PHYSICAL PROPERTIES OF VARIOUS SOIL MIXTURES USED FOR GOLF GREEN CONSTRUCTION

A Thesis

by

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ABSTRACT

Physical Properties of Various Soil Mixtures Used for Golf Green Construction. (December 1976)

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Proper construction of golf greens is of singular importance to the maintenance of a healthy, vigorous turf. Although specifications for golf green soil mixtures have been established by the United States Golf Association Green Section, wide latitudes exist within these specifications. Therefore, a greenhouse experiment was conducted to determine the physical characteristics of a range of soil mixtures composed of commonly used materials. Treatment variables included the texture of sand, kind of inorganic amendment and kind of organic amendment in the soil mixture. Other variables were the presence or absence of a boundary between the soil mixture and the underlaying gravel and the presence or absence of a 22 cm layer of coarse sand between the soil mixture and the gravel. The mixtures were placed in 30 cm diameter containers. Greenhouse measurements were compared to measurements made in the USGA Physical Soil Test Laboratory.

The mixtures were compacted, grass was established and the mixtures were recompacted. Infiltration rates decreased after the grass was established and decreased again after recompaction. Discrepancies existed between greenhouse measurements and USGA laboratory measurements of infiltration rates. Calcined clay fines significantly increased infiltration rates over clay. Mixtures containing 10% clay had extremely low infiltration rates. Calcined clay fines, calcined clay aggregates, basic-slag aggregates and Polyloam^R were adequate inorganic amendments.

Brady sand, a fine textured sand with highly uniform particle-size distribution, does not meet the current USGA specifications for texture. However, Brady sand was found to hold significantly larger amounts of available water, was significantly higher in capillary porosity, and was lower in bulk density than either concrete sand or brick sand. Root growth was greater in Brady sand than in brick sand or concrete sand.

No significant differences were found between mixtures containing rice hulls and peat moss in their effects on infiltration, water holding capacity, CEC or root growth in soil mixtures. More root growth occured in the layered profiles than in their respective prototypes. Boundaries showed little effect on the properties of the soil mixtures in this study. Since particle migration was not in evidence in the profiles of soil mixtures containing clay, the usefulness of boundaries is questionable.

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INTRODUCTION

Golf greens are the most intensively maintained turfgrass areas in existence. Due to the nature of their usage and the traffic they bear, proper construction of golf greens is of utmost importance in maintaining them. The current United States Golf Association Green Section specifications for putting green construction are a revision of the original specifications published in the _USGA-Journal and Turf Management_ in 1960. The revision retains the original concepts of building putting greens with topsoil mixtures which provide satisfactory drainage and resist compaction, but recommends infiltration rates of between 10 to 15 centimeters per hour (11). The soil mixture should retain sufficient water to support the turfgrass for several days, and should contain sufficient air space to permit good drainage. The mixture should be firm enough to support heavy traffic, yet resilient enough to hold a well-played golf shot. There should be minimum deterioration of these characteristics over a long period of time.

Putting greens built according to USGA Green Section specifications are constructed in layers. The bottom layer, which overlies the subgrade, consists of 10 cm of pea gravel provided with drain tile to insure subsurface drainage. A 5 cm layer (or boundary) of coarse sand is recommended for

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placement between the gravel and the top mixture to prevent the downward movement of small particles into the gravel layer. The top mixture usually consists of sand, soil, and organic matter, and must be mixed uniformly off-site.

The USGA Green Section specifications also state that no more than 3% of the topsoil mixture be larger than 2 mm in diameter. There should be no more than 10% particles larger than 1 mm (16 mesh) and no more than 25% particles less than 0.25 mm in diameter (60 mesh). The topsoil mixture should contain less than 5% silt (0.05 to 0.002 mm) and less than 3% clay (less than 0.002 mm). Silica sands of the brick or mason class are preferred. The ideal particle-size distribution for a sand to be used in the mixture would be: 100% below 16 mesh (1 mm), 35% below 32 mesh (0.50 mm), 15% below 60 mesh (0.25 mm), 5% below 160 mesh (0.06 mm). The Green Section also recommends that the soil mixture have a total porosity of between 40 to 55% and that it retain 12-25% water on a volume basis after drainage at 40 cm tension. A composite of the recommended soil properties is presented in Table 1.

The advantages of properly built greens are several. They promote better root development due to high levels of available water and well-aerated conditions. The improved root development facilitates maintenance of a healthy vegetative cover on the surface that can withstand heavy traffic. The USGA greens provide rapid infiltration rates and drainage under wet conditions, and are resistant to severe compaction.

Golf greens built according to USGA specifications are suited for bentgrass (Agrostis spp.) as well as bermudagrass (Cynodon spp.), the two predominant species used for this purpose. Properly built greens are indispensable to the growth and maintenance of bentgrass turf on greens throughout the United States, but particularly in the South, where climatic conditions are not as favorable to this species. Bermudagrass benefits from proper greens construction by developing deeper root systems, thereby encouraging a more favorable overwintering condition and easier spring transition.

As the materials available for putting green soil mixtures vary greatly from region to region, each proposed mixture requires preliminary evaluation. The objective of this study was to ascertain the effects of various components on the physical characteristics of soil mixtures used for golf green construction. The soil mixtures were located in a greenhouse and maintained to simulate golf course conditions. The variables included the components of the upper portion of a golf green profile (sands, soil and inorganic or organic amendments), layers within the profile and boundaries between the top mixture and an underlying gravel layer. The effects of the variables were determined by measuring:

1) infiltration rates of each profile before planting, after establishment of bermudagrass, and after recompaction,
2) the amount of available water held by each profile,
3) the cation-exchange capacity for each soil mixture,
4) root growth within each profile,
5) the instability of the profile as evidenced by particle migration in the top mixture, and
6) bulk density and porosity of each soil mixture.

For comparison, the soil mixtures were tested in the USGA Physical-Soil Test Laboratory for texture, bulk density, porosity, infiltration rate, and percent moisture at a tension of 40 cm of water.

LITERATURE REVIEW

Golf greens sustain considerable compaction both during construction and from the traffic they bear during normal usage. Kunze (9) found that compaction was definitely harmful to the growth of roots in putting green soil mixtures. He concluded that mixtures containing 70 to 85% sand and 5 to 10% clay soil by volume with organic matter as the remaining fraction were ideal for golf greens. Howard (7) investigated the behavior of sand-soil-peat mixtures used in putting greens and corroborated Kunze's findings on ratios of desirable components. Howard concluded that sands with more than 50% of the particles between 0.25 and 0.50 mm in diameter were preferable. Howard also indicated that montmorillonitic clay was preferable to kaolinitic clay.

Swartz and Kardos (13) evaluated the effects of compaction on several sand-soil-peat mixtures at different moisture levels. They found that compacting the soil mixtures at higher moisture contents resulted in decreased percolation rates. Since most of the traffic on golf greens occurs when the soil moisture content is high, they concluded that a soil mixture containing at least 70% sand should be used. They did not include mixtures which contained higher percentages of sand in their study.

Madison (10) reviewed research on sands used in golf green construction. He concluded that the use of find sands with a narrow particle-size distribution would provide a medium for a more tractable turf. Bingaman and Kohnke (1) evaluated sands used for athletic turf. They concluded that when pure sand was used as the growth medium, most of the particles should be from 0.1 to 0.5 mm in diameter and that the sand should have a gradation index (i.e. the diameter below which lie 95% of the sand particles divided by the diameter below which lie 5% of the sand particles) between 2 and 6. The practicality of these findings is limited, however, by the cost and accessibility of such specially sieved sands.

Waddington et al. (15) examined physical properties of physically amended soils and concluded that coarse sand ranked highest in increasing permeability of compacted mixtures. Their conclusion that compaction reduces permeability of soil mixtures corroborates the findings of Swartz and Kardos (13). They also found that permeability was affected by the soil mixture, that coarse sand was the most resistant to compaction of the materials studied, and that calcined clay was an effective amendment for increasing permeability.

Organic constituents are included in most soil mixtures to increase water retention and CEC. Humbert and Grau (8) studied soil and turf relationships and concluded that putting green soil mixtures should contain 15 to 20% organic matter and less than 15% clay by volume. They also indicated that layered greens showed marked local concentrations of roots, often at shallow depths. Richer et al. (12) studied the response of various organic amendments in soil mixtures for golf greens and concluded that peat moss seemed to be the most desirable amendment. Davis et al. (5) evaluated sands and amendments used for heavily trafficked turfgrass areas. Their findings indicated that ammoniated rice hulls were effective organic amendments in increasing air porosity to a desirable range. In comparison to peat moss, however, the rice hulls had less capacity for holding available water.

Brown and Duble (3) investigated physical properties of soil mixtures used in golf green construction. They found that infiltration rates of soil mixtures decreased after the turfgrass became established and decreased further after compaction. The authors concluded that soil mixtures with greater than 5% clay soil by volume were susceptible to severe compaction. The amount of available water retained in mixtures with 5% clay soil was about twice the amount held in pure sand. The authors also stated that little evidence of particle migration into the gravel layer was found in the absence of an intermediate layer (boundary) when the underlying gravel had particles half of which were less than 0.64 mm in diameter.

MATERIALS AND METHODS

Simulated golf green profiles were constructed in 30 cm diameter and 50 cm deep metal cylinders with drainage ports on the bottom. The cylinders were housed in a greenhouse during the study. Medium-sized gravel (0.64 cm diameter) was placed in the bottom of the cylinders to a depth of 15 cm. Four types of boundaries (see Figure 1 for descriptions) were used to separate the underlaying pea gravel from the top mixtures. The boundary titles and descriptions were as follows:

a) no boundary, the soil mixture directly overlay the gravel layer,
b) Petromat^{R}, a non-woven, polypropelene fabric,
c) brick sand, a 5 cm stratum of brick sand (see Table 2 for particle-size distribution), and
d) sieved materials, which consisted of a 5 cm stratum of gravel particles ranging from 2 to 5 mm in diameter overlain by a 5 cm stratum of sand particles ranging from 0.5 to 1.0 mm in diameter.

All top mixtures in this study, henceforth referred to as the boundary study, were 85% brick sand, 5% Lake Charles clay and 10% peat moss by volume. Each boundary constituted one treatment, and each treatment had three replications. All other profiles had no boundary between the gravel layer and top mixture.

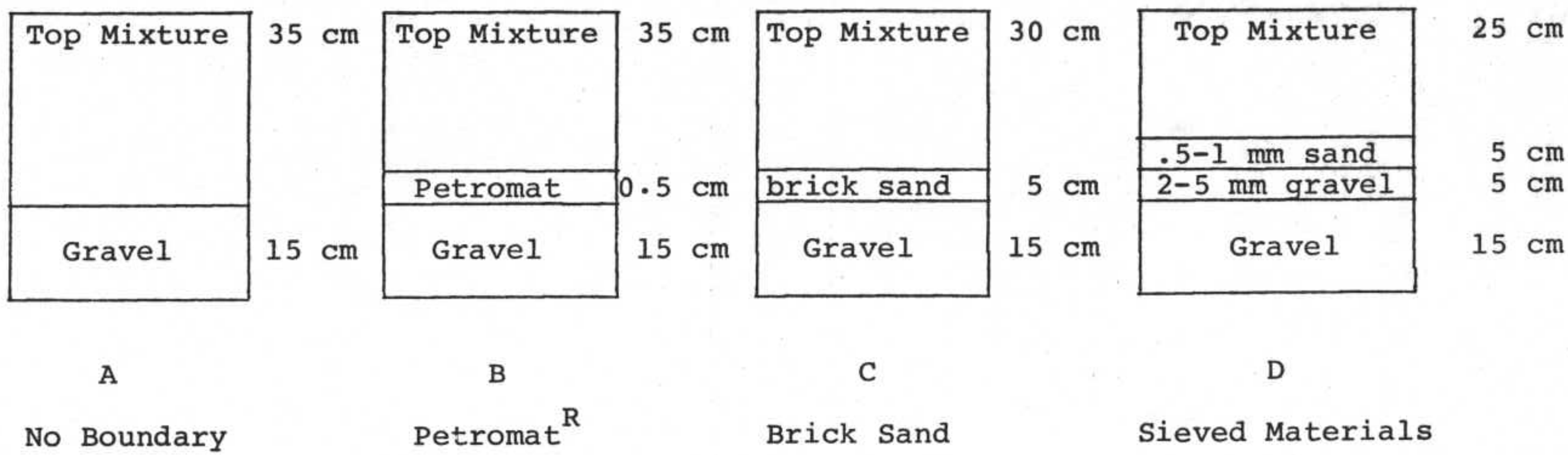


Figure 1. Types and depths of boundaries in experimental golf green profiles.

Note: All top mixtures consisted of 85% brick sand, 5% Lake Charles clay and 10% peat moss by volume.

The top mixtures were prepared from a variety of potentially useful components for golf green soil mixtures. The components included 3 sands, 6 inorganic amendments, and 2 organic amendments. The three sands were as follows:

1) brick sand (BR), a commonly used sand which meets USGA specifications,
2) concrete sand (CN), a coarser textured sand than brick, but one that also meets USGA specifications, and
3) Brady sand (BD), a fine textured sand of uniform particle size which does not meet USGA specifications.

Particle-size distributions of the sands are presented in Table 2. The inorganic amendments included:

1) Lake Charles clay (LC), fine, montmorillonitic, thermic family of typic Pelluderts (see Table 2 for particle-size distribution),
2) calcined clay fines (CF),
3) Hadite^{R} (HA), coarse basic slag aggregates,
4) Corsicana Super Rock^{R} (SR), calcined clay aggregates,
5) synthetic rubber (GR) which was ground into pieces small enough to pass through a 2-mesh sieve, and
6) Polyloam^{R} (PL), an artificial soil amendment.

The organic amendments were:

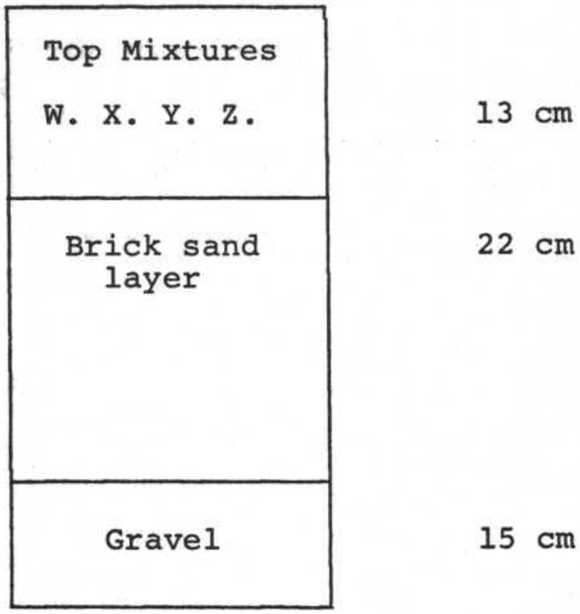
1) peat moss (PM), and
2) ammoniated rice hulls (RH).

Fourteen soil mixtures were prepared from these components. All components of the mixtures were measured by volume and thoroughly mixed in a cement mixer. The volumetric compositions of the mixtures and the abbreviations used to identify them are presented in Table 3. Table 4 contains descriptions of the particle-size distributions of all of the mixtures. Each mixture was placed in a 30 cm diameter cylinder to a depth of 35 cm overlaying 15 cm of pea gravel. For the soil mixture study, each mixture was replicated three times.

In a comparison henceforth referred to as the layer study, four profiles had 13 cm layers of top mixture placed above 22 cm layers of brick sand. The brick sand layers overlay pea gravel. (Figure 2 contains profile descriptions of the layer study.) The layered profiles were compared with their uniform prototypal soil mixture profiles described in the preceding paragraph.

Each profile was constructed by adding the materials in two equal layers. Each layer was compacted by the dropping-weight method described by Swartz and Kardos (13) to simulate traffic during construction. A weight equivalent to 19 gm/cm^2 was dropped 38 cm a total of 50 times on each layer. Following compaction, the first layer was scarified before the next layer was added to prevent the formation of a boundary.

Infiltration rates were measured on each profile before planting grass on them. The procedure was to saturate the



Top Mixtures:

W) 85% brick sand, 5% Lake Charles clay, 10% peat moss.
X) 80% brick sand, 10% Lake Charles clay, 10% peat moss.
Y) 80% brick sand, 10% calcined clay fines, 10% peat moss.
Z) 80% brick sand, 10% calcined clay fines, 10% rice hulls.

Figure 2. Diagram and descriptions of layer study profiles.

profile, establish a 1.25 cm head of water, and record the length of time required for the water to disappear beneath the surface of the profile.

Following the initial infiltration studies, Tifgreen bermudagrass was sprigged in each cylinder. All greens received equal amounts of water and fertilizer, sufficient to maintain dense, uniform stands of grass throughout the study. The grass was clipped twice weekly to a height of 1 cm.

After dense, uniform stands of grass were established, infiltration rates were measured again on all profiles. The profiles were then compacted by the dropping-weight method. The compaction was done within one hour after heavy watering. It was done in two stages, allowing one week between compactions for the grass to recover. A weight equivalent to 19 gm/cm^2 was dropped 38 cm a total of 100 times on each profile. I estimated that the force applied should exceed several years of normal traffic on a typical golf green. After the grass recovered from the compaction, infiltration rates were remeasured. The procedure for the last two sets of infiltration rates was to saturate the profile, maintain a 1.25 cm head of water, and after establishing a steady flow, collect the water issuing from the drainage port at the bottom of the cylinder for a given period of time. The procedure was repeated until the flow rate became constant.

At the completion of the infiltration studies, the profiles were saturated and allowed to drain overnight. A core sample measuring 10.8 cm in diameter and 15.25 cm in depth was then extracted from each profile, wrapped on the sides with aluminum foil and on the bottom with cheese cloth to hold it together, and weighed. Watering was discontinued on the cores and the turf was allowed to wilt. The cores were reweighed as soon as possible after the grass wilted. The difference between the weight following saturation and drainage and the weight at the wilting point estimated the amount of available water in that core and was reported as a percentage of the oven-dry weight of the core.

After the available water measurements had been taken, the profiles were saturated and allowed to drain overnight. Undisturbed core samples 5.4 cm in diameter and 2.9 cm thick were extracted from the cylinders containing the 14 different soil mixtures. These samples were used to measure bulk density by the core method described by Blake (2). Capillary porosity and non-capillary porosity were calculated using the method described by Vomocil (14).

Root growth in each profile was measured by taking core samples with a soil probe to a depth of 20 cm. Each core sample had an approximate volume of 75 cm^3. The roots were separated from the soil mixtures with the aid of an ultrasonic cleaning device. The roots were dried and weighed and the weights were recorded for each profile.

Cation-exchange capacity was determined for each soil mixture by the sodium saturation procedure described by Chapman (5). Analyses for Na^+ were performed with atomic-emission spectroscopy.

Particle migration in the upper profile of clay mixtures was investigated by particle-size distribution analyses for each 2.5 cm increment of soil profile. Differences in particle-size distributions between increments were used to indicate particle migration.

The 14 soil mixtures were taken to the USGA Physical Soil Test Laboratory where they were examined for texture, bulk density, porosity, infiltration rates and moisture retention at a tension of 40 cm of water.

RESULTS AND DISCUSSION

A. Infiltration Rates.

According to the current USGA Green Section specifications, water should infiltrate golf green soil mixtures at a minimum rate of 5 cm/hr. The ideal rate should be between 10 and 15 cm/hr. Table 5 contains the infiltration rates for 14 soil mixtures under three conditions: after compaction, after turfgrass establishment and after establishment and recompaction. The conditions under which infiltration rates are measured are critical, as the data in Table 5 indicate. Brown and Duble (3) reported that infiltration rates decrease after turfgrass establishment, and that the rates decrease further after compaction. The data in Table 5 corroborate their findings. Furthermore, it may be assumed that infiltration rates taken after establishment and recompaction are the most critical since they are the lowest rates. It is also posited that these are the infiltration rates that most nearly simulate actual field conditions.

Table 5 also includes infiltration rates of the 14 soil mixtures obtained by the USGA Physical Soil Test Laboratory using the method described by Ferguson et al. (6). In this procedure, the soil samples are allowed to stand overnight on a tension table with 40 cm H_2O tension acting on them. Then, a weight equivalent to 19 gm/cm^2 is dropped a total of 15 times on each sample. In the greenhouse, the established profiles were compacted within one hour following saturation. The greenhouse profiles were wetter than the USGA laboratory samples, therefore more easily compacted given the application of equivalent compaction efforts to both samples. Also, in the greenhouse, a weight equivalent to 19 gm/cm^2 was dropped a total of 100 times on each sample. Thus, the greenhouse profiles were more severely compacted and had infiltration rates that were 2 to 8 times lower than the USGA laboratory samples. Some of the differences between the two measurements were due to the presence of established turfgrass on the greenhouse profiles.

All greenhouse mixtures containing 10% Lake Charles clay had significantly lower infiltration rates after establishment and recompaction than mixtures without Lake Charles clay. The infiltration rate of the 5% Lake Charles clay mixture was also significantly lower than most other mixtures. 80BR-10LC-10PM had unacceptable infiltration rates both in the USGA laboratory (1.6 cm/hr) and in the greenhouse after establishment and recompaction (0.3 cm/hr). However, according to the USGA laboratory, Lake Charles clay mixtures had acceptable infiltration rates when combined with other sands or organic components. In the greenhouse, after establishment and recompaction, these mixtures had infiltration rates ranging from 2.2 to 3.1 cm/hr. These infiltration rates are sufficient to handle normal irrigation.

The mixtures containing calcined clay fines had infiltration rates intermediate between those containing Lake Charles clay and the mixtures containing the other inorganic amendments. In the greenhouse, the Super Rock^{R} mixture had the highest infiltration rate after establishment and recompaction, followed by ground rubber, Polyloam^{R}, and Hadite^{R} mixtures, respectively. All except the mixtures containing Lake Charles clay had infiltration rates that were too high, according to the USGA laboratory. However, in applying USGA standards to the greenhouse measurements, these mixtures are all acceptable.

There were no significant differences between the infiltration rates of the four types of boundaries (Table 6) after establishment and recompaction. However, it would be difficult to predict how the Petromat^{R} boundary would act with another soil mixture since it is not known whether Petromat^{R} or Lake Charles clay in the soil mixture overlaying the boundary was the limiting factor in the measurements obtained.

In the layer study, infiltration rates after establishment and recompaction are higher in each case for the layered profile than its respective prototype (Table 7). It should be noted here that more root growth occurred in the layered profiles than in their respective prototypes (Table 13). In theory, the infiltration rate of a layered profile is limited by the layer with the lowest rate of water transmission. The results reported here do not support this theory. Perhaps the greater root development in the layered profile enhanced water transmission.

In a factorial experiment comparing the three sand types (Brady, brick and concrete) and two inorganic ammendments (Lake Charles clay and calcined clay fines), no significant differences appeared between the final infiltration rates of the sands. However, mixtures containing calcined clay fines had significantly higher infiltration rates after establishment and recompaction than the Lake Charles clay mixtures. The Lake Charles clay mixtures had an average infiltration rate of 1.7 cm/hr while the mixtures containing calcined clay fines had an average infiltration rate of 15.1 cm/hr (Table 15).

In a 2 x 2 factorial experiment to compare peat moss with rice hulls and Lake Charles clay with calcined clay fines, no significant differences appeared between the infiltration rates of the two organic amendments. Differences similar to those in the 3 x 2 study occurred between the Lake Charles clay mixtures and the mixtures containing calcined clay fines (Table 16).

B. AVAILABLE WATER.

Table 8 shows the percentages of available water for fourteen soil mixtures obtained in the greenhouse and in the USGA laboratory. In general, the greenhouse measurements are higher than the USGA laboratory measurements. When preparing the greenhouse profiles for the available water measurements, the profiles were saturated and allowed to drain overnight. Assuming that the water remaining in each profile had reached equilibrium, since the core samples were taken at approximately 25 cm above the bottom of the soil mixture, the suction on the water at that level was 25 cm of water. In the USGA laboratory, the samples were placed on a tension table with 40 cm of H_2O suction acting on them. Thus, the greenhouse samples were, in general, wetter than the USGA samples and therefore had higher percentages of available water. Furthermore, the presence of a perched water table contributed to the higher percentages of available water in the profiles from the greenhouse.

Of the 14 soil mixtures evaluated in the USGA laboratory, only three met the USGA specifications for available water. These were the two Brady sand mixtures and 80BR-10LC-10PM. According to the measurements obtained in the greenhouse, all 14 soil mixtures met USGA criteria.

In the greenhouse, Brady sand mixtures had significantly higher percentages of available water. The Brady sand treatments were also highest in capillary porosity (Table 10) in both the greenhouse and the USGA laboratory measurements. When compared with the other mixtures in the 3 x 2 factorial study of sands with Lake Charles clay and calcined clay fines (Table 15), Brady sand mixtures were significantly higher in both available water and capillary porosity. Concrete sand mixtures were significantly lower in available water and capillary porosity than the other mixtures. These results expected based on the particle-size distributions of the sand fractions.

The treatments containing Lake Charles clay, calcined clay or calcined clay fines were generally higher in percent available water when compared with mixtures containing Hadite^{R}, Polyloam^{R}, or ground rubber (Table 8). As one might have expected, the mixtures which were low in percent available water, particularly the ground rubber mixtures, had low measurements of capillary porosity (Table 10). A correlation coefficient of 0.72 existed between available water and capillary porosity in the greenhouse measurements.

In the 2 x 2 factorial study of organic amendments, no significant differences were found between rice hull mixtures and peat moss mixtures for either percent available water or capillary porosity (Table 16).

In the layer study, each layered profile had a lower percentage of available water than its prototypal mixture (Table 9). However, only the difference between the 5% Lake Charles clay mixtures was statistically significant.

C. BULK DENSITY AND POROSITY

The bulk densities, capillary and non-capillary porosities of the 14 soil mixtures are reported in Table 10. As explained earlier, the greenhouse profiles were more severely compacted than the USGA laboratory samples. Thus, the bulk density and capillary porosity measurements on the greenhouse profiles were higher than the USGA laboratory measurements.

All samples measured in the USGA laboratory had bulk densities that were within the acceptable range of 1.20-1.60 g/cm^3. However, only the laboratory samples containing Brady sand or 10% Lake Charles clay met the minimum capillary porosity standard of 15%. Since all of the soil mixtures in the greenhouse had capillary porosities of 15% or greater, it would seem that specious measurements were obtained due to the excess wetness of these profiles. This seems even more evident upon examination of the two sets of measurements, particularly focusing upon the laboratory samples which met the minimum standard. The measurements of capillary porosity for these mixtures were similar in both the greenhouse and the USGA laboratory. However, great disparities existed between the two sets of measurements for the remaining mixtures.

In the 3 x 2 factorial experiment of sands and inorganic amendments, Brady sand mixtures had significantly lower bulk densities than the other sand mixtures. At the same time, Brady sand treatments were significantly higher in capillary porosity and retained significantly higher percentages of available water than concrete or brick sand treatments (Table 15). Thus, it seems that Brady sand would be suitable for use in golf greens when compared to the more commonly used sands.

No significant differences in bulk density or capillary porosity were found between mixtures containing calcined clay fines and Lake Charles clay mixtures in either the 3 x 2 factorial study (Table 15) or the 2 x 2 factorial study of organic amendments and inorganic amendments (Table 16). Also in the 2 x 2 factorial study, no significant differences were found between peat moss mixtures and rice hull mixtures for bulk density or capillary porosity.

D. ROOT GROWTH

The root growth results are reported as an average weight of the three samples from each of the 14 soil mixtures (Table 11), each of the boundary study profiles (Table 12), and each of the eight layer study profiles (Table 13). There were no significant root growth differences between the 14 soil mixtures nor the boundary study profiles. The most root growth occurred in the Super Rock^{R} mixtures while the least root growth was in the rubber mixtures. In the layer study, the two Lake Charles clay mixtures with no layer had significantly less root growth than the other profiles. In particular, the 85BR-5LC-10PM-layer and the 80BR-10LC-10PM-layer profiles had significantly more root growth than their prototypes indicating that a layer of more permeable material beneath a layer of less permeable material is more conducive to root growth than a uniform profile of the less permeable material.

No significant differences occurred in root growth of the mixtures in the 2 x 2 factorial study (Table 16) of organic amendments with Lake Charles clay and calcined clay fines. There was also no significant difference between Lake Charles clay and calcined clay fine mixtures in the 3 x 2 factorial study of sands with the two inorganic amendments. Root growth in the Brady sand mixtures was significantly greater than in the brick sand mixtures. Root growth in the concrete sand mixtures was not significantly different than in the other mixtures (Table 15).

E. CATION EXCHANGE CAPACITY.

The CEC values, presented in Table 14, range from a high of 27.8 meq/100 g for the mixture containing 80BR-10LC-10RH to a low of 20.5 meq/100 g for the mixture containing 85BR-5LC-10PM. There were no significant differences in CEC between any of the treatments.

F. PARTICLE MIGRATION

To investigate particle migration in the upper profiles, particle-size distribution analyses were made for each 2.5 cm increment of Lake Charles clay mixtures. The results of these analyses are presented in Table 17. In the mixture containing 85BR-5LC-10PM, the percentages of silt in the bottom four increments were within one standard deviation (0.67) of the mean (2.33%). The percentages of clay in the bottom four increments were also within one standard deviation (1.24) of the mean (4.30%). This uniformity of texture, which was found one year after the construction of the profiles, indicated a lack of particle migration.

In the mixture containing 80BR-10LC-10PM, the mean percentages for silt and clay were 3.11 and 7.42, respectively. The standard deviation for silt was 0.28%. The bottom two increments of soil mixture contained percentages of silt that were within one standard deviation of the mean. The next increment above, however, had a silt percentage that was greater than one standard deviation from the mean. The probability of a larger percentage of silt than the percentage in that increment was .0823. Thus, this difference in texture was not interpreted as having been significant. None of the percentages of clay in any of the increments were more than one standard deviation ($\pm$ 1.79%) away from the mean. The uniformity of texture in this profile also indicated a lack of particle migration and was indicative of an overall stability of the profile.

CONCLUSIONS

The purpose of this study was to ascertain the effects of various amendments on the physical properties of soil mixtures used for golf green construction and to identify components that can be used for the construction of satisfactory golf greens. The data obtained in this study were compared to measurements taken in the United States Golf Association Physical Soil Test Laboratory.

In the greenhouse study, it was found that infiltration rates decreased after establishment of the turfgrass, and decreased further after establishment and recompaction. This corroborates the findings of Brown and Duble (3). Discrepancies between USGA-laboratory and greenhouse measurements of infiltration rates taken after establishment and recompaction may be partially explained by differences in compaction levels. Based on USGA specifications, soil mixtures with acceptable infiltration rates in the greenhouse after establishment and recompaction had unacceptably high infiltration rates in the USGA laboratory. However, the greenhouse profiles were more severely compacted and had a grass cover which may have further reduced infiltration rates. Perhaps the USGA specifications for infiltration rates are too low and need to be revised in light of these results. Alternatively, the degree of soil compaction in the USGA laboratory could be increased.

There were several notable findings concerning the inorganic amendments that were investigated. First, calcined clay finds significantly increased infiltration rates over Lake Charles clay. Super Rock^R, calcined clay aggregates, was also very effective in producing rapid infiltration rates in golf green soil mixtures. Mixtures containing ground rubber were generally too dry and produced a medium inadequate for root growth. A soil mixture containing 10% Lake Charles clay by volume had extremely low infiltration rates. All other inorganic amendments were acceptable components for golf green soil mixtures.

Brady sand, which is a fine textured sand with a highly uniform particle-size distribution, does not meet the current USGA specifications for texture. It was found in the greenhouse study that the infiltration rates of Brady sand mixtures after establishment and recompaction were not significantly different from those of the recommended sands. Brady sand mixtures were found to hold significantly larger amounts of available water than mixtures with the other sands and were significantly higher in capillary porosity and lower in bulk density. Root growth in Brady sand mixtures was significantly greater than in brick sand, perhaps the most commonly used sand for golf green construction. Although not significantly different, root growth in Brady sand appeared to be greater than in concrete sand, a sand which meets USGA specifications for particle-size distribution. It is concluded that while USGA specifications are probably adequate for general use, they do not account for particular cases, such as sands with fine, but highly uniform texture. It is further concluded that the Brady sand would provide a medium for growth and maintenance of turfgrass superior to either brick or concrete sand.

No differences were found between peat moss and rice hulls in their effects on infiltration, water holding capacity, CEC, or root growth in soil mixtures. It is concluded that either of these components would be acceptable organic amendments to golf green soil mixtures.

Layered profiles had more root growth than their respective prototypal soil mixture profiles. Infiltration rates were also higher in the layered profiles than in their respective prototypes, contrary to expectations. The higher infiltration rates are perhaps due to greater root development in the layered profiles.

The boundaries had little effect on the properties of the soil mixtures measured in this study. The principal reason for the inclusion of a boundary in a golf green profile is to prevent particle migration into the underlying gravel layer. However, since particle migration was not found in the upper profiles of soil mixtures containing clay, the boundaries seem to serve little purpose.

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APPENDIX

Table 1. United States Golf Association Green Section recommendations for soil properties of golf green soil mixtures.

1. Infiltration rates.

Ideal:	10-15 cm/hr.
Maximum:	25 cm/hr.
Minima:	bermudagrass 5 cm/hr.
	bentgrass 7.6 cm/hr.

2. Sand: particle size distribution.

100% below 1 mm diameter

35% below 0.5 mm diameter

15% below 0.25 mm diameter

5% below 0.0625 mm diameter

3. Porosity.

Total pore space of 40-55% after compaction.

Not less than 15% non-capillary pores at 40 cm H_2O tension.

4. Bulk density.

Ideal:	1.25-1.45 g/cm^3
Minimum:	1.20 g/cm^3
Maximum:	1.60 g/cm^3

5. Water retention.

12-25% H_2O by weight at 40 cm H_2O tension.

6. Particle size-distribution of soil mixture.

Ideal:	0% over 2 mm diameter
Maximum:	3% over 2 mm diameter
Maximum:	10% over 1 mm diameter
Maximum:	25% below 0.25 mm diameter

Table 1. (Cont'd.)

Maximum: 5% silt

Maximum: 3% clay

Table 2. Particle-size distributions of sands and Lake Charles clay.

Material	Gravel	Sand Fractions					Total Sand	Silt	Clay
	above 2mm	2-1mm	1-0.5mm	0.5-.25mm	0.25-.1mm	0.1-.05mm	2-.05mm	0.05-.002mm	below .002mm
	%	%	%	%	%	%	%	%	%
Brick sand	0.5	3.1	18.1	57.9	18.4	2.0	99.5	0.0	0.0
Concrete sand	11.0	9.8	19.8	43.3	12.9	3.2	89.0	0.0	0.0
Brady sand	0.0	0.1	0.8	15.3	78.2	5.6	100.0	0.0	0.0
Lake Charles sand	0.0						9.0	21.0	70.0

Table 3. Percentage compositions by volume of 14 soil mixtures.

Treatment	Sand			AMENDMENTS Inorganic						Organic	
	Brick (BR)	Concrete (CN)	Brady (BD)	Lake Charles Clay (LC)	Calcined Clay Fines (CF)	Super Rock[R] (SR)	Hadite[R] (HA)	Poly-loam[R] (PL)	Ground Rubber (GR)	Peat Moss (PM)	Rice Hulls (RH)
85BR- 5LC-10PM	85			5						10	
80BR-10LC-10PM	80			10						10	
80BR-10CF-10PM	80				10					10	
80BR-10SR-10PM	80					10				10	
80BR-10HA-10PM	80						10			10	
80BR-10PL-10PM	80							10		10	
80BR-10GR-10PM	80								10	10	
80BR-20GR	80								20		
80CN-10LC-10PM		80		10						10	
80CN-10CF-10PM		80			10					10	
80BD-10LC-10PM			80	10						10	
80BD-10CF-10PM			80		10					10	
80BR-10LC-10RH	80			10							10
80BR-10CF-10RH	80				10						10

Table 4. Particle-size distribution of 14 soil mixtures.

Material	Gravel	Sand Fractions					Total Sand	Silt	Clay
	above 2mm	2-1mm	1-0.5mm	0.5-.25mm	0.25-.1mm	0.1-.05mm	2-.05mm	0.05-.002mm	below .002mm
	%	%	%	%	%	%	%	%	%
85BR- 5LC-10PM	1.2	2.5	15.8	57.7	17.9	1.3	95.2	0.6	3.0
80BR-10LC-10PM	1.6	4.0	16.1	52.6	17.4	1.5	91.6	1.3	5.5
80BR-10CF-10PM	0.5	2.9	17.4	55.9	17.7	1.8	95.7	0.3	3.5
80BR-10HA-10PM	7.1	3.1	14.7	52.3	18.4	1.7	90.2	0.2	2.5
80BR-10SR-10PM	1.0	3.5	16.0	53.7	16.0	0.8	90.0	5.5	3.5
80BR-10PL-10PM	1.0	3.5	18.9	59.3	14.6	0.7	97.0	0.7	1.3
80BR-10LC-10RH	1.0	2.3	14.1	51.5	17.9	1.9	87.6	3.1	8.3
80BR-10CF-10RH	1.1	2.6	15.6	56.1	19.5	2.1	95.9	0.2	2.8
80CN-10LC-10PM	13.9	8.2	16.9	34.7	11.4	2.1	73.3	5.5	7.3
80CN-10CF-10PM	14.1	9.8	20.6	41.4	10.5	1.0	83.3	0.6	2.0
80BD-10LC-10PM	0.1	0.0	0.8	16.6	68.9	4.6	90.9	3.2	5.8
80BD-10CF-10PM	0.0	0.1	0.8	15.0	76.7	5.5	98.1	0.6	1.3
80BR-10GR-10PM	0.7	4.4	18.3	55.8	17.3	1.2	97.0	0.0	2.3
80BR-20GR	0.4	5.0	18.0	56.7	17.6	0.8	98.1	0.0	1.5

Table 5. Infiltration rates for 14 soil mixtures.

	Infiltration I (after compaction)	Infiltration II (after grass establishment)	Infiltration III (after grass establishment and recompaction)	Infiltration IV (USGA lab.)
	------------	------------	cm/hr ------------	------------
80BR-10LC-10PM	84.1 bcd*	27.7 fg	0.3 f	1.6
80BD-10LC-10PM	60.8 d	15.5 g	2.2 f	12.0
80CN-10LC-10PM	100.5 bcd	71.3 cde	2.6 f	16.3
80BR-10LC-10RH	103.5 bcd	104.2 b	3.1 f	22.8
85BR- 5LC-10PM	97.7 bcd	55.4 de	4.4 ef	39.8
80BR-10CF-10RH	109.3 abcd	77.8 cd	9.0 de	51.5
80BD-10CF-10PM	58.7 d	50.0 ef	13.7 cd	36.9
80BR-10CF-10PM	109.0 abcd	96.5 bc	13.7 cd	42.9
80CN-10CF-10PM	160.0 a	109.2 b	18.0 bc	40.3
80BR-10HA-10PM	115.0 ab	106.3 b	20.4 ab	64.3
80BR-10PL-10PM	104.0 bcd	94.8 bc	22.5 ab	104.2
80BR-10RB-10PM	113.9 abc	93.2 bc	22.8 ab	53.7
80BR-20RB	123.9 ab	50.1 ef	23.1 ab	77.8
80BR-10SR-10PM	137.7 ab	135.9 a	25.2 a	62.8

*Values within a column followed by the same letter(s) are not significantly different at the 5% level according to Duncan's multiple range test.

Table 6. Infiltration rates for boundary study (cm/hr).

	Infiltration I (after compaction)	Infiltration II (after grass establishment)	Infiltration III (after grass establishment & recompaction)
	------------	cm/hr	------------
No boundary	97.7 ab*	55.4 ab	4.4 ns
Petromat[R]	10.5 c	36.1 b	3.8 ns
Brick sand	115.2 a	66.9 a	5.9 ns
Sieved materials	94.3 b	72.4 a	3.7 ns

*Values within a column followed by the same letter(s) are not significantly different at the 5% level according to Duncan's multiple range test.

Table 7. Infiltration rates for layer study profiles.

	Infiltration I (after compaction)	Infiltration II (after grass establishment)	Infiltration III (after grass establishment & recompaction)
	cm/hr		
80BR-10CF-10PM-layer	126.5 ns	101.4 b*	19.5 a
80BR-10CF-10PM	109.9 ns	96.5 b	13.7 b
80BR-10CF-10RH-layer	69.9 ns	105.3 b	10.7 b
85BR- 5LC-10PM-layer	86.4 ns	76.7 bc	9.8 bc
80BR-10CF-10RH	109.3 ns	77.8 bc	9.0 bc
85BR- 5LC-10PM	97.7 ns	55.4 cd	4.4 de
80BR-10LC-10PM-layer	134.9 ns	165.5 a	3.1 e
80BR-10LC-10PM	84.1 ns	27.7 d	0.3 e

*Values within a column followed by the same letter(s) are not significantly different at the 5% level according to Duncan's multiple range test.

Table 8. Percentage available water by weight of 14 soil mixtures.

Mixture	Available water	USGA Laboratory
80BD-10CF-10PM	22.9 a*	18.25 ab
80BD-10LC-10PM	21.3 a	20.5 a
80BR-10CF-10RH	17.7 b	9.0 de
80BR-10LC-10RH	17.4 b	11.4 cd
80BR-10SR-10PM	16.0 bc	7.1 de
80BR-10CF-10PM	16.0 bc	8.7 de
80BR-10LC-10PM	15.9 bc	15.3 bc
85BR- 5LC-10PM	15.8 bcd	8.5 de
80BR-10HA-10PM	14.9 bcde	6.2 e
80BR-20RB	14.0 cde	6.5 e
80BR-10PL-10PM	13.4 cde	7.8 de
80BR-10RB-10PM	12.8 cde	7.8 de
80CN-10CF-10PM	12.6 de	7.3 de
80CN-10LC-10PM	11.9 e	10.6 de

*Values within a column followed by the same letter(s) are not significantly different at the 5% level according to Duncan's multiple range test.

Table 9. Percentage available water by weight of layer study profiles.

Treatment	Available Water
80BR-10CF-10RH	17.7 a*
80BR-10CF-10RH-layer	16.3 a
80BR-10CF-10PM	16.0 ab
80BR-10LC-10PM	15.9 ab
85BR- 5LC-10PM	15.8 ab
80BR-10LC-10PM-layer	14.0 bc
80BR-10CF-10PM-layer	13.9 bc
85BR- 5LC-10PM-layer	13.0 c

*Values within a column followed by the same letter(s) are not significantly different at the 5% level according to Duncan's multiple range test.

Table 10. Bulk density, capillary porosity and non-capillary porosity for 14 soil mixtures.

Treatment	Bulk density greenhouse	Bulk density USGA	Capillary porosity greenhouse	Capillary porosity USGA	Non-capillary porosity greenhouse	Non-capillary porosity USGA
	------- g/cm^3 -------		---------- % ----------			
80CN-10LC-10PM	1.68 a*	1.53	21.4 def	19.4	14.9 defgh	22.9
80BR-10LC-10PM	1.65 ab	1.56	28.3 bc	27.8	9.4 h	13.3
80BR-10LC-10RH	1.63 ab	1.48	30.0 ab	19.0	8.3	25.2
80BR-10CF-10RH	1.62 abc	1.38	26.8 bc	12.9	12.1 gh	35.0
80CN-10CF-10PM	1.62 abc	1.60	19.9 efg	12.4	18.8 bcdef	27.2
80BR-10CF-10PM	1.61 abcd	1.40	24.6 cd	12.8	14.3 defgh	34.4
85BR- 5LC-10PM	1.56 bcde	1.56	22.3 de	11.0	18.9 bcde	31.1
80BR-10HA-10PM	1.53 cdef	1.55	21.0 def	8.7	17.6 cdefg	32.8
80BR-10SR-10PM	1.53 cdef	1.43	21.9 de	10.3	20.2 bcd	35.7
80BD-10LC-10PM	1.53 cdef	1.44	33.1 a	32.8	9.2 h	12.9
80BR-10RB-10PM	1.52 def	1.32	17.7 fgh	10.9	24.8 ab	39.3
80BD-10CF-10PM	1.51 ef	1.37	32.7 a	27.6	10.1 h	20.7
80BR-20RB	1.47 ef	1.26	15.9 h	8.4	28.6 a	44.1
80BR-10PL-10PM	1.44 f	1.32	22.1 de	10.9	23.5 abc	39.3

*Values within a column followed by the same letter(s) are not significantly different at the 5% level according to Duncan's multiple range test.

Table 11. Root growth of Tifdwarf bermudagrass in 14 soil mixtures.

Treatment	Root growth
	$mg/75\ cm^3$
80BR-10SR-10PM	20.9 ns*
80BD-10LC-10PM	18.7 ns
80BR-10HA-10PM	18.6 ns
80BD-10CF-10PM	18.6 ns
80BR-10CF-10PM	18.0 ns
80CN-10CF-10PM	17.0 ns
80CN-10LC-10PM	16.9 ns
80BR-10CF-10RH	12.8 ns
80BR-10LC-10RH	11.6 ns
85BR- 5LC-10PM	10.1 ns
80BR-10PL-10PM	9.4 ns
80BR-10LC-10PM	9.0 ns
80BR-10RB-10PM	7.5 ns
80BR-20RB	4.3 ns

*Values within a column followed by the same letter(s) are not significantly different at the 5% level according to Duncan's multiple range test.

Table 12. Root growth of Tifdwarf bermudagrass in boundary study profiles.

Treatment	Root growth
	mg/75 cm^3
Brick sand	17.9 ns
Petromat[R]	15.5 ns
Sieved materials	10.2 ns
No boundary	10.1 ns

*Values within a column followed by the same letter(s) are not significantly different at the 5% level according to Duncan's multiple range test.

Table 13. Root growth of Tifdwarf bermudagrass in layer study profiles.

Treatment	Root growth
	mg/75 cm^3
80BR-10CF-10PM	21.5 a*
85BR- 5LC-10PM-layer	20.2 ab
80BR-10CF-10PM	18.0 abc
80BR-10LC-10PM-layer	17.8 abc
80BR-10CF-10RH-layer	16.9 abcd
80BR-10CF-10RH	12.8 bcd
85BR- 5LC-10PM	10.1 cd
80BR-10LC-10PM	9.0 d

*Values within a column followed by the same letter(s) are not significantly different at the 5% level according to Duncan's multiple range test.

Table 14. Cation-exchange capacities of 14 soil mixtures.

Treatment	CEC --meq/100g--
80BR-10LC-10RH	27.8 ns*
80BD-10LC-10PM	26.7 ns
80BR-10LC-10PM	26.2 ns
80BD-10CF-10PM	25.6 ns
80BR-10PL-10PM	25.1 ns
80CN-10LC-10PM	24.4 ns
80BR-10SR-10PM	23.3 ns
80BR-10RB-10PM	23.2 ns
80CN-10CF-10PM	23.1 ns
80BR-10CF-10RH	22.4 ns
80BR-10HA-10PM	22.2 ns
80BR-10CF-10PM	21.9 ns
80BR-20RB	21.1 ns
85BR- 5LC-10PM	20.5 ns

*Values within a column followed by the same letter(s) are not significantly different at the 5% level according to Duncan's multiple range test.

Table 15. Summary of the 3 x 2 factorial study of sands and inorganic amendments.

	Infiltration rate I	Infiltration rate II	Infiltration rate III
	---------------	cm/hr	---------------
Sands			
Brick	96.6 ns*	62.1 ab	8.0 ns
Concrete	130.2 ns	90.2 a	10.3 ns
Brady	59.8 ns	32.7 b	7.0 ns
Amendments			
Lake Charles clay	81.8 ns	38.2 b	1.7 b
Calcined clay fines	109.3 ns	85.2 a	15.1 a

	Available water	Bulk density	Capillary porosity
	%	g/cm^3	%
Sands			
Brick	15.9 b	1.63 a	26.5 b
Concrete	12.2 c	1.65 a	20.7 c
Brady	21.8 a	1.52 b	32.9 a
Amendments			
Lake Charles clay	16.3 ns	1.62 ns	27.6 ns
Calcined clay fines	16.9 ns	1.58 ns	25.7 ns

	Root growth
	$mg/75\ cm^3$
Sands	
Brick	13.5 b
Concrete	16.9 ab
Brady	18.6 a
Amendments	
Lake Charles clay	14.9 ns
Calcined clay fines	17.9 ns

*Values within a column followed by the same letter(s) are not significantly different at the 5% level according to Duncan's multiple range test.

Table 16. Summary of the 2 x 2 factorial study of organic amendments with inorganic amendments.

	Infiltration rate I	Infiltration rate II	Infiltration rate III
	-----------------cm/hr-----------------		
Organic Amendment			
Peat moss	96.6 ns	62.1 ns	7.0 ns
Rice hulls	106.4 ns	91.0 ns	6.0 ns
Inorganic Amendment			
Lake Charles clay	93.8 ns	65.9 ns	1.7 b
Calcined clay fines	109.2 ns	87.2 ns	11.3 a

	Available water	Bulk density	Capillary porosity
	%	g/cm^3	%
Organic Amendment			
Peat moss	15.9 ns	1.63 ns	26.5 ns
Rice hulls	17.6 ns	1.62 ns	28.4 ns
Inorganic Amendment			
Lake Charles clay	16.7 ns	1.64 ns	29.2 ns
Calcined clay fines	16.9 ns	1.62 ns	25.7 ns

	Root growth
	$mg/75\ cm^3$
Organic Amendment	
Peat moss	13.5 ns
Rice hulls	12.2 ns
Inorganic Amendment	
Lake Charles clay	10.3 ns
Calcined clay fines	15.4 ns

*Values within a column followed by the same letter(s) are not significantly different at the 5% level according to Duncan's multiple range test.

Table 17. Particle migration study of two Lake Charles clay mixtures.

85BR- 5LC-10PM

Increment	% Sand	% Silt	% Clay
1	91.56	3.00	5.44
2	95.06	3.00	1.94
3	93.06	1.50	5.44
4	92.06	3.30	4.64
5	94.57	1.80	3.63
6	94.58	2.00	3.42
7	92.58	2.00	5.42
8	93.56	2.00	4.44

80BR-10LC-10PM

Increment	% Sand	% Silt	% Clay
1	90.40	3.49	6.11
2	91.40	2.79	5.80
3	87.40	2.99	9.60
4	88.43	2.99	8.58
5	86.89	3.50	9.61
6	91.38	3.00	5.62
7	90.42	2.99	6.59

VITA

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