgrade reaction of the root-zone sand increases with higher coefficient of uniformity, C_u. The median grain size has no effect on the stiffness of the sand. Field tests show that the stiffness of the green is dependent on soil properties but it also has increased strength and stiffness due to tensile strength contributed by the root structure. The short-term growing season of established root-zones have no effect on the stiffness of the putting green.

Summary

The third year of research has allowed us to apply and expand on the following two years of research. Continued field-testing is supportive of previous findings. Putting green stiffness increases with sands that have higher coefficients of uniformity. Also, it has been shown the turfgrass roots add significant strength and stiffness to the root-zone sand. The short-term growing period of the root-zone apparently has little effect on green stiffness but long term testing may yield different results. Field-testing continues to show a wide variety of stiffness for putting greens constructed on sands that meet the USGA gradation guidelines. Further field testing will make it possible to apply statistical methods to results allowing us to predicted stiffness based on laboratory data within some degree of certainty. From this, we will develop guidelines that superintendents can utilize to design a sand mixture that will achieve desired results and still meet USGA guidelines.