# Engineering Properties and Maintenance of Golf Putting Greens

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**James R. Crum, John N. Rogers III, Thomas F. Wolff, Eldor A. Paul, Joseph M. Vargas, Jr, and Fred S. Warner**

**Michigan State University**

## Phase One: Engineering Properties

### INTRODUCTION

In the first phase of this research project, the primary objective is to apply engineering principles to the study of strength and stability in sand-textured root zones used for golf putting greens. In addition to completing of the literature review, the second year of study allowed us to expand the types of testing. Evaluation of the properties of the six test sands which were generated in the laboratory and designed to simulate possible mix ranges found in USGA specifications was continued. New constraints were incorporated into the testing procedures already in place. The data generated from the modified tests, along with the data previously collected, provided a more detailed picture of the properties crucial for strength and stability. The field testing portion of the study was also begun. This allowed us to compare laboratory test results with real world turf conditions. From this we will be able to begin creating guidelines for achieving desired soil strength.

### MATERIALS AND VARIABLES

In order to ensure consistency of the variables which 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 ($C_u$). These sands were then given five letter designations for easy clarification. The six sands therefore include $CGHC_u$, $CGLC_u$, $IGHC_u$, $IGLC_u$, $FGHC_u$, $FGLC_u$. The CG, IG or FG stands for either coarse graded, intermediate graded or fine graded. Those sands which have a wider distribution of particle sizes are designated as $HC_u$ which indicates a high coefficient of uniformity while the sands with a more consistent particle size are designated as $LC_u$ indicating a low coefficient of uniformity. As **Figure 1** shows, all six of these test sands were designed to meet the USGA guide lines for golf putting greens.

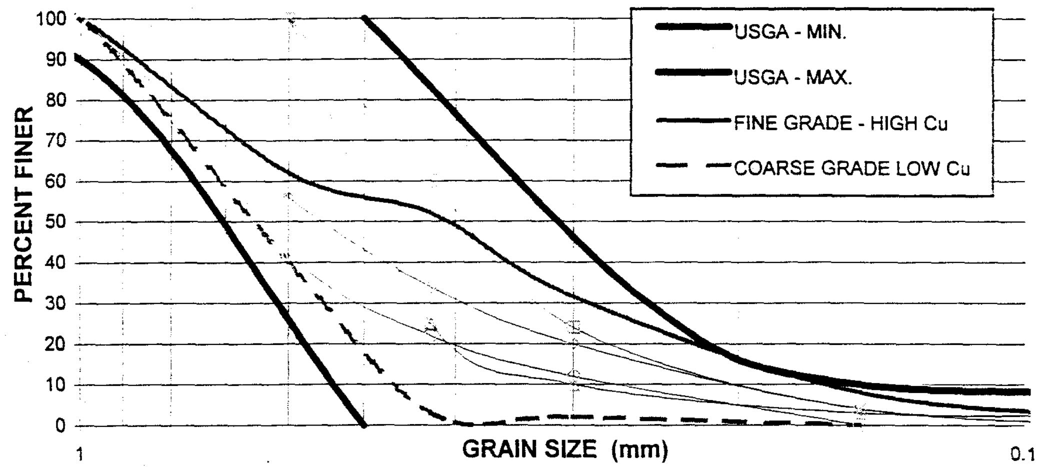


**Figure 1** - Experimental Sands within USGA Specifications

## LITERATURE REVIEW

### EFFECT OF GRAIN SIZE DISTRIBUTION

In general, 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.

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, varying from 26.5° for loose specimens of the well-rounded Ottawa sand to 51.5° for the well-graded gravel.

Koerner (1970) studied the effect of gradation on the strength of cohesionless soils using three single mineral particles (quartz, feldspar and clacite). Gradation was evaluated by varying uniformity coefficient ($C_u$) from 1.25 to 5. The quartz soils were tested in the saturated and air-dry conditions with both drained and undrained triaxial tests; the feldspar can calcite soils were tested under saturated state using drained triaxial tests. The conclusions from his study are as follows:

(1) The drained friciton angle ($\phi_d$) for saturated feldspar and calcite soils increase

with increasing value of $C_u$ ;

(2) The effect of $C_u$ on the drained friction angle ($\phi_d$) for both saturated and dry quartz soils is negligible ;

(3) $C_u$ does not affect the undrained friciton angle of quartz 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 influence on $\phi_d$ and no influence on $\phi_f$.

## LABORATORY TESTING: DIRECT SHEAR

The direct shear testing device (ASTM D3080) is used to measure the friction angle of a sand. This is done by placing a sample of the sand into a testing block. A shearing stress is then applied to the sample and it is allowed to fail on a horizontal plane. After a series of tests, the friction angle can be plotted and measured for each sand. The strength of a sand is determined by it's friction angle. Larger friction angles coincide with stronger sands. This test is appropriate when testing golf putting green strengths since loading on a golf putting green generates shear stresses and the friction angle determines the maximum shear stress that can be sustained. The direct shear testing performed in the past involved compacted and uncompacted dry sands. Although no putting green is built from dry sand, the testing was necessary to get a better understanding of the behavior of the sands under various controlable parameters.

This year the direct shear testing was extended to moist sands. Testing was performed on these samples under both compacted and uncompacted conditions. A total of over 80 direct shear tests were performed (the tests for each sand were replicated over 12 times) to determine an average value for the friction angle. The moist sands were prepared with a gravimet-

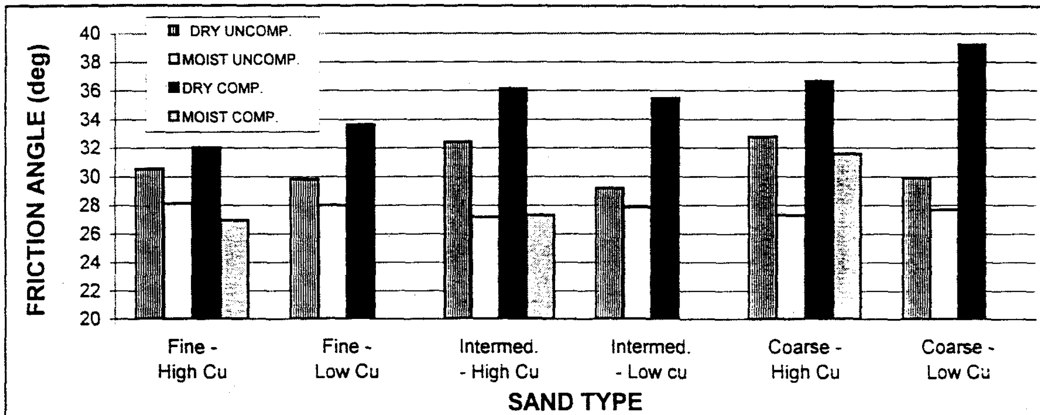


**Figure 2** - Failure Angles among Laboratory Test Sands

ric water content which corresponded to -0.04 Bars of matric potential. Results of all direct shear testing is summarized in **Figure 2** which compares each sands friction angle to the testing condition. These include moist and dry, compacted and uncompacted samples. The data indicates that the dry and compacted sands have the greatest friction angle. Therefore, those sands are the strongest against resisting shear failure. The moist sands, compacted and uncompacted, have lower friction angles than the compacted or uncompacted dry sands in every case.

## LABORATORY TESTING: BEARING CAPACITY

A more direct measure of a soils 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 3** indicates the pressure as a function of piston displacement. The ultimate pressure which the soil can withstand before it fails is designated by the peak of the test graph. The bearing capacity test was run approximately 290 times on the sand samples under all types of conditions. The trends of the bearing tests coincided quite closely with those from the direct shear tests. The sands prove to have higher strengths under dry conditions as opposed to moist. (All sands were compacted for the bearing tests)

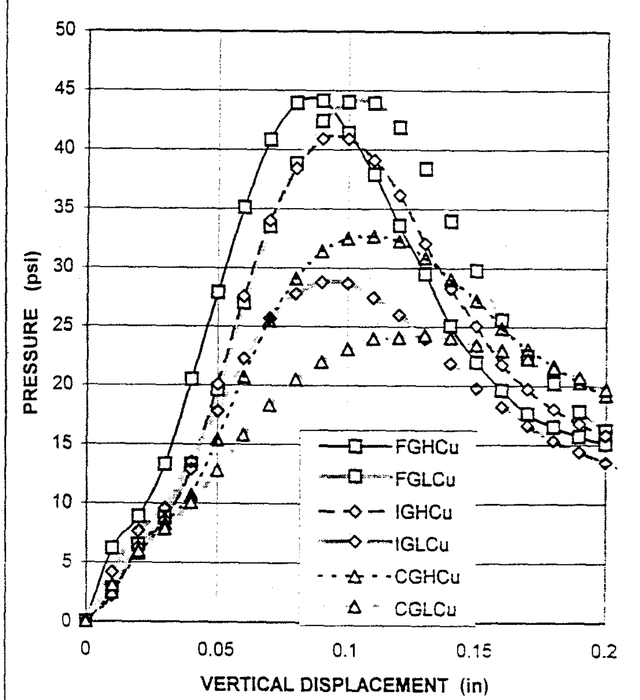


**Figure 3** - Laboratory Bearing Capacity Results

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.

## FIELD TESTING

In cooperation with the Michigan Turfgrass Foundation, the design and construction of the field testing device was completed this year. This allowed for the initiation of the field testing phase. The field testing device (See **Figure 4**) is designed to model the laboratory California Bearing Ratio (CBR) testing device. The field device is mounted to a three point hitch which can be found on the back of most tractors. The device has an adjustable diameter plunger which is forced into the ground. The load cell which is attached to the plunger measures the force which is being applied as the surface of the ground is penetrated. This force is recorded along with the corresponding vertical displacement which has taken place.

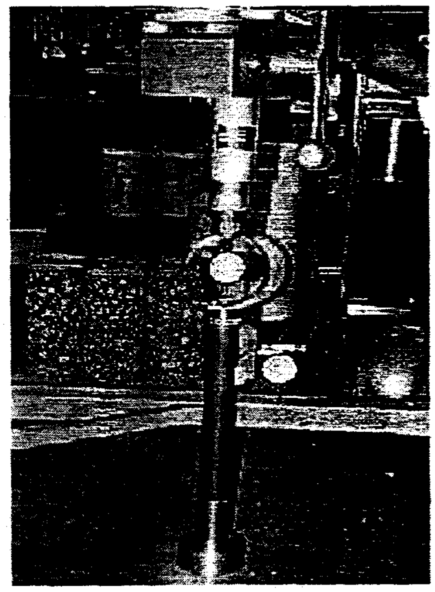
**Figure 4** - Field Testing Device

Initially the testing device was used on plots at MSU's Hancock Turf Research Center. Sample plots included USGA turf samples, Prescription Athletic Turf (PAT) and thin rye grass in native soils. These tests went well, so correspondence with golf courses and athletic field superintendents was begun to set up testing dates at other sites. The first off-campus test took place at Hillsdale College football field. The field was constructed with dune sand which is recognized for its uniformity of size and shape; the field has experienced problems with poor strength. The testing was completed in one day and went well. As expected, Hillsdale College's football field showed a lower ultimate bearing capacity than the other turf grass tests performed at the Hancock Research facility. **Figure 5** shows a comparison of some of the field testing which was done at the research facility, and the average of the tests performed at Hillsdale College. **Figure 5** also contains some of the laboratory tests which were run on the sample sand matrix and displayed in **Figure 3**. The graph clearly shows that the field tests have significantly higher bearing capacities than the laboratory sands. Another distinction between the laboratory and field tests is that the laboratory tests have a definite failure point were the curve peaks out and then begins to drop off. The field tests on the other hand, have an abrupt turn where they switch from a sharp rise to gradual slope. Both of these differences are apparently attributed to the root zone which is present in the field tests. The root zone increases the strength of the soil. It also helps to provide reserve strength after it has failed due to loading. Although the root zone is difficult to simulate in the laboratory environment, comparison of the two test procedures is still beneficial. Soil samples from the field test sights were analyzed to determine their soil gradation. From this a coefficient of

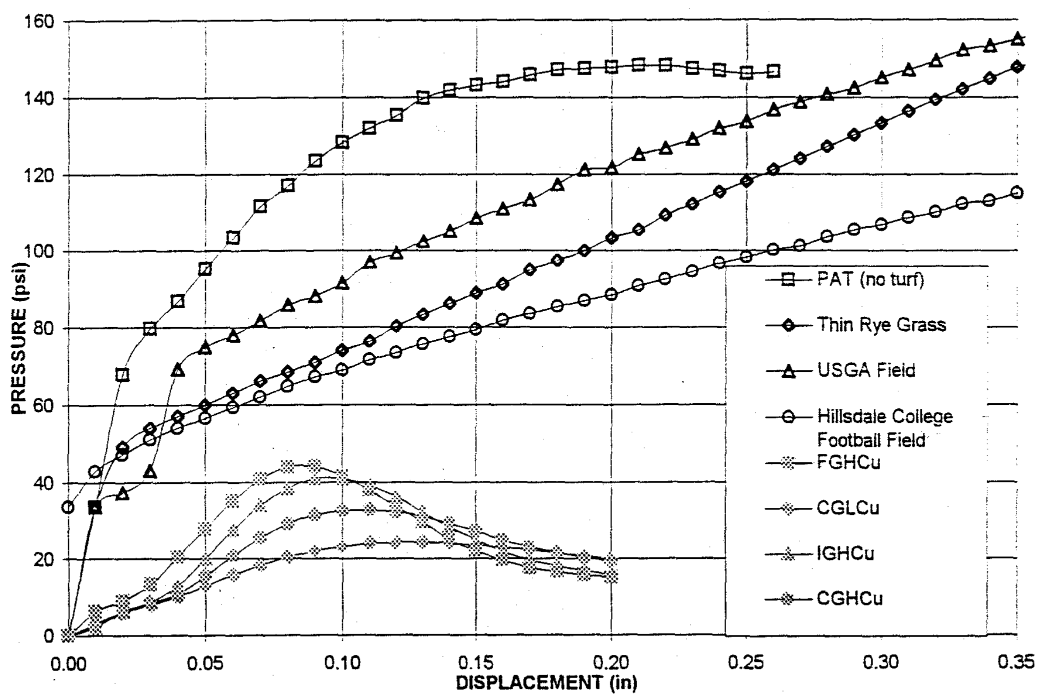


**Figure 5** - Bearing Capacity Results for Field Tests and Laboratory Tests

uniformity ($C_u$) and grain size ($D_{10}$) can be determined. ($D_{10}$ is commonly used in engineering classifications and represents the maximum diameter of soil particles from a particular mix which makes up the bottom 10% of the soil sizes) These values can then be compared with the sample sand which was developed for the laboratory tests. Field samples which were well graded or had a high coefficient of uniformity ($C_u$) performed better than those which were low. **Figure 6** shows the soil profile of two of the laboratory test sands from **Figure 1**, along with two of the field testing sites. It compares the percent of each particular grain size found within the mixture. The thick gray lines indicate the maximum and minimum acceptable gradations by the USGA. Comparison of **Figure 5** and **Figure 6** show that sands with

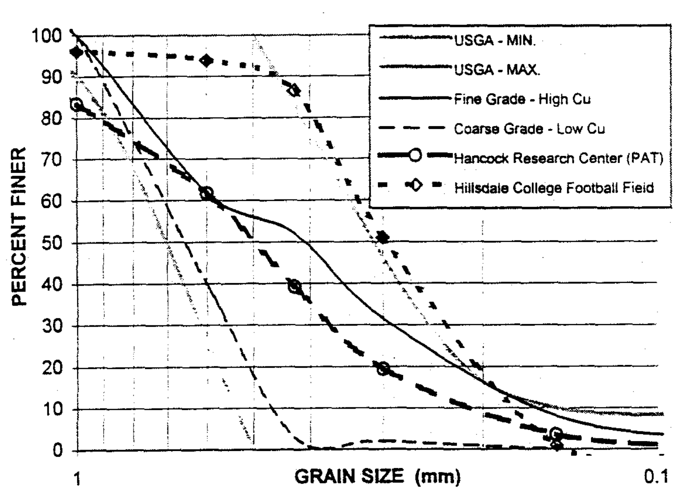


**Figure 6** - Field and Laboratory Gradations

a *high* coefficient of uniformity ($C_u$) and more *gradual* slope have a higher bearing capacity. Those sands with a *lower* coefficient of uniformity ($C_u$) and *steeper* slope, such as the Hillsdale College soil, produce a poorer bearing capacity. This verifies that previous hypothesis and laboratory information was correct.

More in-depth analysis of the field testing results has also allowed us to expand the study to engineering behavior which may be more specific to the needs of the golf course. **Figure 7** shows the *stiffness* of the field tested soils. If the soil is likened to a spring, it behaves as a very stiff spring under low loads, and a much softer spring as it nears failure. In engineering terms, it is a "nonlinear" spring; different from the linear steel springs commonly encountered. The spring properties are inportant in predicting engineering behavior. Once the soil nears and then passes it's failure point (the highest point on the bearing capacity graphs, **Figure 5** and **Figure 6**) it loses it's stiffness and deforms very easily.

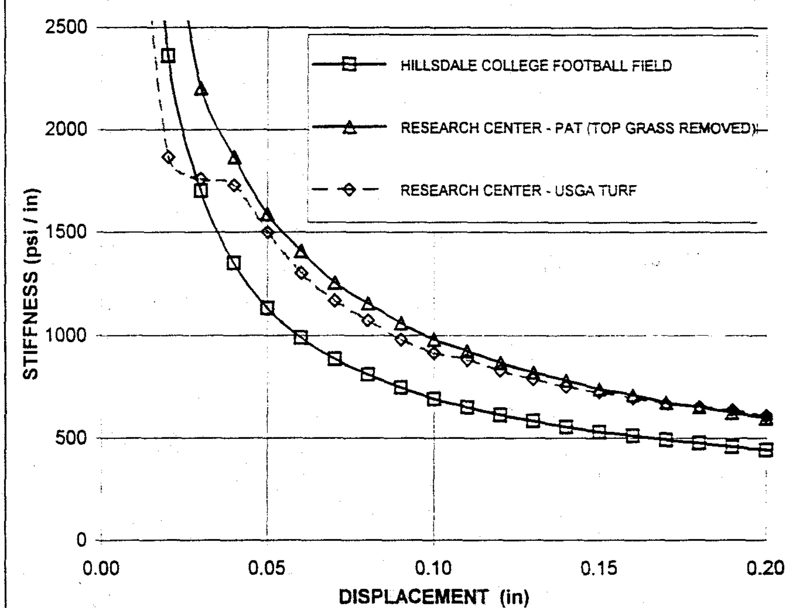

**Figure 7** - Stiffness of Field Tested Soils

As **Figure 7** shows, the three field tests present very close stiffness values for the corresponding loading. Additional field testing will invariably produce results with more variance.

## FINDINGS

Based on engineering principles, the research up to this point has allowed us to conclude many things about what parameters are most beneficial for obtaining a desirable sand mixture. Certain trends have been established which will be beneficial for golf course superintendents who wish to choose a sand mixture in order to attain desired properties. **Figure 8** shows some initial findings. As the coefficient of uniformity ($C_u$) is *increased*, the ultimate bearing capacity is also *increased*. This is exactly as expected and directly coincide with the previously sited literature review. On the other hand, as the grain size ($D_{10}$) *decreased* the ultimate bearing capacity *increased*. Together these trends indicate that the broader the particle size distribution in a sand mixture is, and the smaller the particles within that broadly distributed mixture are, the more capable the sand will be to support greater loads.

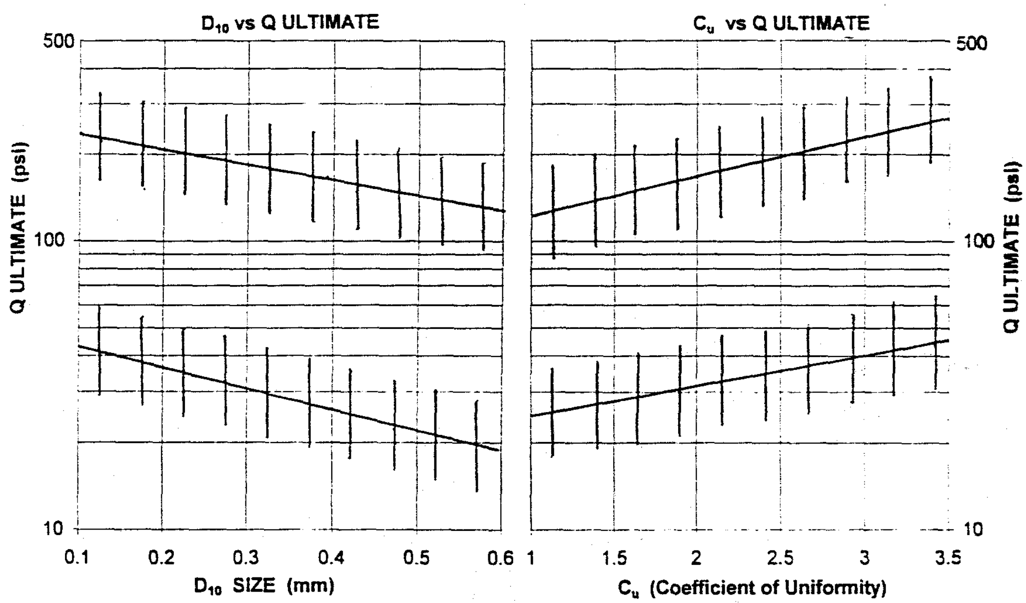


**Figure 8** - Trends among $D_{10}$, $C_u$ and $q_{ult}$

## SUMMARY

The second year of research has allowed for extensive laboratory testing. This has made it possible to test the strengths of sands under numerous controlable parameters. Tests included the direct shear test and the California Bearing Ratio (CBR) tests. From these tests we were able to determine that although small amounts of water may cause some apparent cohesion within a sand, drier more-well compacted sands withstand a greater load before failing. In addition the initial phase of field testing was begun and has already produced significant amounts of information. It was possible to directly relate the field test results with the laboratory tests. From this, the previous hypothesies could be confirmed and new questions could be generated. The testing has shown us that a soil will be able to carry a greater load without failure if it is comprised of soil particles which cover a wide range of sizes. In addition, the smaller the minimum sized particles in this wide range of sizes are, the greater load the sand will be able to carry. Through the tests it has also been found that for most soils within the root zone, once a large enough load has been applied to cause a given deformation, very little increase in loading is needed to casue further failure of the soil. All of this information points to the fact that significant variations in the bearing capacity and resistance to deformation can be found among similar sands even thought they are all within USGA specifications.

The increased number of field tests which will be possible in the future will make it possible to further analyze the most crucial soil parameters for affecting strength. Once this is accomplished, guidelines will be developed so that superintendents will be able to design a sand mixture which will produce the exact results which they desire while still falling within USGA specified guidelines.

## Phase Two: Maintenance

## INTRODUCTION

The objective of this phase is to evaluate and quantify responses of variously constructed putting greens as subjected to typical maintenance practices. This five-year project has now finished its second year and all objectives are well under way. While it is somewhat unwise to draw conclusions from results from some of these objectives due to the time frame of the experiment, there are trends emerging from the research. The major trends are the focus of this report and should be marked and scrutinized for the remainder of the project.

Specific objectives of the second portion of the proposed research were:

1. Evaluate three putting greens constructed by different methods and their response to sand topdressing and season long rolling (split plot) under simulated trafficked conditions 3 to 7 years after establishment.
2. Evaluate the effects of nitrogen and potassium fertility on trafficked creeping bentgrass quality and wear tolerance on three putting green construction methods with a rolling variable.
3. Determine the long term effects of plant growth regulators on putting green speed and creeping bentgrass quality on three putting green construction methods with a rolling variable.
4. Monitor the long-term changes in turfgrass rooting, soil physical characteristics, nematodes, and pathogens under three putting green construction methods.
5. Monitor the long-term changes in organic matter and forms of soil nitrogen among three putting green construction methods.
6. Compare topdressing with crumb rubber from used tires to sands in putting green collars of the three putting green construction methods.

## GENERAL MAINTAINENCE PROCEDURES

The area has been mowed six times a week with a walk behind mower at a cutting height of .157 inch. Topdressing of the entire area with sand was accomplished on a light frequent basis throughout the growing season. Irrigation was applied on a daily light-frequent practice with acceptation of dry down periods to collect data regarding localized dry spot. Pesticides were only applied on a curative basis to allow for disease, insect, and weed data collection. Core cultivation was not performed in 1997 because the formation of the black layer began to occur in the 80:10:10 root zone mix in the late fall of 1996. Core cultivation will take place in the spring of 1998 after samples are taken from all 18 greens in an attempt to quantify the effect of the black layer with gas exchange measurements.

*Traffic simulator* - Traffic to simulate typical wear on putting greens was applied to the plots six times/week with a triplex greens-mower modified with spiked rollers in lieu of reel units. The rollers are 60 cm long and 20 cm in diameter. 6-mm spikes are spaced at 2.5cm intervals on the unit. Front and rear 5-cm rollers level each of the three traffic simulator units.

## SPECIFIC OBJECTIVES PROCEDURES AND RESULTS

**OBJECTIVE 1: Evaluate three putting greens constructed by different methods and their response to sand topdressing and season long rolling (split plot) under simulated trafficked conditions 3 to 7 years after establishment.**

### METHODS

One half of each plot was rolled with an Olathe roller 3 times/week during the growing seasons from 1995 through 1997. Sand topdressing has been applied as referred above. The average measured topdressing depths were 14, 21, and 27.5mm for 1995, 1996, and 1997.
Data were collected for disease pressure, insect activity, moss and algae growth, and yellow tufts. Other data collection from these plots include Stimpmeter readings, color and quality ratings, rooting, soil bulk density, hydraulic conductivity, and pore size distribution.. Other interesting trends include localized dry spot and the formation of the black layer.

### RESULTS

Light-frequent sand-topdressing appears to have an effect on the activity of dollar spot. The USGA constructed green has displayed the greatest capacity for dollar spot damage. However, data presented in Tables 1, 2, and 3 indicate the difference in dollar spot activity between the USGA and 80:10:10 mix is diminishing on non-rolled plots.

In 1995 the USGA rolled always displayed the most dollar spot with the USGA check plot consistently having the second most dollar spot. In 1996 the USGA rolled continued to display the greatest severity to this disease. However, by late August the 80:10:10 non-rolled displaced the rolled USGA for having the second most dollar spot. This trend continued in 1997 with the exception of June of 97 when the 80:10:10 non-rolled green produced the greatest dollar spot activity.

It is hypothesized that the diminishing difference in dollar spot activity between the USGA and 80:10:10 non-rolled greens is the result of the light-frequent sand-topdressing program. It is anticipated that differences between all three root zone mixes will continue to diminish in regard to this disease as the study continues.

**Table 1.** Effects of construction method and rolling on dollar spot incidence, East Lansing, MI, 1995.

| | June 17 | | August 15 | | September 1 | |
|---|---|---|---|---|---|---|
| Soil Type | rolled | check | rolled | check | rolled | check |
| USGA | 54 | 54 | 130 | 197 | 486 | 594 |
| 80:10:10 | 8 | 11 | 17 | 83 | 88 | 478 |
| Native | 3 | 3 | 2 | 2 | 30 | 17 |

**Table 2.** Effects of construction method and rolling on dollar spot incidence, East Lansing, MI, 1996.

| | June 14 | | June 24 | | August 2 | | August 22 | |
|---|---|---|---|---|---|---|---|---|
| Soil Type | rolled | check | rolled | check | rolled | check | rolled | check |
| USGA | 20.3 | 41.3 | 100 | 152 | 24 | 56 | 201 | 467 |
| 80:10:10 | 0.3 | 14.0 | 3 | 75 | 2 | 23 | 27 | 329 |
| Native | 0.3 | 1.7 | 2 | 11 | 1 | 3 | 24 | 73 |

**Table 3.** Effects of construction method and rolling on dollar spot incidence, East Lansing, MI, 1997.

| | June 24 | | July 23 | | August 20 | |
|---|---|---|---|---|---|---|
| Soil Type | rolled | check | rolled | check | rolled | check |
| USGA | 28 | 63 | 47 | 111 | 60 | 100 |
| 80:10:10 | 4 | 72 | 9 | 97 | 4 | 69 |
| Native | 6 | 11 | 5 | 11 | 2 | 1 |

The comparison of rolling on differently constructed greens that are sand topdressed is vital, particularly in light of the number of courses with more than one type of green construction present. Tables 1-3 demonstrate the impact of light-weight green rolling on the occurrence of dollar spot insinuating that this cultural practice may have more to offer than increases in green speed.

Few color and quality differences occurred between rolled and non-rolled plots with acceptable ratings being recorded on most days. 1997 color and quality ratings are reported in Tables 4 and 5. However, in September of 1996 an 80:10:10 green that was rolled 3 times/week began to discolor and formation of the black layer was observed. For this reason core cultivation planned for that fall was canceled to observe if the black layer would form on other plots in 1997. During the summer of 1997 all replications of the 80:10:10 rolled plots formed the black layer. The discoloration caused by the black layer is reflected in the October 10 data. Quality ratings are often slightly lower on check plots because the rolled plots always displayed less dollar spot and localized dry spot.

**Table 4.** Effects of construction method and rolling color ratings, East Lansing, MI, 1997.

| Soil Type | May 30 | | June 13 | | July 11 | | August 10 | | October 10 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | rolled | check | rolled | check | rolled | check | rolled | check | rolled | check |
| USGA | 6.9 | 6.6 | 7.1 | 7.0 | 7.5 | 7.6 | 8.0 | 7.2 | 7.1 | 7.2 |
| 80:10:10 | 7.2 | 7.0 | 7.5 | 7.4 | 7.0 | 7.5 | 7.8 | 7.0 | 5.9 | 7.2 |
| Native | 7.6 | 7.6 | 7.7 | 7.6 | 7.6 | 7.6 | 8.0 | 7.4 | 6.8 | 6.8 |

9=excellent, 6 and above is regarded as acceptable

**Table 5.** Effects of construction method and rolling on quality ratings, East Lansing, MI, 1997.

| Soil Type | May 30 | | June 13 | | July 11 | | August 10 | | October 10 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | rolled | check | rolled | check | rolled | check | rolled | check | rolled | check |
| USGA | 6.2 | 5.8 | 6.6 | 6.3 | 7.8 | 6.8 | 7.8 | 6.9 | 6.7 | 6.7 |
| 80:10:10 | 6.9 | 6.6 | 7.2 | 7.0 | 7.4 | 6.8 | 7.5 | 6.5 | 5.1 | 7.1 |
| Native | 7.1 | 7.4 | 7.3 | 7.0 | 7.6 | 7.1 | 8.0 | 7.3 | 6.4 | 6.2 |

9=excellent, 6 and above is regarded as acceptable

**OBJETIVE 2: Evaluate the effects of nitrogen and potassium fertility on trafficked creeping bentgrass quality and wear tolerance on three putting green construction methods with a rolling variable.**

## METHODS

Six fertility programs continue to be evaluated over the 18 subplots (3 reps x 3 soils x 2 rolling regimes). The fertility program design is a 2x3 factorial with two levels of nitrogen (3 and 5 lb. N/1000 $ft^2$/ year) and three levels of potassium (soil test recommendations, 4, and 8 lb. K2O/1000 $ft^2$/ year). The season's initial and final nitrogen application was applied as urea. The other nitrogen treatments are made with granular applications of methylene urea. All potassium treatments are applied as sulfate of potash. Data collection from this study includes color and quality ratings, annual soil tests, clipping analysis, Stimpmeter ratings, disease counts, and turfgrass rooting. This portion of the study was initiated in August of 1996, thus 1997 has been the first full year of the fertility regime. Fertilizer application dates are reported in Table 6.

**Table 6**. Fertilizer application schedule for three putting green construction methods, East Lansing, MI, 1997

| Date applied | Annual Nitrogen/1000 ft$^2$ | | Annual Potassium/1000 ft$^2$ | | |
|---|---|---|---|---|---|
| | 6.0 lbs. | 3.0 lbs. | 8.0 lbs. | 4.0 lbs. | soil test |
| May 16$^{th}$ | | | 2.0 lb./ft$^2$ | 1.0 lb./ft$^2$ | |
| May 20$^{th}$ | 1.0 lb./ft$^2$ | 0.5 lb./ft$^2$ | | | |
| June 24$^{th}$ | 1.0 lb./ft$^2$ | 0.5 lb./ft$^2$ | | | |
| July 3$^{rd}$ | | | 1.0 lb./ft$^2$ | | 1.0 lb./ft$^2$ |
| July 30$^{th}$ | 1.0 lb./ft$^2$ | 0.5 lb./ft$^2$ | 1.0 lb./ft$^2$ | 1.0 lb./ft$^2$ | 1.0 lb./ft$^2$ |
| August22nd | 1.0 lb./ft$^2$ | 0.5 lb./ft$^2$ | | | |
| September 12$^{th}$ | | | 1.0 lb./ft$^2$ | | * |
| October 8$^{th}$ | 1.0 lb./ft$^2$ | 0.5 lb./ft$^2$ | 1.0 lb./ft$^2$ | 1.0 lb./ft$^2$ | * |
| November 26$^{th}$ | 1.0 lb./ft$^2$ | 0.5 lb./ft$^2$ | 2.0 lb./ft$^2$ | 1.0 lb./ft$^2$ | * |

* Rate varied for each plot depending upon the soil test results from October 1996.

## RESULTS

On August 20, 1997 an interaction between soil type, nitrogen level, and lightweight green rolling was observed regarding dollar spot activity. The data are presented in Table 7. A pattern exists regarding amount of sand, nitrogen, and rolling. The data implies that the amount of nitrogen per application rate and lightweight green-rolling 3x/week on predominantly sand-based greens reduce the occurrence of dollar spot. Lightweight green rolling 3x/week has more of a positive effective on minimizing dollar spot outbreaks than nitrogen rate per application.

**Table 7**. Effects of construction method and rolling on dollar spot incidence, East Lansing, MI, 20 Aug, 1997.

| | Rolled | | Not-rolled | |
|---|---|---|---|---|
| Soil Type | 0.5 lbs. N/app. | 1.0 lbs. N/app. | 0.5 lbs. N/app. | 1.0 lbs. N/app. |
| USGA | 60 c | 60 c | 116 a | 83 b |
| 80:10:10 | 5 d | 4 d | 71 bc | 67 c |
| Native | 2 d | 2 d | 2 d | 2 d |

$LSD_{(0.05)}$ 0.04

On June 24 an interaction was recorded regarding potassium rate and green rolling. Data is reported in Table 8. Plots with the highest annual potassium rate and no lightweight green rolling obtained the highest average in dollar spot activity. The amount of potassium was insignificant regarding the amount of dollar spot on greens receiving the rolling treatments.

**Table 8.** Effects of potassium rate and rolling on dollar spot incidence, East Lansing, MI, 24 June, 1997.

| Annual Potassium Rate | Rolled 3x/week | None rolled plots |
|---|---|---|
| 8 lbs. | 11 c | 63 a |
| 4 lbs. | 13 c | 36 b |
| Soil Test | 15 c | 47 b |

$LSD_{(0.05)}$ 0.03

Stimpmeter data collected on the fertilized plots is reported in Table 9. For all date the cultural practices of lightweight green rolling had a greater impact on green speed than the amount of nitrogen per application.

**Table 9.** Effects of construction method, rolling, and nitrogen rate on stimpmeter readings (feet), East Lansing, MI, 1997.

| | Rolled 3x/week | | Non- rolled plots | |
|---|---|---|---|---|
| | 0.5 lbs. N/app. | 1.0 lbs. N/app. | 0.5 lbs. N/app. | 1.0 lbs. N/app. |
| Soil Type | June 4 | | | |
| USGA | 10.3 | 9.9 | 9.0 | 8.6 |
| 80:10:10 | 10.2 | 10.2 | 8.8 | 8.4 |
| Native | 9.9 | 9.6 | 8.7 | 8.4 |
| | June 20 | | | |
| USGA | 9.6 | 9.4 | 8.1 | 8.1 |
| 80:10:10 | 9.6 | 9.8 | 8.1 | 8.3 |
| Native | 9.3 | 9.6 | 8.0 | 8.3 |
| | July 11 | | | |
| USGA | 11.5 | 11.3 | 10.3 | 10.4 |
| 80:10:10 | 11.6 | 11.7 | 9.8 | 9.9 |
| Native | 10.9 | 11.2 | 10.0 | 10.3 |

**OBJECTIVE 3: Determine the long-term effects of plant growth regulators on putting green speed and creeping bentgrass quality on three putting green construction methods with a rolling variable.**

**METHODS**

The second year of the study began on 28 May 1997 with the first application of plant growth regulators. The experimental design was 3 x 2 x 3 split-split randomized block design. Three construction methods consisted of the main plots with a rolling factor split over the construction methods. A plant growth regulator factor was split over the rolling factors.

The PGR's used were trinexapac-ethyl and flurprimidol applied at a rate of 0.05 oz. a.i./M at five-week intervals. The third and final application for the season was made on 14 August 1997. A check plot was also included. Traffic was applied with a triplex greens mower fitted with golf shoe spike mounted rollers six days per week to represent 150 rounds of golf per day.

Data included stimpmeter readings taken three days per week on the same day that rolling was applied. Both turfgrass quality and color ratings were taken on a monthly basis (scale 1-9 for each). Turfgrass rooting weights were also recorded.

The data were analyzed using ANOVA procedures. The least significant difference test was used to analyze differences between factors.

**RESULTS**

Ball roll distance readings representing data collected during both seasons are presented in Table 10. Construction methods did not produce significant differences in ball roll distance. Rolled plots produced consistently higher ball roll distance. PGR's produced higher ball roll distance readings than check plots from 7 to 14 days after each application. In 1996, rolled plots that received a PGR application produced higher ball roll distance readings than rolled plots that did not receive PGR's. This response was not seen in 1997. An interaction between construction method and rolling for ball roll distance was seen in 1997 but not in 1996 where both high sand content soils (USGA and 80:10:10) produced greater ball roll distance than the sandy clay loam plots when rolling was applied.

Color ratings representing data collected for both seasons is also presented in Table 10. When color differences were seen between construction methods, 80:10:10 and sandy clay loam construction methods produced higher ratings than USGA plots. Trinexapac-ethyl and check plots produced higher color ratings than flurprimidol from 7 to 21 days after each application.

An interaction between construction methods and rolling was observed for rooting weights from 0-15cm in October 1996 (Table 11). 80:10:10 plots produced significantly higher rooting weights than the USGA and sandy clay loam plots when rolling was applied. Also, sandy clay loam plots produced significantly greater rooting weights than both USGA and 80:10:10 plots.

**Table 10**. Effects of construction method, rolling and PGR on ball roll distance and color ratings, East Lansing, MI, 8 Jun 1997.

| Construction Method | Ball roll distance (cm) | Color |
|---|---|---|
| USGA | 329 | 5.8 |
| 80:10:10 | 332 | 6.1 |
| Sandy Clay Loam | 326 | 6.4 |
| $LSD_{(0.05)}$ | ns | 0.2 |
| Rolling | | |
| Rolled | 337 | 6.1 |
| Not Rolled | 319 | 6.2 |
| $LSD_{(0.05)}$ | * | ns |
| PGR | | |
| Trinexapac-ethyl | 323 | 6.4 |
| Flurprimidol | 338 | 5.3 |
| Check | 323 | 6.7 |
| $LSD_{(0.05)}$ | 7 | 0.2 |

Color Ratings: 1-9: 1= Poor (dead, brown), 9=dark green, and 6=acceptable.

**Table 11**. Effects of construction method and rolling on total root weights (0-15cm). East Lansing, MI, Oct 1996.

| | Rolled | Not Rolled |
|---|---|---|
| Construction Method | -------(mg)------- | |
| USGA | 103 | 95 |
| 80:10:10 | 115 | 77 |
| Sandy Clay Loam | 174 | 189 |
| $LSD_{(0.01)}$ | | |
| between rolling | 29 | |
| between construction methods | 55 | |

**OBJECTIVE 4: Monitor the long-term changes in turfgrass rooting, soil physical characteristics, nematodes, and pathogens under three putting green construction methods.**

RESULTS

Annual collection of soil cores for data collection pertaining to soil bulk density, hydraulic conductivity, and pore size distribution have been made by removing the verdure and keeping as much of the topdressing layer intact as possible. In Table 12 are the results of soil cores taken in 1996. Soil cores have been collected for the 1997 season but the data is not processed. Soil cores measured 7.6 cm in height and 7.6 cm in diameter. No differences occurred regarding bulk density or total soil porosity. However, at .04 bar the rolled USGA and 80:10:10 greens had statistically significantly less porosity than their non-rolled counterparts, and the 80:10:10 mix also has less porosity at .1 and .33 bars. These changes imply a decrease in the amount of macropores in these two soils. However, since the total porosity was unchanged than more micropores are present in the soils when lightweight green rolling was applied. This can be theorized as the reason less localized dry spot was observed on rolled plots.

**Table 12.** Effects of construction method and rolling on bulk density and porosity, East Lansing, MI, 11 July 1996.

| | | —— Porosity —— | | | |
|---|---|---|---|---|---|
| | Bulk Density | 0.04 bar | 0.1 bar | 0.33 bar | Total |
| USGA Rolled | 1.57 g $cm^{-3}$ | 20.7 b | 24.7 a | 26.0 a | 40.7 |
| USGA Check | 1.54 g $cm^{-3}$ | 23.0 a | 23.0 a | 28.0 a | 41.0 |
| 80:10:10 Rolled | 1.62 g $cm^{-3}$ | 11.0 d | 14.7 c | 17.3 c | 38.0 |
| 80:10:10 Check | 1.57 g $cm^{-3}$ | 14.3 c | 19.0 c | 21.7 b | 38.3 |
| Native Rolled | 1.72 g $cm^{-3}$ | 6.7 e | 8.7 d | 10.7 d | 36.3 |
| Native Check | 1.71 g $cm^{-3}$ | 5.3 e | 7.0 d | 8.3 d | 36.3 |
| $LSD_{(0.05)}$ | n.s. | .03 | .03 | .01 | n.s. |

Nematode collection took place twice per year in summer and fall. The trend indicates that numbers of nematodes are increasing in the USGA and 80:10:10 greens. However, 1997 was an unusual year in that stunt nematode population densities declined from the previous year on virtually all greens. This may be a result of the change of sampling location from previous years to accommodate the other studies being conducted at the site. Mean numbers of stunt nematodes are presented in Table 13.

**Table 13.** Mean numbers of stunt nematodes, Tylenchorhynchus nudus, recovered/100cm$^3$ soil on selected sampling dates from three creeping bentgrass putting green construction methods located at the Hancock Turfgrass Research Center, East Lansing, MI.

| | *T. nudus* counts | | | | | |
|---|---|---|---|---|---|---|
| | 1995 | | 1996 | | 1997 | |
| Construction Method | 15-Jun | 8-Nov | 12-Jul | 19-Nov | 13-Jun | 14-Nov |
| USGA | 2 | 13 | 50 | 90 | 42 | 18 |
| 80:10:10 | 4 | 3 | 75 | 63 | 3 | 48 |
| Sandy Clay Loam | 187 | 640 | 219 | 240 | 11 | 64 |

**OBJECTIVE 5: Monitor the long-term changes in organic matter and forms of soil nitrogen among three putting green construction methods.**

**RESULTS**

Three sub-samples were obtained from each soil type replication with a 3.3cm diameter soil probe in October of 1996 and 97. Each sub-sample was divided into three segments. The first segment was the topdressing layer. The second sub-sample was obtained by taking the portion of the core measuring 7.6 cm below the soil topdressing interface. The third sub-sample was the portion of the core measured 7.6cm below the second sub-sample. The 1997 data has not been analyzed to date. The 1996 data is presented in Table 14, and 15.

**Table 14.** Effects of construction method and sampling depth on % nitrogen, East Lansing, MI, Oct 1996.

| Construction Method | Topdressing layer | Interface to 7.6 cm | 7.6 - 15.2 cm |
|---|---|---|---|
| USGA | 0.17 b | 0.04 b | 0.03 c |
| 80:10:10 | 0.29 a | 0.07 ab | 0.06 b |
| Native | 0.31a | 0.11a | 0.10 a |
| $LSD_{(0.05)}$ | 0.07 | 0.04 | 0.03 |
| $LSD_{(0.05)}$ | 0.01 | 0.04 | 0.00 |

**Table 15.** Effects of construction method and sampling depth on % organic matter, East Lansing, MI, Oct 1996.

| Construction Method | Topdressing layer | Interface to 7.6 cm | 7.6 - 15.2 cm |
|---|---|---|---|
| USGA | 4.7 b | 3.7 a | 3.4 a |
| 80:10:10 | 6.7 a | 3.3 a | 3.3 a |
| Native | 6.3 a | 1.7 b | 1.3 b |
| $LSD_{(0.05)}$ | 1.20 | 0.94 | |
| $LSD_{(0.05)}$ | 0.02 | 0.01 | 0.00 |

Portions of this research are not yet reported, as they require further lab and/or statistical analysis. In fact, much of the data presented requires further statistical analysis. The intriguing science and practicality of this study relies on its' longevity. Thus, regression models at the end of the third season (1998) should begin to reveal interesting trends. Data collected but not included in this report include clipping weights, root weights, nutrient content of grass clippings (NIR) and wet chemical, and disease activity data other than dollar spot.

**OBJECTIVE 6: Compare topdressing with crumb rubber from used tires to sands in putting green collars of three putting green construction methods.**

The study began on 23 May 1996 with the first application of crumb rubber. The experimental design was a 3 x 2 x 4 split-split randomized block design. The three construction methods and rolling variables remained consistent with the studies described above. The topdressing variable was split across the rolling variable. The topdressing consisted of; 1/8" rubber, 3/8" rubber, 1/8" rubber and 1/8" sand mixed, and sand topdressing alone.

Data collected included Clegg impact absorption, shear vane, color and quality ratings, rooting weights and % *Poa annua* ratings. The data were analyzed using ANOVA procedures. The least significant difference test was used to assess between factors.

**RESULTS**

Clegg impact absorption readings showed that plots treated with the highest rate of crumb rubber produced lower readings than all other topdressing treatments (Table 16). Plots not receiving a rolling treatment produced lower Clegg readings than rolled plots. Shear vane readings showed that rolled plots produced higher readings than not rolled plots in both years of the study. It has been shown (Vanini, 1995) that turf will not respond until one year after the application of crumb rubber in terms of shear vane readings. Our research supported this finding with the first year having no differences between topdressing treatments and the second year showing that the highest rate of crumb rubber produced lowest readings (Table 16).

It has been shown that crumb rubber is known to perform to the benefit of the turfgrass stand when environmental stress is at high levels (Vanini, 1995). The first season of the study, 1996, was very mild and did not produce color and quality differences between topdressing treatments. In 1997, however, plots treated with 1/8" rubber and 3/8" rubber produced higher color and quality ratings in July when environmental stress was highest. No differences in color and quality ratings were observed between construction methods. Rolling did produce lower color and quality ratings than plots that did not receive a rolling treatment.

Percent *Poa annua* ratings resulted in an interaction between construction methods and topdressing treatments in 1996. This interaction was not observed in 1997. Both seasons showed that plots topdressed with the highest rate of crumb rubber (3/8") had the least amount of *Poa annua* invasion. Also, plots that received a rolling treatment had significantly higher *Poa annua* invasion than plots not receiving a rolling treatment. An interaction between topdressing treatments and rolling was observed in 1997 (Table 17). This interaction was not seen in 1996.

**Table 16.** Effects of construction method, rolling and topdressing treatments on Clegg impact absorption and shear vane readings at the Hancock Turfgrass Research Center.

| | Shear vane (nM) | | | Clegg Impact Absorption ($g_{max}$) | | |
|---|---|---|---|---|---|---|
| | 12-Aug 96 | 18-Sep 96 | 5-Jun 97 | 24-Jul 96 | 7-May 97 | 25-Jun 97 |
| Construction Method | | | | | | |
| USGA | 11.2 | 11.2 | 17.3 | 66.6 | 70.0 | 65.0 |
| 8:10:10 | 12.0 | 12.0 | 18.8 | 64.1 | 68.0 | 64.0 |
| Native | 12.6 | 12.9 | 19.6 | 73.5 | 73.9 | 69.3 |
| $LSD_{0.05}$ | ns | ns | Ns | ns | ns | ns |
| Rolling | | | | | | |
| Rolled | 11.4 | 11.6 | 18.8 | 72.2 | 72.7 | 68.9 |
| Not Rolled | 12.5 | 12.5 | 18.4 | 63.9 | 68.2 | 63.0 |
| $LSD_{0.05}$ | * | * | Ns | * | * | * |
| Topdressing | | | | | | |
| 1/8" rubber | 12.1 | 12.1 | 19.4 | 68.6 | 71.8 | 66.8 |
| 3/8" rubber | 12.1 | 11.7 | 19.0 | 68.9 | 65.3 | 61.6 |
| ¼"sand &¼" rubber | 11.3 | 12.1 | 17.3 | 67.7 | 72.8 | 65.1 |
| sand alone | 12.2 | 12.2 | 18.6 | 67.0 | 72.0 | 70.4 |
| $LSD_{0.05}$ | ns | ns | 0.7 | ns | 2.8 | 2.4 |

**Table 17.** Effects of rolling, and topdressing treatments on *Poa annua* encroachment of putting green collars at the Hancock Turfgrass Research Center.

| | 1996 | 1997 | | |
|---|---|---|---|---|
| | 5-Oct | 28-May | | 10-Oct |
| | | ------Interaction------ | | |
| Topdressing Treatment | | Rolled | Not Rolled | |
| 1/8" Rubber | 14.4 | 33.7 | 12.6 | 25.9 |
| 3/8" Rubber | 17.4 | 20.9 | 8.1 | 17.3 |
| ¼" Sand & ¼"Rubber | 12.9 | 27.2 | 14.7 | 30.8 |
| 3/8" Sand | 13.2 | 38.9 | 15.3 | 34.2 |
| | ns | | | 11.1 |
| LSD0.05 | | | | |
| between rolling | | 8.0 | | |
| between topdressing | | 5.7 | | |
| | | | | |
| Rolling Variable | | | | |
| Rolled | 20.8 | | | 35.8 |
| Not Rolled | 8.1 | | | 18.3 |
| LSD0.05 | * | | | * |