12-2001

The Influence of Peat and Inorganic Amendments on Physical Properties of Sand-Based Rootzones

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Recommended Citation

Waltz, Freddie C. Jr., "The Influence of Peat and Inorganic Amendments on Physical Properties of Sand-Based Rootzones" (2001). *All Dissertations*. 2653.
https://tigerprints.clemson.edu/all_dissertations/2653

December 14, 2001

To the Graduate School:

This dissertation entitled "The Influence of Peat and Inorganic Amendments on Physical Properties of Sand-Based Rootzones" and written by Freddie C. Waltz Jr. is presented to the Graduate School of Clemson University. We recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy with a major in Crop and Soils Environmental Science.

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THE INFLUENCE OF PEAT AND INORGANIC AMENDMENTS ON PHYSICAL PROPERTIES OF SAND-BASED ROOTZONES

A Dissertation
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy
Crop and Soil Environmental Science

by
Freddie C. Waltz Jr.
December 2001

Co-advisors: Drs. L. B. McCarty and V. L. Quisenberry

ABSTRACT

Many golf course putting greens and athletic fields are constructed with a medium consisting of a high sand content. Peat is the most common amendment to rootzone sand (RZS). However, a trend to replace peat with inorganic soil amendments (IOSA), such as calcined clay (CC) and diatomaceous earth (DE), is occurring. Laboratory studies were conducted to evaluate physical and hydraulic properties of rootzone mixtures and a field study investigated the potential of IOSA as a replacement to peat. In laboratory evaluations, amended RZS reduced the bulk density of all mixtures, while saturated hydraulic conductivity (K_{sat}) for the RZS and mixtures of Canadian sphagnum peat (CSP) and CC exceeded USGA specifications. The DE mixture had the lowest K_{sat}, which was attributed to the 2% by weight of particles <0.05 mm in diameter. Similarly, RZS water retention and drainage were influenced by amendments. In amended sand mixtures, 0.015 to 0.116 $cm^3\ cm^{-3}$ more water was retained compared to unamended sand. Of water retained in the rootzone, the peat mixture held >50% in the upper 15 cm, while straight RZS held the least (37.2%). In drainage experiments, approximately 75% of the total water was lost within the first 15 minutes; however, only 65% was lost in the first 15 minutes for the CSP mixture. After 24 hours of drainage, the CC mixture lost the most water (5.9 cm). Pressure potentials were also measured during drainage. For all mixtures, within 5 minutes of drainage, pressure potentials were negative in the surface 20-cm and positive below the 25-cm depth, indicating saturation. Twenty-four hours after drainage, positive pressure potentials were measured in the gravel layer at the 35-cm depth. In field evaluations of rootzone mixtures on turfgrass growth and the rootzone environment, bentgrass (*Agrostis palustris* Huds. X *A. stolonifera* L. ‘L-93) seeded into plots amended with peat became established 3 months prior to plots with IOSA and 15 months prior to straight RZS plots. Lower bulk densities were measured in the upper 10-cm of field cores for amended plots. Also, soil surface strength of peat amended plots were 13 to 31% lower than RZS and IOSA amended plots. Resistance to penetration in the lower 20 to 30 cm depths ranked in the order of CC > DE > RZS > CSP. The capacitance probe (CP) has been used in mineral soils but not in sand-based, rootzone mixtures to measure soil water content. In laboratory studies, the CP underestimated water content as compared to gravimetric methods; however, linear calibration equations were developed for each mixture. CP readings were unaffected by soil bulk density, but were influenced by amendments. Because of differences between calibration equations for each rootzone mixture, further investigation of the CP is necessary for usefulness as an irrigation tool. Due to greater water retention, lower flow rates, reduced bulk densities, improved turfgrass establishment, and lower impact absorption characteristics, it appears peat remains the best amendment for USGA specification sands.

DEDICATION

I dedicate this dissertation to Mary Catherine. All the hard work and effort was for you.

ACKNOWLEDGMENTS

First, I would like to thank Bert for the opportunity and encouragement to pursue this degree. I truly appreciate his assistance and guidance, and look forward to future collaboration. Also, I would like to thank Dr. Quisenberry for his continuous push to "understand" and ask "why". To the members of my committee, Drs. Jim Camberato, Roy Dodd, and Bruce Martin, I am grateful for your assistance and insight. Furthermore, I appreciate all the support and encouragement of the other faculty in soils, Drs. Horace Skipper and Bill Smith, in the completion of this dissertation. The friendship and support of this entire group has made this an experience I shall never forget.

For the contribution of materials and labor, I thank Simmons Irrigation, Golf Agronomics, Southern Soil Technologies, Profile™ Products LLC, and PSA™. For the assistance in construction and maintenance I would like to acknowledge the staff at The Walker Course at Clemson University and the staff at Ag. Support.

For the assistance in gathering data and running samples I thank Nancy Allgood and Mike McLeod. Also, in appreciation of hard work and long days in the summer heat I need to acknowledge Staci, Travis, Angel, and Philip. For continuous support and encouragement I appreciate my fellow graduate students, with a special thanks to Jason, Jeanne, Todd, Teresa, and Ian. Likewise, the kindness of Mike and Camie and their willingness to open their house and share their family with Leigh and I will never be forgotten. For that I am truly grateful. It is this group that reemphasized that learning is not always academic and it is friendships that make life fun and exciting.

To Mom and Dad, thank you for instilling the desire for an education and your unending love. Also, Sandra I am grateful for your support and encouragement. Lastly, to my wife Leigh, you have been the unsung hero, thank you for the last eight plus years. I know you have worked hard for this degree as well, and for that I am grateful. Through patience and trust in each other we have achieved a lot and with you at my side I am anxiously awaiting the challenges that lie ahead.

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CHAPTER 1

INTRODUCTION

During most years, water-supply shortage is regarded as the primary environmental concern of United States golf course superintendents (Golf Course Management Staff, 2001). As water conservation and usage issues become more important, golf course superintendents will be forced to make judicious use of water resources. Turfgrass managers will have to justify the use and volume of water and forgo the days of indiscriminate irrigation.

It is accepted that soil water is dynamic and is influenced by soil properties, cultural practices, and crop uptake (Paltineanu and Starr, 1997; Whalley et al., 1992). Since the soil in the rootzone acts as a storage reserve for water, an understanding of the soil moisture status is essential for efficient irrigation practices. With many factors (plant species, soil type, physiological stage of the plant, microenvironments, etc.) affecting soil water status, managers currently have few *in situ* means of determining soil water conditions.

Over-irrigation is often the normal practice and not the exception (Kneebone et al., 1992; Tovey et al., 1969; Morgan and Marsh, 1965). Golf greens are often irrigated daily for a certain time period regardless of prior rainfall, rooting depth, water content and soil water holding capacity, or daily turfgrass evapotranspiration (ET) rates. A possible reason for over-irrigation is the lack of a practical means to guide turfgrass irrigation. Several methods for guiding irrigation are qualitative and adapted to quick field adjustments, while others are time consuming but provide quantitative information. An efficient and accurate method of measuring soil water content could improve water management in turfgrass systems.

Various companies have been developing technology and instrumentation for modern golf course maintenance for several years. For example, current irrigation systems with central computers and hand held remote controls allow for easier and more efficient water application. Such systems allow turfgrass managers to apply water with greater precision and uniformity, resulting in improved water management and decreased energy consumption. While water delivery has become more efficient, indiscriminate water usage still often occurs.

Also, a poor understanding of the components within the turfgrass rootzone environment may influence the tendency for over-irrigation. Many golf putting greens have been constructed to meet United States Golf Association (USGA) specifications, which include high sand contents (Hummel, 1993). These construction standards are a uniform guideline that can provide many benefits in turfgrass establishment and maintenance. The sand provides good drainage, compaction resistance, and aeration for root growth, but is poor at retaining adequate moisture and nutrients for turfgrass growth (Beard, 1973). Physical characteristics of rootzone soils and soil amendments used for putting greens have been investigated. Parameters studied include particle size distribution, bulk density, water holding capacity, infiltration rates, hydraulic conductivity, air filled and capillary porosity (Baker and Richards, 1997; Morgan et al., 1966). However, research investigating soil water content and soil-matric potential at various depths within the rootzone has been limited.

Amendments, organic and inorganic, have been used to reduce leaching of water while maximizing plant available water and nutrient holding capacity (Bigelow et al., 2001; Sartain, 1995). Huang and Petrovic (1995) reported that peat, the most common amendment used in greens construction, loses its desirable characteristics over time. Other materials are on the market with user testimonials claiming increased turfgrass rooting and soil oxygen while retaining nutrients and water. With the lack of scientific research to help sort through these different construction methods and amendments, the end-user (golf course developers and superintendents) has little basis to decide which construction options are best for a particular situation.

The objectives of this research were:

1. To gain an understanding of common and alternative golf course putting greens construction methods in respect to inorganic soil amendments like calcined clay (CC) and diatomaceous earth (DE).
2. To evaluate two inorganic amendments (CC and DE) as a potential replacement to peat in putting green rootzones.
3. To evaluate and calibrate a capacitance probe for use in four golf course putting green rootzone mixes to better define soil moisture status.
4. To evaluate field performance of inorganically amended sand to unamended sand and sand amended with a traditional organic amendment, Canadian sphagnum peat.

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CHAPTER 2

LITERATURE REVIEW

Many factors, environmental and imposed, affect turfgrass water uptake and use. In a greenhouse study, Shearman and Beard (1973) investigated water use rate of bentgrass (*Agrostis palustris* Huds.) and reported light intensity, mowing height, and nitrogen nutrition levels had greater influence on water use rates than other factors such as growing temperature, and frequency of irrigation and mowing. It was concluded that when these cultural parameters are manipulated singularly, they may not be significant, but in combination they could reduce the water requirements of a turfgrass. Fry and Butler (1989) reported water use rate on bentgrass in Colorado as 4.6 mm day^{-1} when mowed at 6 mm and 4.9 mm day^{-1} when mowed at 12 mm. Research in Israel on other turfgrasses reveal that delaying irrigation until the onset of temporary wilting caused a significant decrease in water consumption and growth (up to 35%) for most grasses (Biran et al., 1981). Other management practices such as aerification (water injection verses traditional solid and hollow tine), topdressing, and fungicide application can influence turfgrass quality (Carrow, 1996). Research related to preconditioning turfgrass to heat and drought stress could allow for more efficient water use while maintaining an acceptable quality.

Soil drying can have significant effects on turfgrass physiology and growth. Biran et al. (1981) observed a decrease in net photosynthesis of warm and cool-season turfgrasses as soil water potentials decreased. Likewise, Dean-Knox et al. (1998)

reported a decrease in bermudagrass and tall fescue clipping yields and turfgrass cover as soil matric potentials decreased. However, plant response to soil moisture levels may be species dependent. Aronson et al. (1987) reported a decline in leaf growth of Kentucky bluegrass (*Poa pratensis* L.) and perennial ryegrass (*Lolium perenne* L.) at soil water potentials of –50 kPa, while red fescue (*Festuca rubra* Gaud.) and hard fescue (*F. ovina* L.) continued growth to a soil water potential of –400 kPa. Garrot and Mancino (1994) reported no permanent effect on quality of fairway grown bermudagrass (*Cynodon dactylon* [L.] Pers.) at soil water pressures below –1500 kPa (accepted permanent wilting point) measured at 90-cm. To reduce unnecessary irrigation, continued research to identify signs of imminent drought stress for specific turfgrass species is needed.

Irrigation Guidance

Water is important for turfgrass survival and previous research on turfgrass water use is varied. Aspects that have been investigated are water use for breeding purposes (Lehman et al., 1993; Salaiz et al., 1991; Biran et al., 1981) and determination of evapotranspiration (ET) rates for irrigation management. Investigations have focused on using a guide to direct timing and amount of irrigation, as compared to irrigating turfgrass on a set schedule. While there has been little agreement as to the most efficient method to direct irrigation, there is a consensus that water application based on soil or plant moisture status is more efficient than applying water on a set schedule. Methods to guide irrigation include basing water applications on estimated daily turfgrass evapotranspiration (ET) rates, soil water potential, and soil volumetric moisture status.

ET Guided Irrigation

Evapotranspiration is the combined loss of water through plant transpiration and evaporation of water from the soil. The water budget method used to guide turfgrass irrigation is based on estimated daily turfgrass ET rates. This technique uses local weather information (i.e. temperature, relative humidity, wind velocities, solar radiation, etc.) in an equation, also called a model, to estimate the amount of moisture lost through ET. Irrigation water is then applied to compensate for the moisture lost. The practice of adjusting irrigation amounts based on ET data has been shown to effectively conserve water resources (Richie et al., 1997; Salaiz et al., 1991; Fry and Butler, 1989). There are several models that estimate ET and are used to guide turfgrass irrigation. Fry et al. (1997) found turfgrass species, mowing height, and nitrogen fertility to influence the accuracy of ET models. Also, certain models may provide more accurate estimates in one part of the country as compared to another. Using ET to guide irrigation requires the input of many factors and site specific calibration. When the proper information is used, ET can be an effective method of managing water resources; however, knowledge of many variables is required for efficient use.

Probe Guided Irrigation

Researchers have continually shown that efficient water management is achieved by using a reliable device to guide irrigation timing. The use of instrumentation, or sensors, is yet another method of determining soil moisture status. There are various types of instruments that measure moisture content (i.e. porous blocks, thermal dissipation blocks, neutron probes, dielectric constant probes, plus others) with each having positive and negative attributes. Permanently buried sensors have the potential to be valuable tools in the decision process of when to irrigate and how much water to apply. Criteria for an effective moisture probe for golf course use includes readings that are

- accurate,
- independent of soil type or organic matter content, and soil compaction,
- independent of pesticide or fertilizer application (soil ionic strength),
- effective in a real-time manner,
- easily interfaced with a computer system,
- relatively permanent, and
- small enough not to disturb the playing surface or required maintenance practices (i.e. hole locations and routine aerification).

However, which device and what information to be used, are subject to debate. Some scientists believe water applications should be scheduled based on the soil water potential (Letey, 1985), while others believe irrigation based on direct measurements of volumetric soil moisture status can be an effective method of guiding turfgrass irrigation (Kome, 1996).

Probes

Tensiometers

It has been shown that irrigations guided by tensiometers, which measure soil water potential, can reduce irrigation frequencies, soil compaction, and nutrient leaching. When compared to a set irrigation schedule, Morgan and Marsh (1965) reported, for a clay loam soil, irrigation of a mixture of bluegrass (*Poa* sp.) and fescue (*Festuca* sp.) guided by tensiometers installed at two depths (5 cm and 12.5 cm) could reduce water use by 83% as compared to daily irrigation during June and July. Improved root vigor and depth were also observed on tensiometer irrigation guided greens, while playability did not suffer. In a separate study, Morgan et al. (1966) reported less compaction and fewer irrigations for common bermudagrass under tensiometer-guided irrigation compared to set irrigation schedules on a sandy loam soil. Compared to plots irrigated on a set irrigation schedule, O'Neil and Carrow (1982) were able to decrease water use by 28 to 66% using tensiometers to irrigate Kentucky Bluegrass (*Poa pratensis* L.). On 'Tifgreen' bermudagrass (*Cynodon dactylon* (L.) Pres. X *C. transvaalensis* Burtt-Davey) managed as golf course fairways, Augustin and Snyder (1984) were able to use 42 to 95% less water using tensiometer-guided irrigations (0.06 to 0.38 cm d^{-1}) compared to plots that received daily irrigation (0.91 to 1.22 cm d^{-1}). In addition, improved root vigor and depth were observed on tensiometer irrigation guided greens. Also, appropriate irrigation practices can influence nutrient leaching. For a sandy soil, Snyder et al. (1984) observed a reduction in nitrogen leaching under tensiometer-guided irrigation. In the Northeastern United States, Aronson et al. (1987) suggest tensiometers can improve water conservation by reducing irrigation frequency when –80 kPa is used as a threshold for irrigation.

Irrigation based on soil water potential can conserve water and improve the turfgrass rootzone environment. However, water savings have not been demonstrated on a modified sand profile construction as prescribed by the United States Golf Association (USGA). Also, the use of tensiometers by turfgrass managers has not been widely adopted. Possible reasons include tensiometers require continual maintenance, are subject to damage by turfgrass cultivation machinery (e.g. verticutters and aerifiers), and irrigation regimes based on soil water pressure are poorly understood by turfgrass managers. Cassel and Klute (1986), recommend tensiometers installed in the field to be inspected at least twice a week with more frequent inspections during hot and dry soil conditions. Soil water pressures used for irrigation scheduling have varied greatly. Augustin and Snyder (1984) used –10 kPa as a threshold for irrigating hybrid bermudagrass, while Garrot and Mancino (1994) reported acceptable bermudagrass quality when soil water pressures reached –1500 kPa at the 90 cm depth. For cool-season grasses, soil water pressures used for irrigation guidance has ranged from –12 to –80 kPa (Aronson et al., 1987; O'Neil and Carrow, 1982; Morgan and Marsh, 1965).

Neutron Probes

Although highly accurate for measuring soil water content, neutron probes are not practical for golf course use due to limitations and the high cost associated with the system. Because neutron probes use radioactive materials (radium-beryllium or americium-beryllium) to measure hydrogen ions associated with water molecules, they are highly accurate (Miller and Gardiner, 1998; Evett and Steiner, 1995). Due to the use of radioactive materials special licensing is required for their use (Devitt and Morris, 1997; Miller and Gardiner, 1998; Evett and Steiner, 1995). Also, neutron probes are unreliable near the soil surface (Hanks and Ashcroft, 1980; Kome, 1996; Song et al., 1998).

Despite the reported disadvantages, Aragao et al. (1997) found neutron probes beneficial for determining field capacity and scheduling irrigation on sand-based putting greens. However, a 43% discrepancy was reported between laboratory and probe measurements of field capacity, with probe measurements being higher. The authors did not recommend practical use of the neutron probe for turfgrass managers. Instead, for the medium sand used in this study, they recommended 50% depletion of available water which would give a water storage of 2.7 to 3.2 days, assuming an ET rate of 6 mm d^{-1}.

TDR Probes

A relatively new technology to determine soil moisture is the measurement of the soil dielectric constant (DC). The DC is a unit-less measurement of a solvent's ability to keep opposite charged particles apart; in this case the solvent is water (Voet and Voet, 1995). The DC of dry soil ranges from 2 to 7, while the accepted DC value for water is 80.4 at 20° C and atmospheric pressure (Miller and Gardner, 1998; da Silva et al., 1998; Paltineanu and Starr, 1997). Due to the difference between dry soil and water, moisture content can be measured because changes in DC are primarily the result of volumetric water content and are sensed as changes in oscillation frequency (Seyfried and Murdock, 2001). Greater moisture contents cause higher DC values while lower DC readings indicate reduced moisture content. There are two basic types of probes that measure DC, time domain reflectometry (TDR) probes and capacitance probes.

Time domain reflectometry is a safe technique that provides reliable, instantaneous readings that can be automated. TDR operates by emitting an electromagnetic pulse from a source through a wire and into two parallel probes or waveguides in the soil. The time for the pulse to travel down the wire, through the probes, and return to the source is a function of the DC. When the soil matrix contains moisture, the return time is slowed due to the high DC of water (Devitt and Morris, 1997; Miller and Gardiner, 1998).

When compared to moisture contents from neutron probes and gravimetric techniques, Hanson and Peters (1997) found good correlation with several commercially available TDR probes. In a sandy soil, Cereti et al. (1997) observed good relationship between gravimetric and TDR techniques. Likewise, Vaz and Hopmans (2001) reported excellent agreement between TDR and gravimetric measurements of soil water content.

Organic soils, however, may require separate calibration. When evaluating TDR to guide irrigation of plants in various organic potting media (a peat : sand mixture was included) used in greenhouse production, Anisko et al. (1994) found differences in water content between organic mixtures and sand. The increased water content of organic mixes was attributed to greater amounts of bound water, but through calibration, TDR can be applied to monitor water contents of organic media.

Researchers have been using time domain reflectometry (TDR) since the early 1980s for scheduling irrigation. However, little research has been specific to turfgrass. In fairway turf, Kome (1996) reported potential water savings of 46% from irrigations scheduled based on measuring soil moisture depletion with TDR compared to evapotranspiration estimates. However, water savings have not been demonstrated on a USGA sand profile.

TDR wave guides can be of variable length (20 to 80 cm) and when compared to weighing lysimeters in a turfgrass ecosystem, Young et al. (1997) found TDR probes measured up to 96% of the water lost through ET. However, it was concluded the longer probes more accurately estimated the soil water content because they removed some of the near-surface variability than the shorter probes. As technology improves, TDR may become a practical method of guiding turfgrass irrigation.

Capacitance Probes

Whereas the use of TDR to schedule irrigation is relatively new, recent (since the early 1990s) technological advances have introduced capacitance probes (CP) into the water measurement arena. Like TDR, capacitance probes measure water content based on soil DC. Capacitance probes can be buried in the soil, are small (4.2 cm diameter and 10 cm long), easily integrated into automated data collection systems, and are less expensive than TDR (Devitt and Morris, 1997). As a result, CP can provide real time moisture information such that turfgrass managers can quickly and accurately assess moisture in individual greens. Also like TDR, soil temperature and ionic strength can influence CP readings (Campbell, 1990). However, some CP measure soil salinity and temperature along with DC, allowing for more reliable moisture readings (Paltineanu and Starr, 1997). Although only limited data exist for the use of CP in turfgrass, Starr and Paltineanu (1998) found CP to provide acceptable real-time sensitivity when measuring soil water moisture in field grown corn (*Zea mays* L).

If CP are to serve as tools for water management on golf course putting greens constructed with high sand contents, refinements may be necessary. There may be a need to calibrate CP to particular soils. After evaluating a CP, Seyfried and Murdock (2001) concluded a separate calibration curve was necessary for each of 4 soils as soil water contents increased. Also, soil temperature and electrical conductivity affected the probe. Likewise, Whalley et al. (1992) concluded soil bulk density could affect readings of a probe based on soil dielectric measurements. With further research and advancements in technology, CP may prove to be an economically justifiable tool for guiding irrigation practices on golf courses.

Other Probes

Other types of probes have been used to determine soil water content. On a USGA specification rootzone media, Freeland et al. (1990) used parallel, bare wire ends to measure soil resistivity. An empirical equation was used to convert resistivity values to moisture contents. While this technique is inexpensive, rapid and useful in measuring relative moisture contents, sensors are sensitive to fluctuating soil temperatures, compaction, and soil ionic concentrations.

Song et al. (1998) used a dual probe heat-pulse technique to measure soil moisture in laboratory packed columns seeded with 'Kentucky 31' tall fescue (*Festuca arundinacea* Schreb.). The dual-probe heat-pulse technique is nondestructive, easily automated, and not sensitive to soil bulk density. However, the accuracy is subject to soil temperatures and low water contents, although the authors did not feel that these limitations were of practical significance.

Another type of probe used to measure soil moisture is thermocouple psychrometers. This technique is based on measuring the relative humidity of a sample and relating it to water potential. Unfortunately, due to temperature differentials when buried in the upper 30 cm of soil, the reliability of thermocouple psychrometers are compromised (Brown and Oosterhuis, 1992). Although very sensitive, this technique is not practical for golf course use because a calibration curve is required and the lack of reliability in shallow soils.

Within the market several moisture probes exist, but their accuracy, dependability, and cost limit their use on a golf course. Also, limitations of all probes are the measurement of small soil volumes and are therefore subject to problems associated with spatial variability. Minimal research has been performed using probe-guided irrigation with little agreement between reports. However, the potential benefits of probe guided irrigation are evident and moisture sensing probes may serve as a tool for water management on golf courses.

Soil Properties

Since 1960, when the USGA released the first specifications for golf putting green construction (The USGA Green Section Staff, 1960), many golf greens and athletic fields have been constructed on high sand media. These construction standards are a uniform guideline that can provide many benefits in turfgrass establishment and maintenance. The purpose of the high sand content in these specifications is to provide good drainage, compaction resistance, and aeration for root growth, but sand is inefficient at retaining adequate moisture and nutrients for turfgrass growth (Beard, 1973). Therefore, organic and inorganic amendments are possible means to reduce leaching of water while maximizing plant available water and nutrient holding capacity (Bigelow et al., 2001; Sartain, 1995).

One of the primary reasons sand is used for golf course putting green construction is to reduce the risk of soil compaction. However, individual sand particles within a putting green can move and become tightly packed with years of continuous traffic (Taylor and Blake, 1981). With increased packing, water movement within the profile may be affected; as a result, amendments may be added to keep the soil open and conducive for root growth. Due to the dynamic nature (i.e. the rootzone environment continually changing due to natural and imposed factors) of putting green rootzones, some believe laboratory measured hydraulic conductivity should not be the primary criterion for selection of materials within a rootzone profile (Latham, 1990). Practitioners commonly view conductivity as the most important factor in material selection, however.

Soil bulk density (BD) and soil strength (SS) are indicators of soil compaction. Bulk density and SS play major roles in turfgrass growth and keeping the greens in playing condition. While BD throughout the rootzone may influence turfgrass growth, surface SS can influence the play of the golf green. The harder or more firm the green, the less receptive it can be to golf shots, making the course more challenging.

Bulk Density and Porosity

An ideal BD range for turfgrass growth is 1.3 to 1.6 g cm^{-3}. A BD greater than 1.7 g cm^{-3} is generally considered restrictive to plant growth (Brady and Weil, 1999; Gliński and Lipiec, 1990). The USGA specifications for rootzone putting green media recommends a total porosity of 0.55 to 0.35 cm^3 cm^{-3}, resulting in a BD range of 1.19 to 1.72 g cm^{-3} (The USGA Green Section Staff, 1993).

While some researchers regard soil BD as a poor indicator of turfgrass growth (Smalley et al., 1962), others view soil BD as an important gauge for soil gas exchange. If the bulk density is too great, plant growth is restricted from a lack of adequate air pore space (DePew, 2000). The exchange between the atmosphere and the rootzone of oxygen and carbon dioxide is restricted in soils with high bulk densities (Neilson and Pepper, 1990).

Soil Strength

Soil strength, also referred to as soil consistence, is a measurement of a soil's resistance to deformation. There are several methods to evaluate mechanical soil strength or firmness. One method to measure the soil's resistance is to use a penetrometer. Little research using a penetrometer in turfgrass has been performed. However, Wood and Law

(1972) used penetrometer readings to determine effects of imposed wear stress on soil compaction when evaluating Kentucky bluegrass (*Poa pratensis* L.) cultivars. They found soil resistance varied among cultivars and increased in plots receiving wear stress treatments. Guertal et al. (1999) reported similar results, resistance to soil penetration increased as traffic increased on fairway maintained bermudagrass. Derrick et al. (2000), using a cone penetrometer, reported lower soil resistance after aerification on a native soil. For a sandy soil, Smalley et al. (1962) reported improved growth and quality of bermudagrass turf as penetration force decreased in the upper 10 cm of the rootzone. There are no published reports containing data of soil resistance in sand based rootzones. Depew et al. (1997) reported using a penetrometer in constructed sand-based rootzones, but no data were included.

A Clegg Impact Soil Tester (CIT) can be used to measure the impact absorption characteristics of the soil. The CIT is a lightweight, approximately 4.5 kilograms for some models, portable apparatus that consists of three parts, a blunt ended hammer (also referred to as a missile), a guide tube, and a display box. Sensors in the handle of the hammer measures the peak deceleration (g_{max}) as energy is transferred from the hammer to the soil surface (Rogers and Waddington, 1990a). Therefore the higher the g_{max}, the greater the soil firmness.

Baden Clegg developed the CIT for measuring the surfaces of sub-grades used for road construction in western Australia (Rogers and Waddington, 1990a). But, in relevance to turfgrass, the CIT has been used primarily in Europe and on athletic fields to evaluate root zone firmness on player performance (Rogers and Waddington, 1990a, b). Research has shown decreases in maximum deceleration as a result of increases in soil water content, thatch, and turfgrass cover (Rogers and Waddington, 1992; Dunn et al., 1994). When compared to penetrometer readings, Ford (1999) found the CIT more accurate at detecting soil firmness extremes on grassed surfaces. Reported use of the CIT on golf course putting greens is limited, thus, a standard to compare measurements does not exist.

Soil Amendments

Peat

Peat, the most common amendment used in putting green construction, provides an organic source to the rooting media. Furthermore, peat added to sand lowers the soil bulk density (Thomas et al., 1996; McCoy, 1992; Juncker and Madison, 1967), improves aeration (Letey et al., 1966), allows the media to retain more plant available water (Bigelow et al., 2000; McCoy, 1992), and allows for a gradual release of available water (Bigelow et al., 2000; Juncker and Madison, 1967). Other advantages of the incorporation of peat into sands used for putting green construction includes reduced leaching of nitrate (NO_3^--N) and ammonium (NH_4^+-N) nitrogen (Bigelow et al., 2001). Also, during establishment, peat's ability to hold more water at the soil surface may allow for improved germination (Bigelow et al., 1999; McCoy, 1998).

Although many studies on golf course rootzone mixtures have been performed since the first publication of the USGA specification in 1960, the only study to investigate the amount and location of water held in a layered rootzone system was performed by Taylor et al. (1997). They reported an additional 2.4 to 5.4 cm of water was retained in a 30-cm profile when Canadian sphagnum peat was added to sand. Also, of the total water retained in a 30-cm rootzone, only 31 to 38% was retained in the upper

15-cm of the profile. Matric potentials were not reported. However, Canadian sphagnum peat has been shown to retain water at tensions beyond that available to turfgrass, while Michigan sphagnum peat and Dakota reed-sedge peat retained water at tensions more available to plants (McCoy, 1992).

Due to natural decomposition, peat eventually loses its desirable characteristics (Huang and Petrovic, 1995). However, it is believed once the peat begins to decay, the turfgrass itself is replenishing the lost organic content by seasonal root sloughing and secretion of organic compounds (Thomas et al., 1996).

Ceramic Clays

Ceramic clay (CC) amendments are inorganic materials derived from mined expanding clays, usually montmorillinite or illite. The clay is heated from 260° C to 1700° C, and screened for size distribution (Wehtje et al., 2000; Waddington, 1992). To obtain various ceramic properties, such as stability and porosity, the heating process and duration may vary for different products. It is common for products needing stability, like soil amendments, to be treated at higher temperatures and longer duration. By super-heating, the original expanding clay mineral is permanently transformed into a stable, porous particle. Similar to ceramic clays, calcined clays are made from the same clay minerals, except heated at lower temperatures for a shorter duration, reducing production costs.

Desirable soil amendment characteristics of ceramic clays include resistance to degradation, low bulk densities (0.56 to 0.64 g cm^{-3}), high porosity, and greater water holding capacity than sand (Bigelow et al., 2000; Waddington, 1992). These physical properties allow ceramic clays to withstand compaction and improve infiltration and aeration.

A disadvantage to the heating process is the loss of nutrient retention. In their natural forms, these clays have high cation exchange capacities (CEC), approximately 30 and 100 cmol$_c$ kg^{-1} for illite and montmorillinite, respectively. The heating process compromises the interlayer exchange sites, therefore, the CEC is reduced to around 9 cmol$_c$ kg^{-1}. However, the nutrient retentive properties are greater than sand (< 0.25 cmol$_c$ kg^{-1}), which is considered negligible (McCoy and Stehouwer, 1998).

Another reported disadvantage of ceramic clays is water being bound too tightly within the clay particle to be available to the turfgrass plant (Horn, 1969; Waddington, 1992; Minner et al, 1997). For straight CC, Bigelow et al. (2000) reported 0.35 cm^3 cm^{-3} capillary water retention at –4 kPa and 0.33 cm^3 cm^{-3} water retention at –50 kPa, resulting in a 2% available water holding capacity. With large amounts of water retained at high tensions, it was concluded that the amendment was composed of very small pores. To the contrary, McCoy and Stehouwer (1998) concluded a CC amendment released water from internal pores at pressures (-12.8 kPa) below reported first signs of turfgrass wilt.

Diatomaceous Earth

Diatomaceous earth (DE) materials are remnant cellular wall structures of marine and fresh water algae, called diatoms. Because mined DE contains greater than 85% silica (SiO_2), it is considered chemically inert (Sylvia et al., 1999). Some commercial DE products are similar to ceramic clays in that they are heated (or calcined), while some products are merely dried raw material. In either case, DE is porous, stable and has a low bulk density (0.39 to 0.59 g cm^{-3}) (Bigelow et al., 2000; Waddington, 1992).

Published field work regarding DE use in turfgrass has been limited. In a dry-down study, Ralston and Daniel (1973) reported 'Penncross' creeping bentgrass (*Agrostis palustris* Huds) plots containing a DE product maintained normal growth for 15 days, while ceramic clay amended plots needed watering after 5 days. To improve water-holding properties, Oppold et al. (1997) recommended the use of DE as an amendment to sand. However, Waddington (1992) reports that water is bound too tight for plant use and is therefore unavailable. Bigelow et al. (2000) reported similar physical properties for porosity and water retention of a DE product as CC. Li et al. (2000), however, reported a DE product to have greater internal porosity than CC.

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CHAPTER 3

THE EFFECTS OF SOIL AMENDMENTS ON PHYSICAL AND HYDRAULIC PROPERTIES OF ROOTZONE MIXES FOR GOLF PUTTING GREENS

Abstract

Many golf course putting greens and athletic fields have been constructed on a medium with a large sand content as suggested by the United States Golf Association (USGA). The sand is usually amended with small amounts (≈ 10 to 20% by volume) of various materials with peat moss being the most common, to improve moisture and nutrient retention while maximizing rootzone drainage, compaction resistance and aeration. Due to limited supplies, a trend to replace peat with inorganic soil amendments (IOSA), such as calcined clay (CC) and diatomaceous earth (DE), is occurring in the construction of new greens and athletic fields. Washed rootzone sand (RZS) meeting USGA specifications for putting green construction was amended with either Canadian sphagnum peat (CSP), CC, or DE and evaluated as a potential replacement for peat. Laboratory experiments were conducted to evaluate physical and hydraulic properties of the rootzone mixtures. Amendments were incorporated at 15% v/v. The addition of an amendment to RZS reduced the bulk density and increased the total porosity of all laboratory mixtures. Saturated hydraulic conductivity (K_{sat}) for the RZS and mixtures of CSP and CC exceeded the USGA specifications for rootzone media (30 to 60 cm h^{-1}).

The DE mixture had the lowest K_{sat} (41.9 cm h^{-1}) which was attributed to the 2% by weight of particles <0.05 mm in diameter. Although IOSA altered the physical properties of the RZS, they were not as effective as CSP at retaining water. The IOSA mixtures retained 0.021 to 0.084 cm^3 cm^{-3} less water than the CSP mixture at pressures less than -2.5 kPa. The location of water held in the profile is important since most turfgrass roots are in the upper portion of the rootzone. The CSP mixture held significantly more water in the entire profile and in the upper 15-cm compared to IOSA mixtures and straight RZS. Water retention below 30 cm, in the gravel layer of a USGA specification profile, was attributed to particle migration of rootzone media into the larger pores of the gravel. The mixtures containing IOSA retained 1.4 to 5% more water below 30 cm. In laboratory drainage columns, approximately 75% of the total water was lost within the first 15 minutes after drainage initiation for straight RZS and the IOSA mixtures, however only 65% was lost in the first 15 minutes for the CSP mixture. After 24 hours of free drainage, the CC mixture lost the most water (5.9 cm), while the DE mixture lost the least (4.2 cm). Straight RZS and the CSP mixture lost 5.3 and 4.7 cm, respectively. Differences among the rootzone mixtures were measured in the first 3 minutes of drainage, with straight RZS and the CC mixture having the greatest flow rate (2.0 cm min^{-1}) compared to 1.8 and 1.1 cm min^{-1} for the DE and CSP mixture. After 15 minutes, drainage rates indicated the bulk of the drainage had concluded. Within 5 minutes of drainage, pressure potentials were negative in the surface 20 cm and were positive below the 25-cm depth, indicating saturation. After 24 hours of free drainage, the gravel layer remained saturated. Due to greater water retention and lower flow rates in the CSP mixture it appears peat remains the best amendment for USGA specification sands, however, DE had similar properties.

Introduction

Since 1960, when the United States Golf Association (USGA) released the first specifications for golf putting green construction (The USGA Green Section Staff, 1960), many golf greens and athletic fields have been constructed on high sand media. These construction standards are a uniform guideline that provides many benefits in turfgrass establishment and maintenance. The purpose of the high sand content in these specifications is to provide good drainage, resist compaction, and promote aeration for root growth, but sand is inefficient in retaining adequate moisture and nutrients for turfgrass growth (Beard, 1973). Also, with years of continuous traffic, individual sand particles within a putting green can move and become tightly packed (Taylor and Blake, 1981). Therefore amendments, organic and inorganic, are possible means to reduce soil compaction and leaching, while increasing plant available water and nutrient holding capacity.

Peat, reed sedge or sphagnum, are the most common amendments used in putting green construction (Waddington, 1992). The benefits of peat include reduced soil bulk density, improved rootzone aeration, increased soil moisture retention, gradual release of plant available water, and improved turfgrass germination (Lettey et al., 1966; McCoy, 1992; Juncker and Madison, 1967; Bigelow et al., 1999). Because peat is an organic material and subject to natural decomposition, it may eventually lose its desirable characteristics (Huang and Petrovic, 1995). Also, since peat is a naturally occurring resource, the supply is limited. Therefore, the amendment of putting green rootzones with a material that will retain its physical properties for many years is desired. Inorganic soil amendments (IOSA) such as calcined clay (CC) and diatomaceous earth (DE) may provide an adequate substitute for peat in high sand rootzones.

Attractive characteristics of CC and DE include resistance to degradation (4 and 9.5%, respectively, change in mean particle diameter after impact/abrasion tests) and low bulk densities (0.56 to 0.64 g cm^{-3} and 0.39 to 0.59 g cm^{-3} respectively) (Wasura and Petrovic, 2001; Petrovic et al., 1997; Waddington, 1992). Additional attributes include, high porosity and greater water holding capacity than sand (Bigelow et al., 2000; Li et al., 2000). These physical properties allow IOSA to withstand compaction and improve infiltration and aeration.

A reported disadvantage of IOSA is adsorbed water being bound too tight within the internal pore space of the particle to be available to the turfgrass plant (Waddington, 1992). For straight CC, Bigelow et al. (2000) reported 0.35 cm^3 cm^{-3} capillary water retention at –4.0 kPa tension and 0.33 cm^3 cm^{-3} water retention at –50.0 kPa tension, resulting in a 2% available water holding capacity. Similar properties were reported for DE. With large amounts of water retained at high tensions, it was concluded that these amendments were composed of very small pores. Likewise, Li et al. (2000) reported a DE product to have greater internal porosity than CC. To the contrary, McCoy and Stehouwer (1998) concluded a CC amendment released water from internal pores at tensions (-12.8 kPa) below reported first signs of turfgrass wilt.

The overall objective of this research was to evaluate two inorganic amendments as a potential replacement to peat in putting green rootzones. Specific objectives were (i) to evaluate selected hydraulic properties of a rootzone sand amended with peat, calcined clay, or diatomaceous earth; and (ii) to establish a basis for choice of a particular amendments for rootzone sand.

Materials and Methods

Rootzone media were constructed using washed quartz sand (Golf Agronomics, Lugoff, SC 29078) commonly used for putting green construction in South Carolina. Various rootzone media were prepared using one of three amendments, Canadian sphagnum peat (CSP) (93.4% organic matter loss on ignition at 800° C), a calcined clay (CC) product (PROFILE, Aimcor Consumer Products LLC. Buffalo Grove, IL 60089), and a diatomaceous earth (DE) product (PSA, Golf Ventures, Inc., Lakeland, FL 33809). To prepare media, amendments were added to rootzone sand (RZS) on a 15% v/v basis using bulk densities of 0.13, 0.59, and 0.46 g cm^{-3} for CSP, CC, and DE respectably.

Particle size distribution of the RZS, individual inorganic amendments and various rootzone media are presented in Table 3.1. For the sand and gravel fraction, particle size distribution was determined by mechanical sieving, while the pipet method was used to separate the fine fraction (<0.05 mm) (Gee and Bauder, 1986). Physical properties of the rootzone media were determined by standard methods and presented in Table 3.2 (Hummel, 1993). Total porosity was calculated using measured bulk density and particle density. Macroporosity, or air-filled porosity, was calculated by subtracting the –4.0 kPa water content from the total porosity, while microporosity was determined as the volumetric water content at –4.0 kPa.

Saturated hydraulic conductivity (K_{sat}) of prepared rootzone mixes was measured using a Marriott tube to maintain a constant water head of 11.3 cm with water flow upward through the soil (Figure 3.1). Eight replications of each rootzone mixture were hand packed into 4.8-cm diameter plastic tubes and sealed with a plastic cap and liquid

Table 3.1 Particle size distribution of rootzone sand (RZS) and rootzone media amended with Canadian sphagnum peat (CSP) and inorganic amendments, calcined clay (CC) and diatomaceous earth (DE), at 15% by volume along with the gravel used to construct simulated golf greens. USGA = United States Golf Association.

	Particle Size (mm)						
Rootzone Media	> 2.0	1.0	0.50	0.25	0.10	0.05	<0.05
	% by weight						
RZS	0.0	4.9	37.1	43.8	13.7	0.4	0.2
CC	0.0	0.0	59.2	40.0	0.7	0.2	----
DE	0.0	23.3	68.9	5.9	1.4	0.6	----
RZS : CSP	0.0	6.9	35.6	41.4	15.1	0.5	0.5
RZS : CC	0.0	2.9	28.9	46.2	21.1	0.6	0.3
RZS : DE	0.0	3.4	30.3	44.6	19.0	0.6	2.0
USGA Specifications	<10		>60		<20	<10	

	Particle Size (mm)				
	12.7	6.3	4.0	2.0	<2.0
Gravel	0.0	86.2	12.9	0.4	0.6

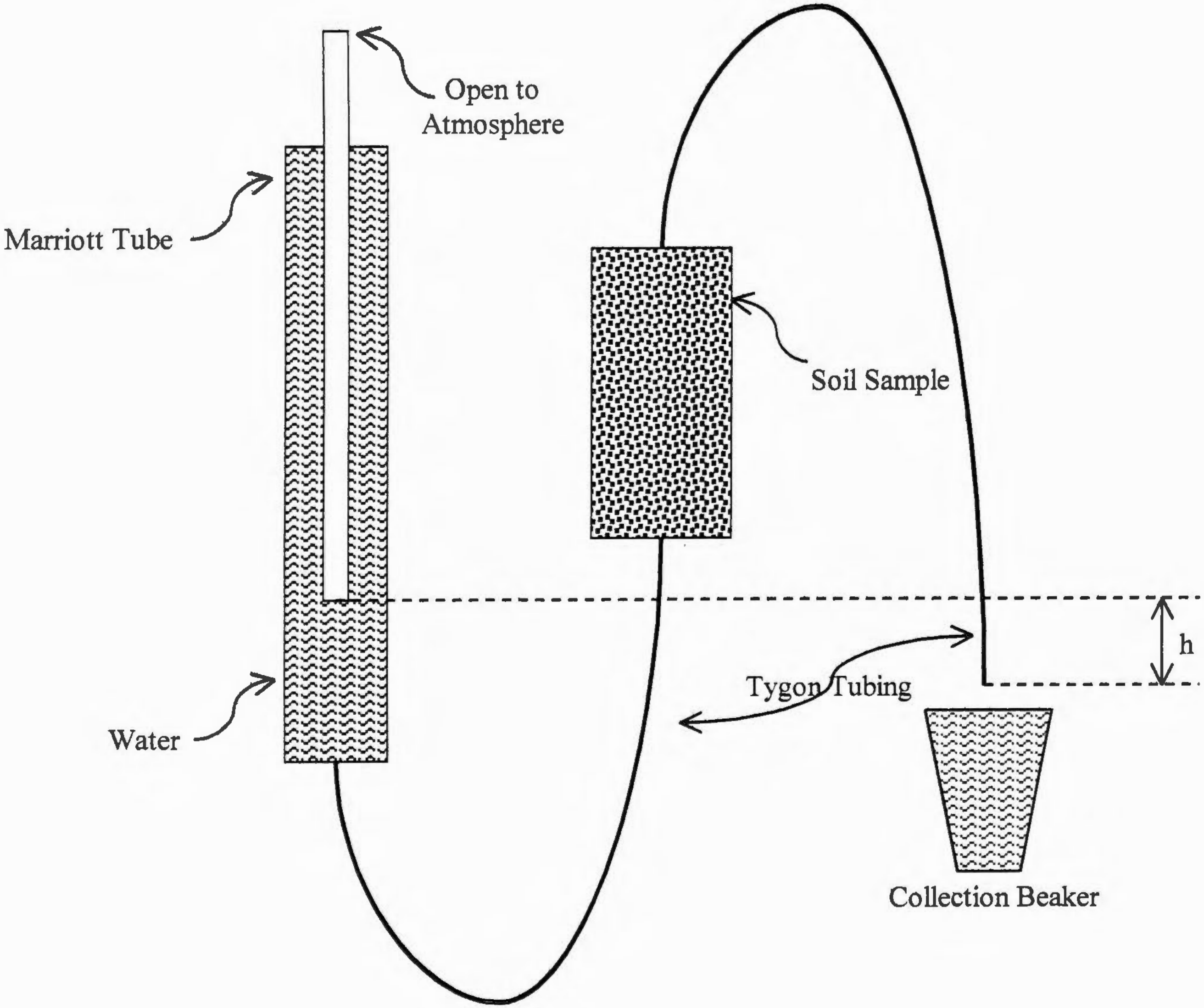

Figure 3.1 Schematic used for measuring saturated hydraulic conductivity using a Marriott tube.

electrical tape to ensure the columns were airtight. The outer reservoir of the Marriott Tube was filled with distilled de-ionized water and the top of the tube was open to the atmosphere for soil columns to slowly saturate from the bottom to the top. Once saturated, the outer reservoir of the Marriott Tube was capped and a constant head was established as the difference in elevation between the inner Marriott Tube and the outlet tube. Water flowing through the sample for the first 10 minutes was discarded. Thereafter, water was allowed to flow through the sample for 12 minutes with 4 sub-samples collected on 3-minute intervals. The volumes of water were collected, measured, and K_{sat} calculated. All data was averaged using the SAS general linear model procedure with means separated using least significant difference (LSD) at $P = 0.05$ (SAS Inst., Inc., 2001).

Water Retention Curves

Water retention curves were determined by methods similar to Juncker and Madison (1967). Columns 45 cm high were assembled by connecting 37 polyvinyl chloride (PVC) rings (5.2 cm inside diameter with a wall thickness of 0.4 cm) together with vinyl electrical tape. Each ring was 1.3 cm high, except the next to last bottom ring, which was 2.5 cm high. To retain the rootzone mixture, four layers of cheesecloth covered the bottom ring. Each premixed, air-dried mixture was added and tamped as individual rings were attached until the full 45-cm column was constructed. Filled columns were placed in an equally high plastic container and saturated with distilled, de-ionized water from the bottom to the top until ponding at the surface was observed. After the columns were allowed to equilibrate overnight, most of the water was siphoned from the plastic container to the point that the bottom one and half rings remained below the waterline. During drainage, the top of each column was covered with plastic wrap to prevent evaporation. Columns were allowed to drain for 72 h before they were sectioned from top to bottom by removing the tape and inserting a thin metal spatula between each ring. To determine water content, individual rings were placed in pre-weighed cans, weighed, oven dried (105° C) overnight, and re-weighed. Moisture content was determined for each ring and data were plotted as tension vs. gravimetric moisture content (θ_{wt}). Volumetric moisture content (θ_v) was calculated as the product of the θ_{wt} and the bulk density. Two columns were run for each rootzone mixture and data were analyzed using the SAS general linear model procedure with means separated using least significant difference (LSD) at $P = 0.05$ (SAS Inst., Inc., 2001).

Drainage Columns

Similar to columns constructed for moisture retention curves, experimental rootzones were built as nine-ring columns. The entire 38.1-cm columns were constructed from PVC rings. The bottom ring (7.6 cm) was filled with gravel meeting USGA specifications for golf putting greens (Table 3.1) and the remainder of the columns was filled with the various rootzone mixes (USGA, 1993). The rootzone was 8 total rings, four 1.3 cm rings overlay the gravel ring, one 2.5 cm ring followed, and three 7.6 cm rings extending to the surface, giving a total depth of 30.5 cm of rootzone media. Rootzone columns were constructed, filled and wet as described for moisture retention columns.

To determine total cumulative drainage and drainage flux characteristics, each column was allowed to freely drain with drainage being caught at specific time intervals (0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4, 5, 10, 15, 20, 30, 60, 120, and 1440 minutes) for the first 24 hours. After 24 hours, the column was sectioned as described for water retention columns to determine θ_{wt} and θ_v. Data were analyzed as previously described.

Tension Readings

In a process similar to Morgan et al. (1966), columns were constructed from 25.4-cm inside diameter (0.8 cm thick wall) PVC pipe (Figure 3.2). Individual columns were 40 cm high with a 1.95 cm inside diameter hole drilled at the bottom for drainage and wetting. A 10 cm layer of gravel (Table 3.1) was placed in the bottom of the columns (approximately 8.5 kg, giving a bulk density of 1.69 g cm^{-3}). Thirty centimeters of air-dry rootzone media (Table 3.1) was added in several stages. The surface of each stage was tamped and scarified before additional media was added until 30 cm was reached. No separation of the amendments during the filling process was evident.

Ceramic tensiometers were inserted through holes on the side of the column at depths of 5, 10, 15, 20, 25, 30, and 35 cm below the soil surface. The tensiometer at the 35 cm depth was constructed into the gravel layer when the gravel was added, the other tensiometers were pressed into place after the filling process to ensure good soil contact. A 0.18 cm inside diameter nylon tube ran from the tensiometer to a mercury manometer board. The tensiometers at 5, 10, 20, and 30 cm were positioned opposite from Vitel HydraProbes (Vitel, Inc., Chantilly, VA 22021) which were inserted into the columns during construction (to be discussed further in chapter 4).

By extending the drainpipe to an up position, columns were saturated from the bottom up to minimize entrapped air. Once wetting was complete, a 0.5 cm head was established and columns were allowed to equilibrate for 0.5 hours. To initiate drainage, the drainpipe was capped, rotated to a down position and uncapped. Drainage was caught

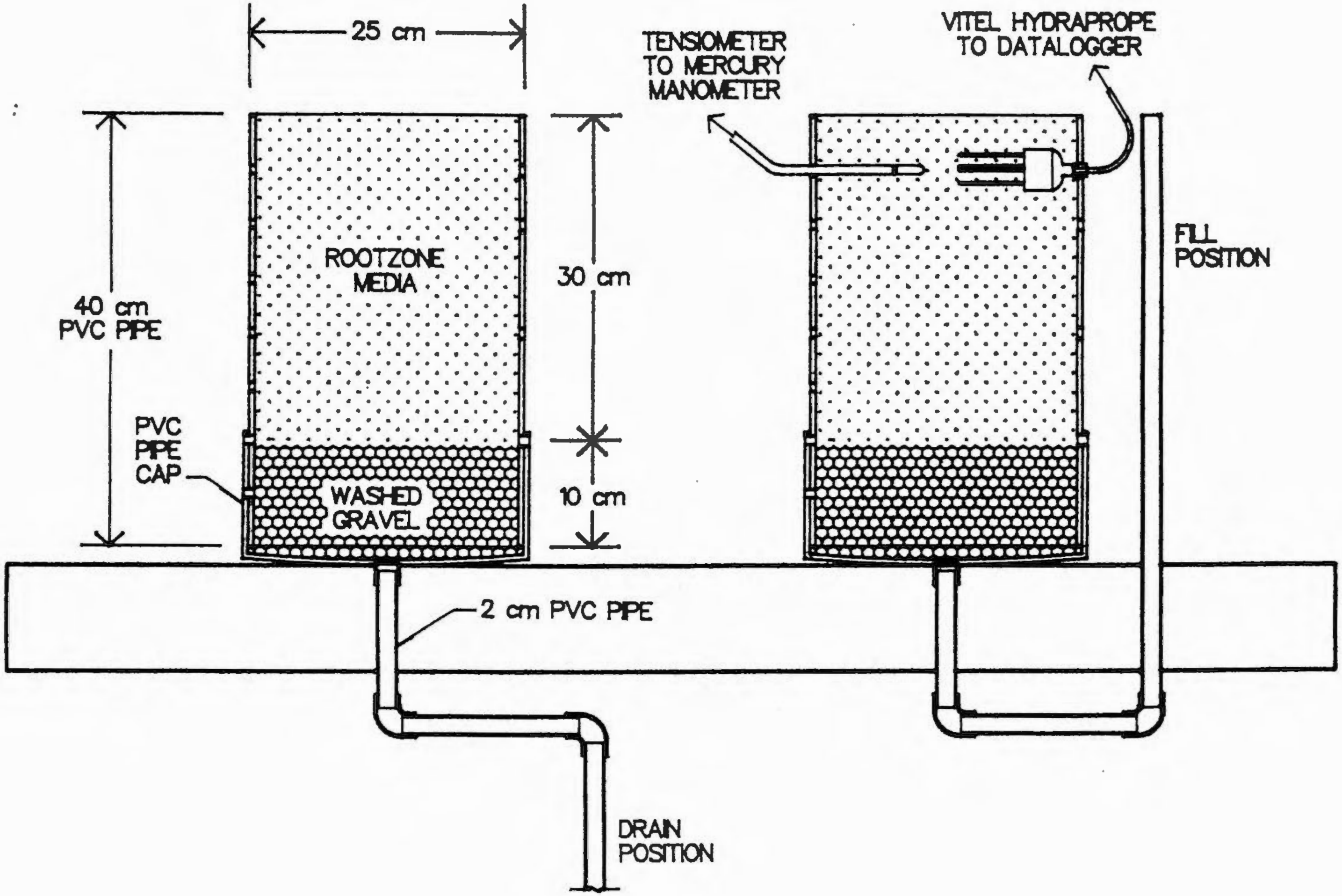

Figure 3.2 Schematic diagram of columns used for tension and moisture probe measurements.

at 5, 10, 15, 30, 60, 120, and 1440 minutes after the initiation of drainage and determined on a mass basis. To reduce evaporation and ensure loss of water through drainage alone, columns were covered with plastic. Corresponding tension readings were made at each time and soil pressure potential was calculated using the equation:

$$\psi_m = -[(12.55\,x) - y - z] \qquad \text{Equation 3.1}$$

where ψ_m is the pressure potential (cm), x is the height of mercury rise (cm), y is the height from the soil surface to the mercury surface, and z is the depth of the tensiometer below the soil surface (cm).

Results and Discussion

Physical Properties

Compared to straight RZS, the addition of peat decreased bulk density by 12.4%, while the addition of an IOSA reduced bulk density by a maximum of 8.1% (Table 3.2). This result was expected due to CSP having the lowest BD (0.13 g cm^{-3}) of the three amendments. Likewise, the addition of an amendment increased the total porosity of the RZS as much as 0.068 cm^3 cm^{-3}. At a water potential of -4 kPa, sand modified with CSP had 0.107 cm^3 cm^{-3} more capillary water than straight RZS. Compared to RZS, the addition of an IOSA increased capillary porosity by 0.043 to 0.057 cm^3 cm^{-3} for DE and CC mixtures, respectively. These results agree with those of Li et al. (2000) and McCoy and Stehouwer (1998).

The K_{sat} for 3 of the 4 amendment combinations (RZS alone and RZS amended with peat or CC) exceeded the USGA (1993) accelerated range specifications of 30 to 60 cm h^{-1} (Table 3.2). Rootzone sand amended with DE was the only mixture within the

Table 3.2 Physical properties of rootzone sand and rootzone media amended with peat and inorganic amendments at 15% by volume used for simulated putting greens.

Rootzone Media	Particle Density ($g\ cm^{-3}$)	Bulk Density ($g\ cm^{-3}$)	Total Porosity[†] ($cm^3\ cm^{-3}$)	Air-filled Porosity[‡] ($cm^3\ cm^{-3}$)	Capillary Porosity[§] ($cm^3\ cm^{-3}$)	K_{Sat}[¶] ($cm\ h^{-1}$)
Rootzone Sand (RZS)	2.65	1.61	0.392	0.191	0.201	64.1 b
RZS : Peat	2.62	1.41	0.460	0.152	0.308	62.6 c
RZS : Calcined Clay	2.68	1.48	0.449	0.191	0.258	70.3 a
RZS : Diatomaceous Earth	2.64	1.50	0.433	0.189	0.244	41.9 d
USGA Specifications	---	---	0.35 – 0.55	0.15 – 0.30	0.15 –0.25	30 - 60

[†] Total porosity was calculated as Total Porosity = (1- (bulk density ÷ particle density)).

[‡] Air-filled porosity was calculated as the difference between total porosity and capillary porosity.

[§] Capillary porosity determined at –4.0 kPa pressure.

[¶] Saturated hydraulic conductivity was determined using a Marriott tube to maintain a constant head. Means followed by the same letter in the same column are not significantly different at $P = 0.05$, (LSD = 1.3, C.V. = 7.51).

range. Amendment of RZS with CC increased the K_{sat} 9.7%, while the addition of peat and DE decreased the K_{sat}, 2.3 and 34.6% respectably, compared to unamended RZS. Similarly, increased K_{sat} with the addition of CC to sand was reported by Smalley et al. (1962). Also, others (Li et al., 2000; McCoy and Stehouwer, 1998) have reported depressed K_{sat} values with DE amended sand, however not as extreme as in this research. Relative to the other rootzone mixtures, a possible reason for lower K_{sat} values when sand is amended with DE could be attributed to the dusty nature of the DE product. The RZS:DE combination had a greater number (4 times greater than other combinations) of fines, particles below the 0.05 mm size fraction (Table 3.1).

To test the effect of 2% by weight of fines, a mixture of RZS, colloidal kaolinite and soil with a high silt content was combined to simulate the particle size distribution of the DE mixture. Soil columns were packed as previously described and K_{sat} was measured. The resultant K_{sat} of the sand and soil mixture was 14.2 cm h^{-1}, which was below measured values of the DE mixture. It can be concluded the addition of amendments with a high proportion of fines (dusty materials) can significantly decrease the K_{sat} of a sandy rootzone media. However, the amount of fines remaining after successive leaching of water through the rootzone was not determined, therefore, K_{sat} might increase in these media as the fine particles are leached from the rootzone.

Bigelow et al. (2001) reported greater (about five times higher) K_{sat} measurements of a sand with similar particle size distribution. Like the columns of Bigelow et al. (2001), these columns were packed with dry material. However, columns in our study were allowed to saturate at the time of testing compared to being saturated and drained to -4 kPa before being packed, as described by the Hummel (1993) procedure. Also, in our experiments, a constant head was maintained with a Marriott Tube. Our results were similar to the ranges prescribed by the USGA and congruent to results of others (Li et al., 2000; McCoy and Stehouwer, 1998).

Water Retention and Drainage

To establish water retention characteristic for straight RZS, samples of dry RZS were packed into 5.4 cm diameter metal rings. After slowly saturating the samples from the bottom up, water retention of each mixture was determined by the water desorption method using a hanging water column (Jury et al., 1991). For straight RZS, natural saturation was 0.081 $cm^3\ cm^{-3}$ less than total porosity (Figure 3.3). To check the pressure applied on the sample by the water column, a hole was drilled into the metal ring, a ceramic tensiometer was inserted, and connected to a mercury manometer by a 0.18 cm inside diameter nylon tube. Rings were filled with RZS and water retention was determined as before with pressure measurements taken at each lowering of the water column. A 1:1 relationship would be expected between pressure applied by the water column and pressure measured by the tensiometer. However, measured pressures were consistently lower for the tested range (0 to -4.5 kPa) (Figure 3.4). Therefore, the water retention curve for these rootzone mixtures were determined as described by Juncker and Madison (1967).

The saturated volumetric water content (θ_{vsat}), θ_v at 0 kPa, and the total porosity (Table 3.2) should be identical. However, using the Juncker and Madison (1967) method to determine the moisture release characteristic (Figure 3.5), the measured θ_{vsat} was less than the calculated θ_{vsat} from the total porosity for each mixture. The natural saturation was 0.063, 0.015, 0.076, and 0.034 $cm^3\ cm^{-3}$ lower than total porosity for RZS and

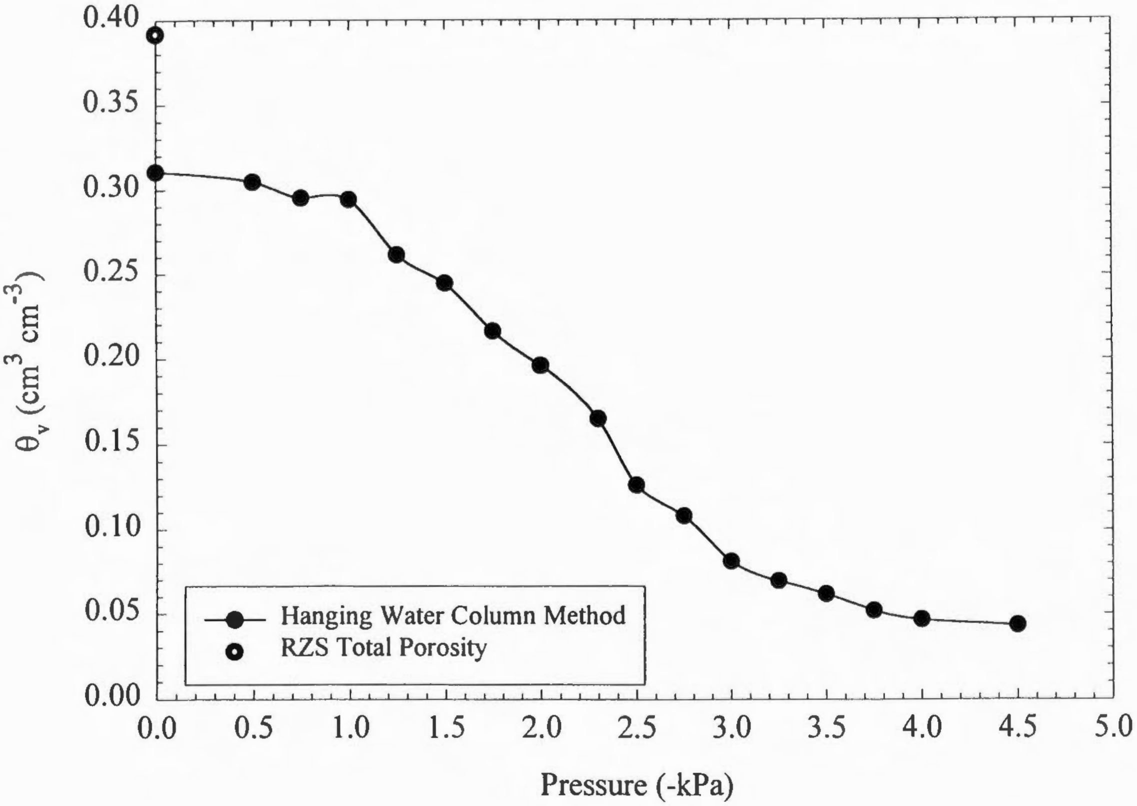

Figure 3.3 Water retention curve for rootzone sand (RZS) by the hanging water column method.

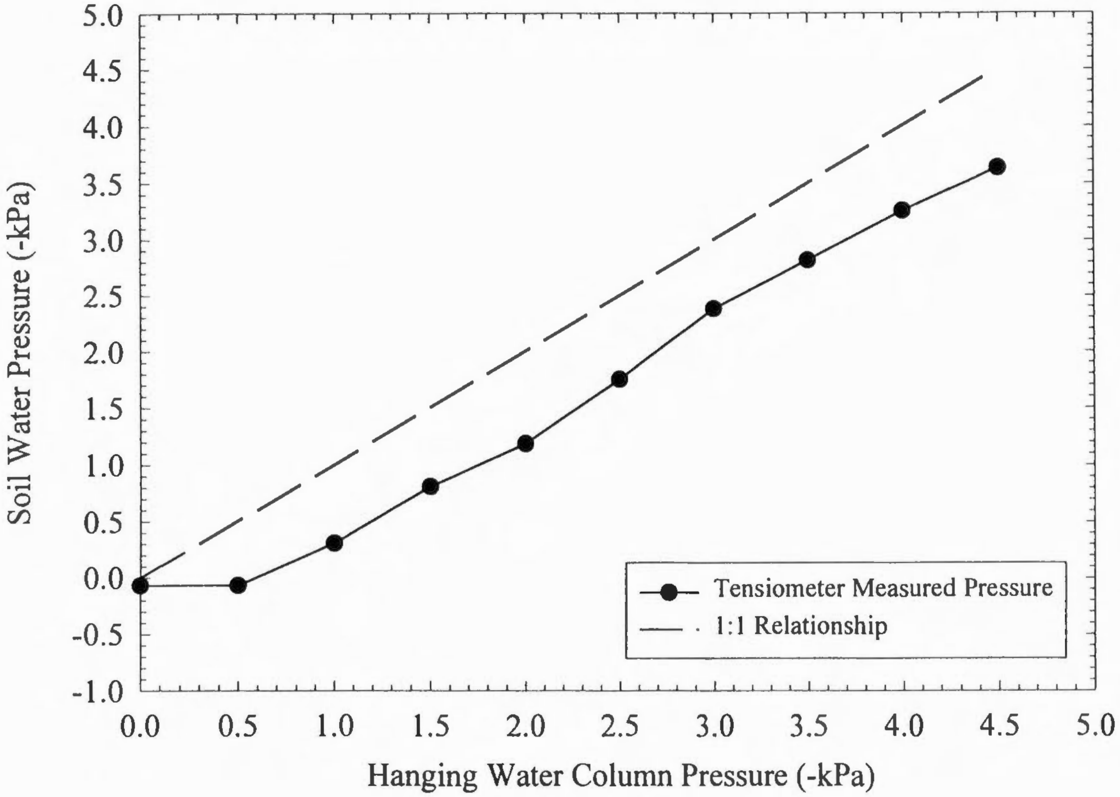

Figure 3.4 Relationship between hanging water column pressures and measured soil water pressures.

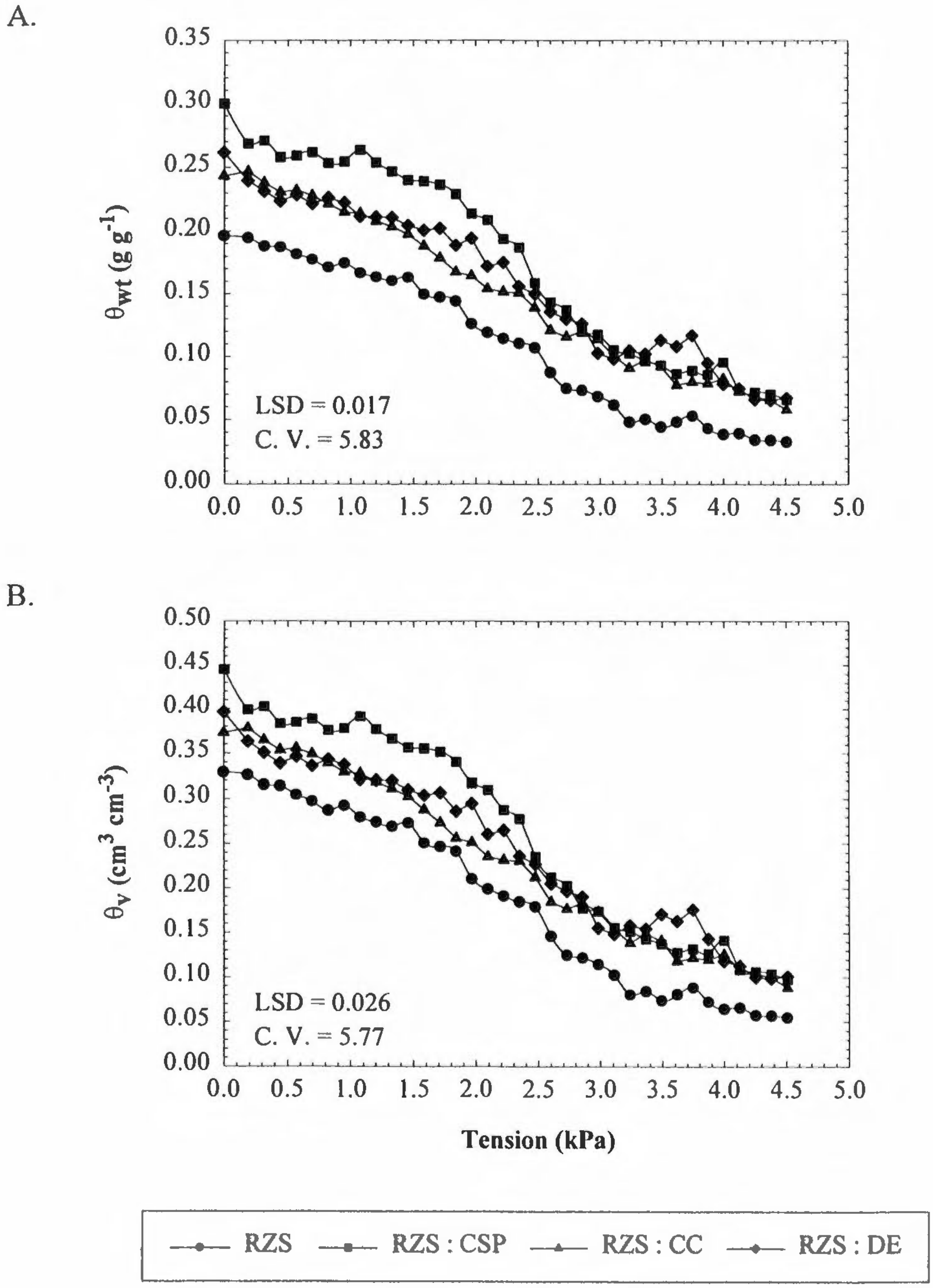

Figure 3.5 Gravimetric (A) and volumetric (B) water retention curves for rootzone sand (RZS), and RZS amended with 15% v/v Canadian sphagnum peat (CSP), calcined clay (CC) or diatomaceous earth (DE).

mixtures of CSP, CC, and DE respectively. The difference between the two measurements was considered a measure of air entrapment (Klute, 1986).

Gravimetric and volumetric water retention curves for RZS and sand amended with CSP, CC, and DE are presented in Figure 3.5. At all tensions, sand amended with CSP or an IOSA retained 0.015 to 0.116 $cm^3 cm^{-3}$ more water than unamended RZS. Compared to RZS amended with CSP, RZS amended with an IOSA retained 0.021 to 0.084 $cm^3 cm^{-3}$ less water at pressures greater than –2.5 kPa, while at more negative pressures no differences were measured.

Water holding properties of the amended RZS overlaying gravel followed a similar trend as water retention curves (Figure 3.6). On a volumetric basis in the upper 25-cm, RZS amended with CSP held 0.041 to 0.078 $cm^3 cm^{-3}$ more water than RZS and 0.032 to 0.051 $cm^3 cm^{-3}$ more than the IOSA mixes. Similarly, RZS amended with an IOSA held 0.022 to 0.046 $cm^3 cm^{-3}$ more water in the upper 17 cm of the rootzone. For all depths, differences were not measured between the IOSA mixtures; also, differences between RZS and other mixtures were not detected below the 25 cm depth.

For each soil mixture, the addition of an amendment to RZS caused significant differences in the amount of water retained at various depths (Table 3.3). After 24 hours of free drainage, CSP amended sand retained the most water (27.0 cm) within the profile, while straight sand retained the least (19.9 cm). Likewise, RZS amended with CSP retained 3.5 to 7.1% more water in the upper 7.6 cm of the rootzone and 3.1 to 7.6% more at 7.6 to 15.0 cm interval than RZS or the IOSA mixtures. In the upper half of the profile, straight RZS retained the least water compared to amended mixtures, however, this trend was reversed in the bottom 15 to 30 cm of the profile. Rootzone sand retained

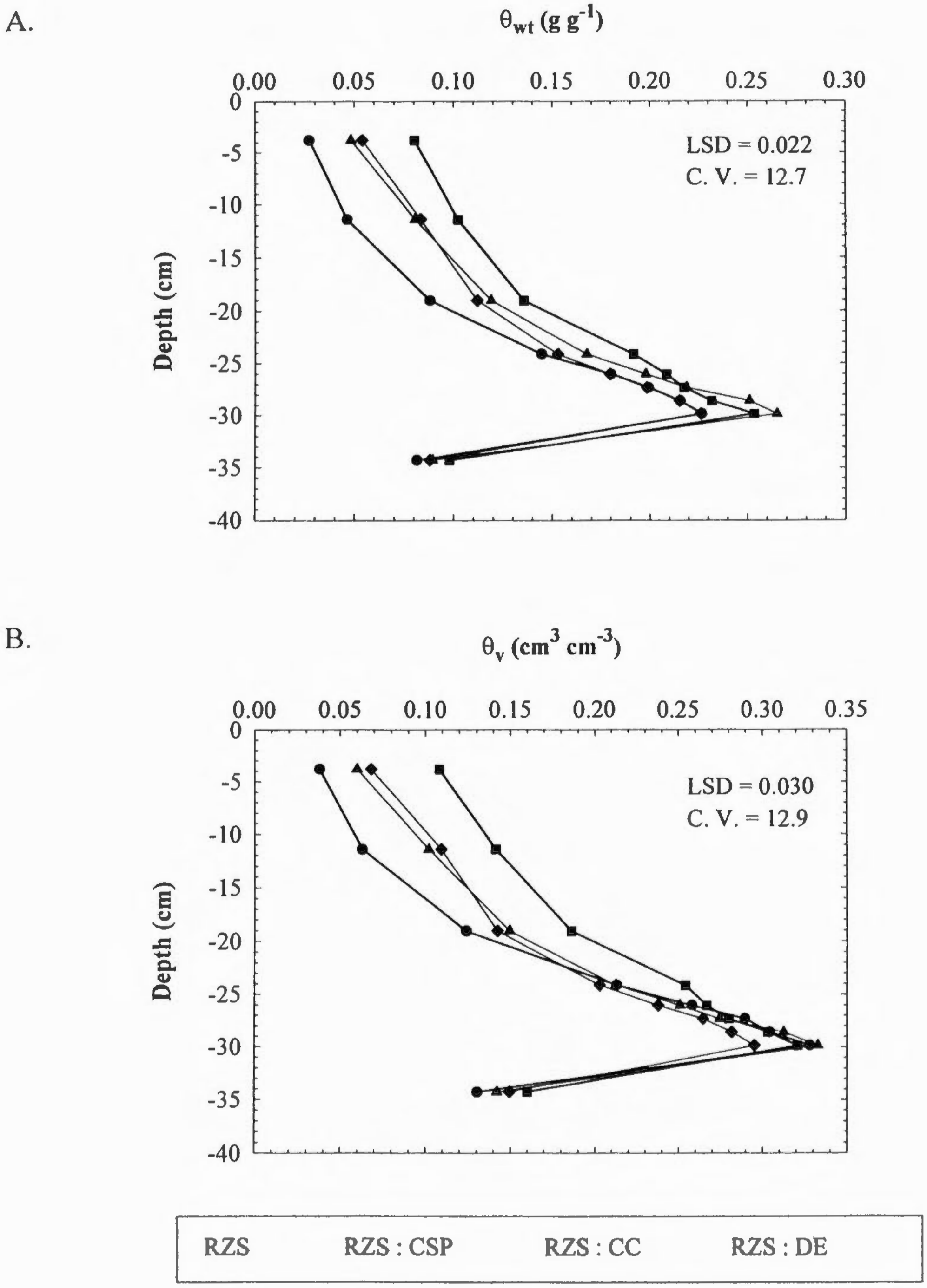

Figure 3.6 Gravimetric (A) and volumetric (B) water content with depth for rootzone sand (RZS), and RZS amended with 15% v/v Canadian sphagnum peat (CSP), calcined clay (CC) or diatomaceous earth (DE) overlaying 7.6 cm of gravel meeting United States Golf Association specifications.

Table 3.3 Water retention following 24 hours of free drainage of rootzone sand (RZS) and rootzone media amended with Canadian sphagnum peat (CSP) and inorganic amendments, calcined clay (CC) and diatomaceous earth (DE), at 15% by volume. All mixtures overlay 7.6 cm of gravel meeting United States Golf Association specifications.

	Total Water Retained	Depth			
Rootzone Media	(cm)	0 to 7.6 cm	7.6 to 15 cm	15 to 30 cm	Below 30 cm
		% Total Water Retained			
RZS	19.9 c	6.1 c	31.0 c	43.3 a	18.2 b
RZS : CSP	27.0 a	13.2 a	38.6 a	32.5 c	15.7 c
RZS : CC	23.1 b	8.3 bc	34.9 b	37.2 b	19.6 a
RZS : DE	22.8 b	9.7 b	35.5 b	34.0 c	20.7 a

6.1 to 10.8% more water than the amended mixtures. Below the 30-cm depth, RZS amended with an IOSA retained 1.4 to 5% more water than straight sand or the CSP mixture. The reason for water retention below the 30 cm depth can be attributed to the migration of rootzone media into the larger pores of the gravel layer, thus, a transition layer was formed. Of the total water retained in the profile, 15 to 21% was found below the 30 cm depth.

Figure 3.7 shows cumulative drainage with time for each rootzone mixture. Although different amounts of water drained through each mixture, >75 % of the total water lost through drainage occurred within the first 15 minutes for three (RZS and RZS amended with an IOSA) of the four-rootzone mixtures. For the CSP mixture, only 65% of the total water drained from the rootzone at 15 minutes; an additional 15 minutes was required to reach 75%. Also at 15 minutes, sand amended with DE or CSP allowed 25 to 38% less water to pass through the soil column compared to straight RZS. The CC mixture was not different from the unamended sand. Although at a slower rate, water continued to drain for 240 minutes. After 1440 minutes (24 hr) of free drainage, the CC mixture lost 5.9 cm of water, while the DE mixture lost the least, 4.2 cm. Between 240 and 1440 minutes, the CSP mixture lost an additional 1 cm of water, indicating continual drainage. Others have noted a more gradual loss of water in sand amended with peat, compared to unamended sand or sand amended with an IOSA (Bigelow et al., 2000; McCoy and Stehouwer, 1998).

Flux with time was plotted to determine the velocity of water movement through the rootzone mixes (Figure 3.8). Differences between mixes were observed within the first 3 minutes following the onset of drainage. After 0.5 minutes, the downward flow of

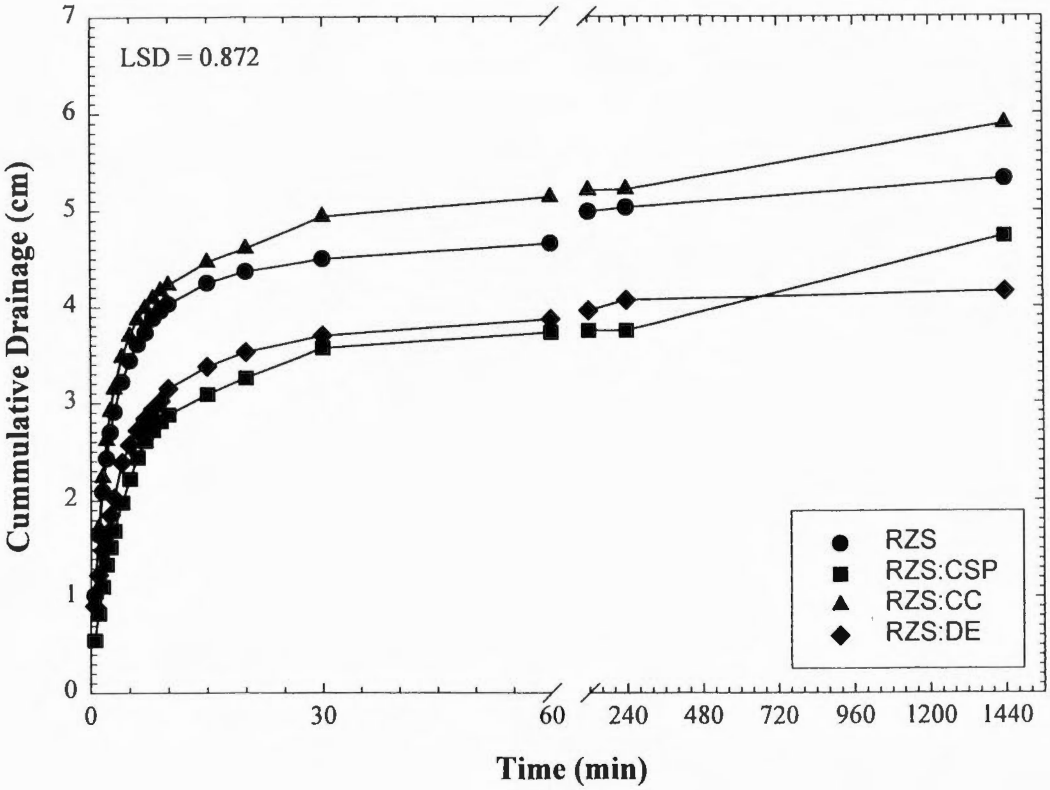

Figure 3.7 Cumulative drainage with time for rootzone sand (RZS), and RZS amended with 15% v/v Canadian sphagnum peat (CSP), calcined clay (CC) or diatomaceous earth (DE) overlaying 7.6 cm of gravel meeting United States Golf Association specifications.

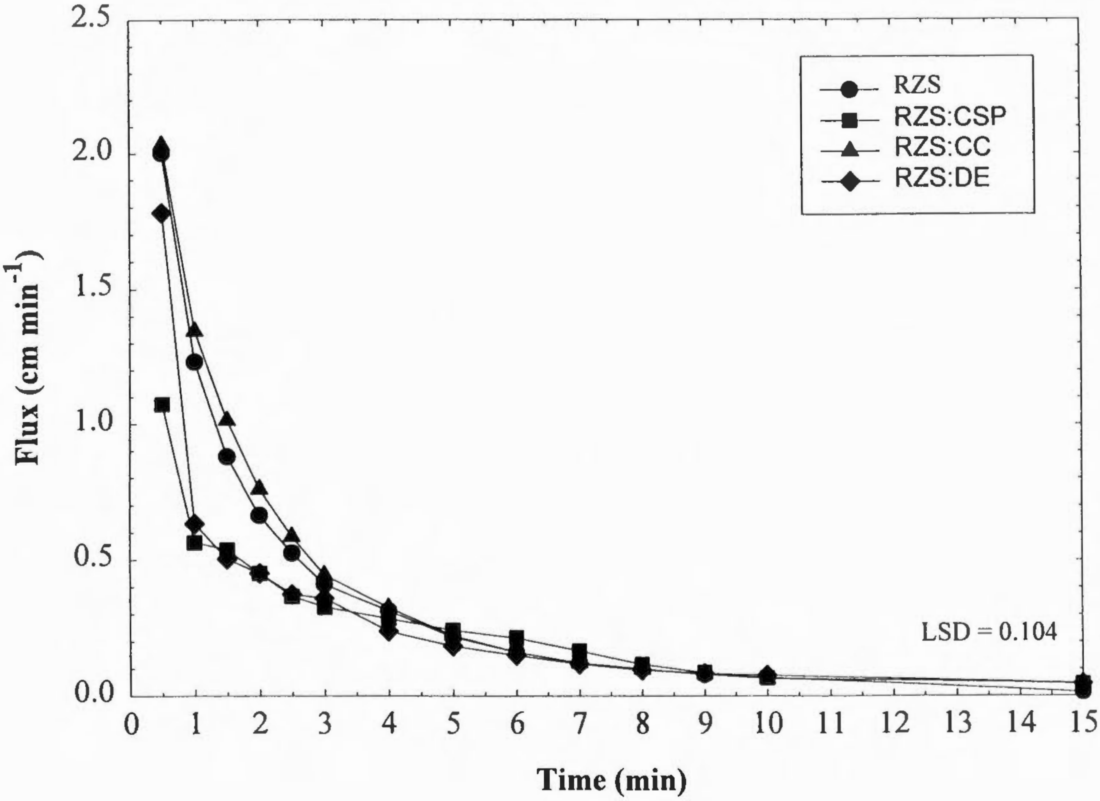

Figure 3.8 Flux with time for rootzone sand (RZS), and RZS amended with 15% v/v Canadian sphagnum peat (CSP), calcined clay (CC) or diatomaceous earth (DE) overlaying 7.6 cm of gravel meeting United States Golf Association specifications.

water for RZS and RZS amended with CC was 2.0 cm min^{-1}, while DE and CSP mixtures were significantly less, 1.8 and 1.1 cm min^{-1} respectively. As flow velocities decreased during the first 3 minutes, this trend continued, thereafter, no differences between any rootzone mixes were measured. After 15 minutes, the downward flow for all mixes was <0.05 cm min^{-1}. Water velocity measurements of these magnitudes were an indication the bulk of the drainage had concluded.

Water Potential

Pressure potential measurements within the various sand mixtures during a 1440-minute (24 hr) drainage period are shown in Figure 3.9. At 0 minutes after drainage, positive pressure potentials were measured throughout the profile, indicating saturation. Drainage in the upper 5 cm from the columns was rapid in all soil mixtures, with pressure potentials falling to less than –1.0 kPa within 5 minutes of the removal of surface water. Also, at 5 min, negative pressure potentials were measured for all mixtures to the 20-cm depth, while positive pressure potentials were recorded at the 25-cm depth for the CSP and CC mixtures and all mixtures at 30 and 35 cm. The drop in pressure potentials was followed by a gradual decrease in potential through the remainder of the drainage period.

Interestingly, at the 35-cm depth, positive pressure potentials were measured 1440 min for all mixtures, indicating free water within the gravel layer. At this same time, drainage flux for all amendments ranged from 0.0003 to 0.0005 cm min^{-1} (Figure 3.10), indicating drainage had nearly ceased and columns had about reached equilibrium. Previous reports have not indicated the presence of free water in the gravel layer of a rootzone profile constructed to USGA specifications.

By relating pressure potentials to the water retention curve (Figure 3.5), θ_v at each

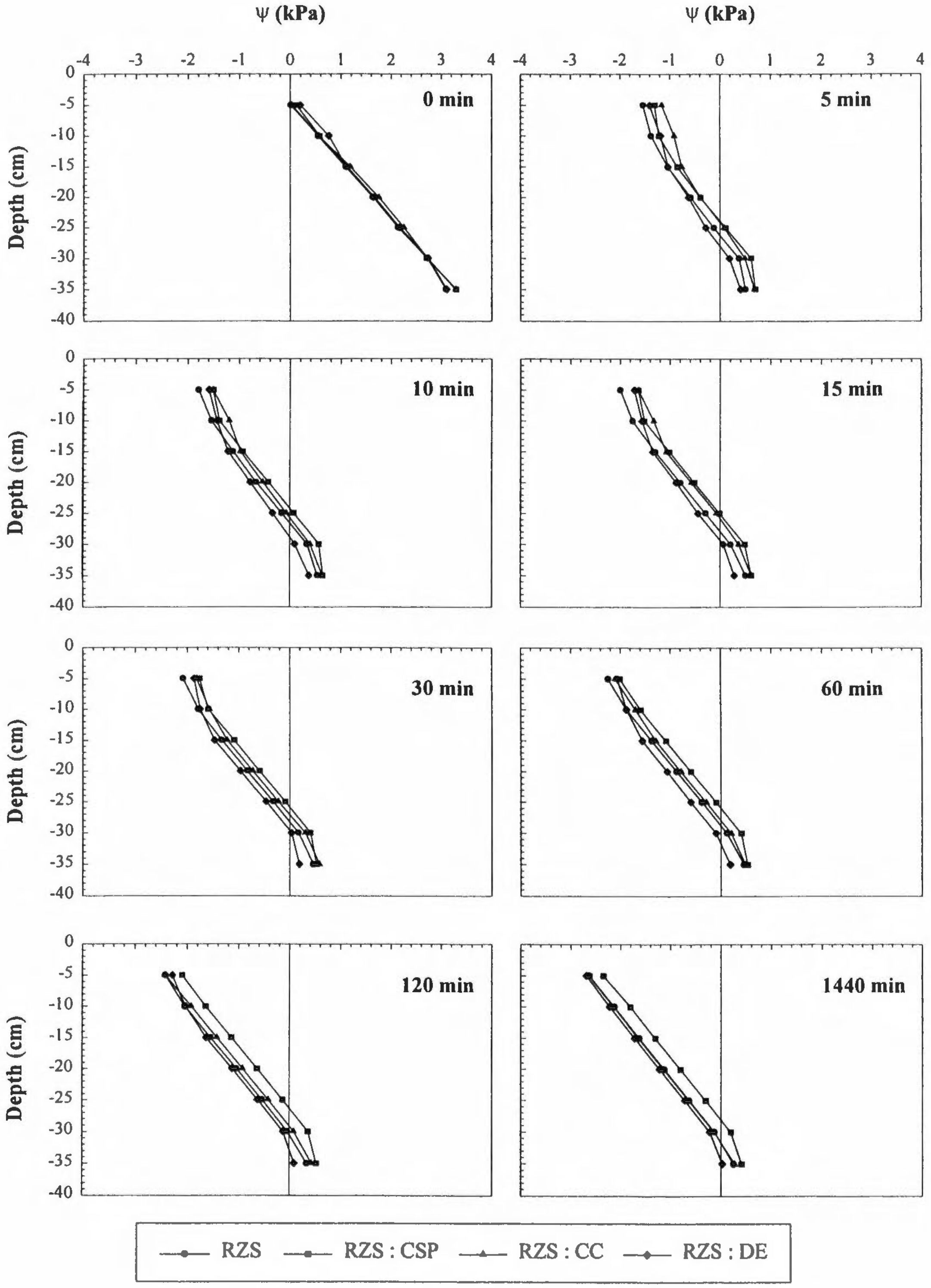

Figure 3.9 Pressure potential with depth for rootzone sand (RZS), and RZS amended with 15% v/v Canadian sphagnum peat (CSP), calcined clay (CC) or diatomaceous earth (DE) overlaying 7.6 cm of gravel meeting United States Golf Association specifications.

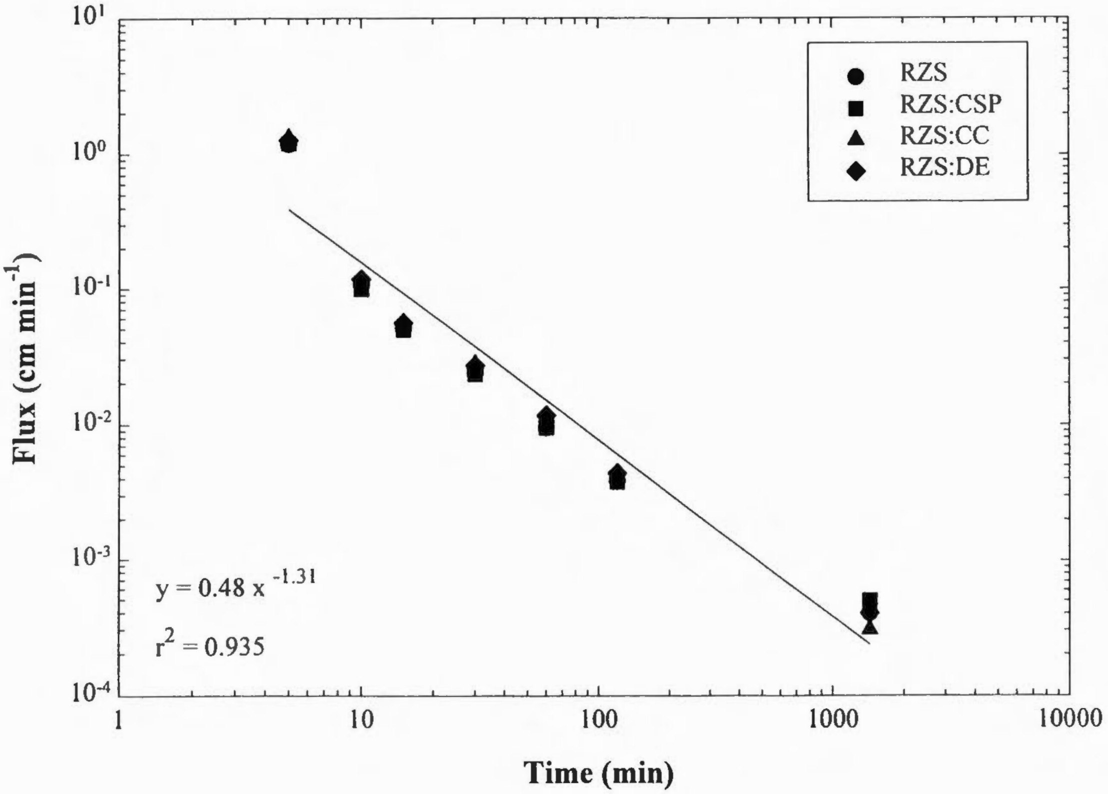

Figure 3.10 Flux during a 24-h drainage period for rootzone sand (RZS), and RZS amended with 15% v/v Canadian sphagnum peat (CSP), calcined clay (CC) or diatomaceous earth (DE).

depth was estimated (Figure 3.11). At 5 min, decreases in θ_v were measured at the 5 through 20-cm depth, but were not discernible below the 25-cm depth; the exception was DE amended sand, which had a 0.053 cm^3 cm^{-3} decrease. As would be expected, θ_v decreased through the remainder of the drainage period. After 1440 minutes of drainage, three of the four mixtures remained saturated at the 30 and 35-cm depths, the exception was the DE mixture, with a 0.040 cm^3 cm^{-3} decrease.

Conclusions

The amendments used in this study had different effects on the physical and hydraulic properties of the sand. Despite the increase of total porosity when CSP and DE were added to RZS, the addition of these amendments decreased the air-filled porosity and hindered water movement. Also, a high proportion of fine particles can influence water dynamics within the rootzone. The result was lower K_{sat} and flow rates compared to unamended sand. However, the addition of CC to sand increased the K_{sat} and flux, although the air-filled porosity for the CC mixture and unamended RZS were identical.

In amended sand mixtures, 0.015 to 0.116 cm^3 cm^{-3} more water was retained compared to unamended sand. The location of water in the profile is important for turfgrass roots, especially in the upper portion of the rootzone. Of the water retained in the rootzone, the CSP mixture held >50% in the upper 15 cm, while straight RZS held the least (37.1%). Comparing the IOSA, the DE mixture held slightly more water in the upper 15 cm than the CC mixture, 45 and 43% respectively. However, with the abruptness with which incipient wilt in turfgrass becomes severe wilt, the slightest increase of water in the rootzone may make a difference in turfgrass survival.

A USGA rootzone is conceptualized as a layered system; however, sand and

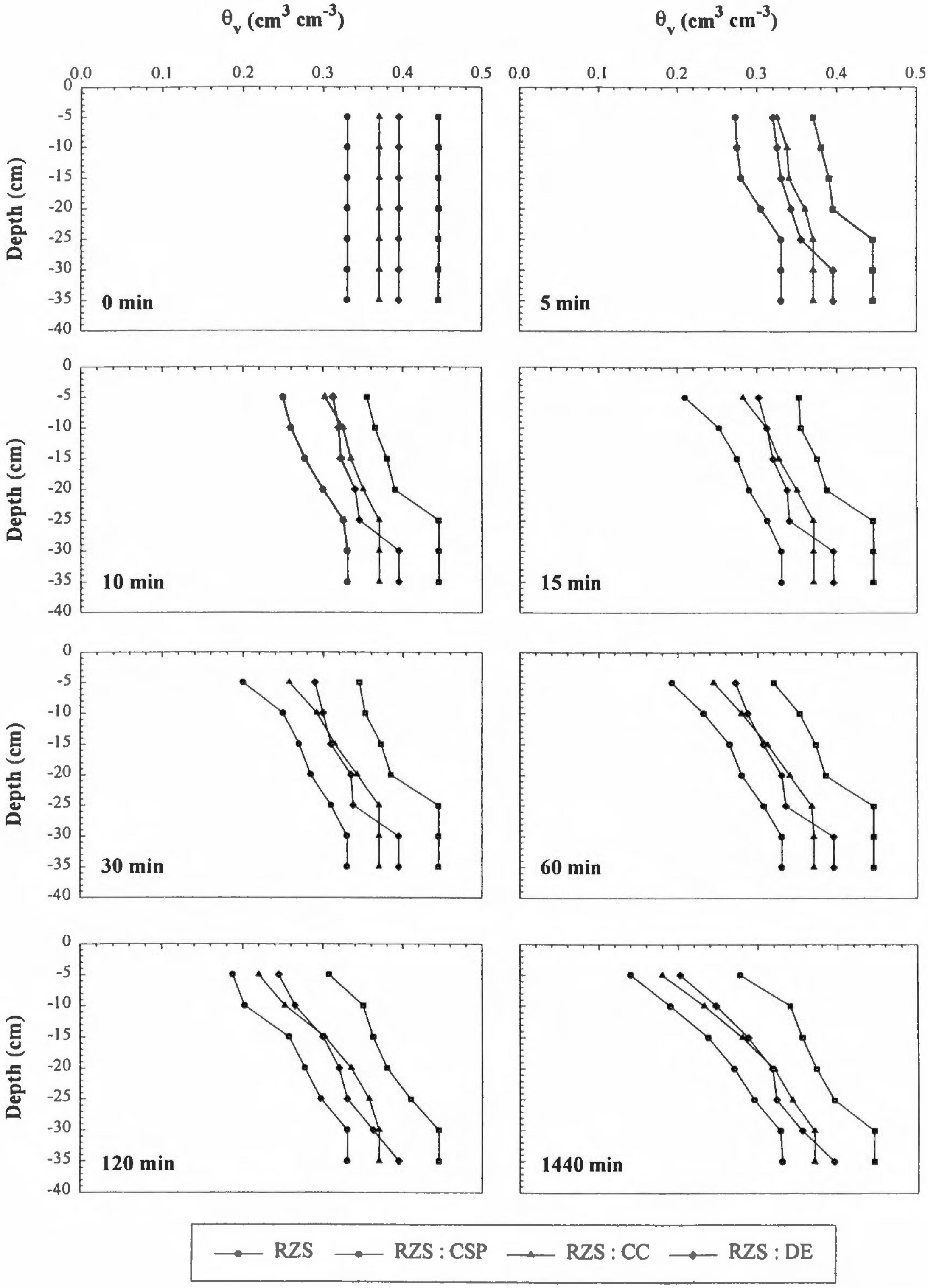

Figure 3.11 Estimation of volumetric water content (θ_v) from the water retention curve at 7 depths within a 40 cm rootzone for the first 24 h following drainage for rootzone sand (RZS), and RZS amended with 15% v/v Canadian sphagnum peat (CSP), calcined clay (CC) or diatomaceous earth (DE).

amendments move into the pore space of the gravel, if only in the upper few millimeters (Baker and Binns, 2001). Therefore, a transition layer is formed and this layer may influence the distribution of water. Negative pressure potentials were measured at the 30-cm depth after 1440 minutes of drainage. However at this depth, tensions were not great enough to remove water from the largest pores, resulting in a water saturated zone at the 30-cm depth.

In every soil mixture, water content decreased from the surface to the gravel layer. It has long been believed that the construction of a layered profile to establish a reservoir of water in the lower portions of the rootzone is desirable for turfgrass survival. Often the roots of closely mowed turf do not extended into the lower depths, thus this water is unavailable to the roots. Others have suggested the increased water retention in the lower sections of the rootzone may lead to reduced root growth and other problems associated with wet soils (Taylor et al., 1997)

Straight (100%) sand profiles built to USGA specifications retain water poorly in the upper half of the rootzone. Of the materials tested peat had better overall attributes as an amendment to the sand used in this research.

It could be assumed amendments that slow water movement and retain more water in the upper portion of the rootzone would have less water stress than turf grown on media that retained less water due to rapid drainage. By comparing the physical analysis and the hydraulic properties of the various rootzone media, it appears that RZS amended with CSP would provide the most conducive rootzone for turfgrass growth. As with the conclusions of McCoy and Stehouwer (1998), the DE mixture had water retention and drainage characteristics most similar to the CSP mixture and of the two IOSA, evaluated it would probably make the better substitute for peat in putting green rootzone media.

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CHAPTER 4

CALIBRATION OF A CAPACITANCE PROBE FOR USE IN FOUR GOLF COURSE PUTTING GREEN ROOTZONE MIXES

Abstract

It has been demonstrated that efficient water management can be achieved by using a reliable device to guide irrigation timing. The capacitance probe (CP) method of measuring water content has been applied to mineral soils but not to sand-based rootzone media (≈ 98% sand by weight) used for golf putting greens. Three laboratory studies were conducted to evaluate the use of a commercially available CP to measure water content in sand-based rootzone mixtures. The first study evaluated the effect of soil bulk density of four rootzone mixtures on CP measurements. The mixtures included straight washed rootzone sand (RZS) meeting United States Golf Association (USGA) specifications for putting green construction and RZS amended at 15% by volume with Canadian sphagnum peat (CSP), calcined clay (CC), or diatomaceous earth (DE). Rootzone mixtures were prepared to specific gravimetric water contents (0.09, 0.12, and 0.15 g g^{-1}), loaded into polyvinyl chloride columns, compacted to three levels, and CP readings recorded. The second study evaluated the effect of increasing organic matter content on CP readings. RZS was amended with various amounts (0, 5, 15, 25, and 35% v/v) of CSP, wet to gravimetric water contents of 0.09, 0.12, 0.15, and 0.18 g g^{-1}, identically compacted, and CP measurements taken. Use of the CP to measure water contents in a simulated putting green profile was the objective of the third study. Probes were positioned at 5, 10, 20, and 30 cm in columns filled with rootzone mixes, saturated, and allowed to drain. In the first two studies, the CP underestimated water content when compared to gravimetric methods. This discrepancy could be attributed to the lack of manufacture's calibration to sand-based soils. However, measured calibration results were well described by linear equations ($r^2 = 0.959$ to 0.993) for each mixture. Statistical analysis indicated no significant difference among linear relationship for the various organic matter mixtures, therefore, a single calibration curve for CSP amended RZS was derived. In simulated rootzone profiles, decreases in water content were measured at the 5- and 10-cm depths for all mixtures 5 minutes after the initiation of drainage. For 24 hours, continued drainage was recorded for all mixtures at 5, 10, and 20 cm. At the 20-cm depth, the DE mixture had the greatest (0.137 $cm^3\ cm^{-3}$) change in Vitel HydraProbe volumetric water content (θ_{VHP}) from the initiation of drainage to 1440 minutes. The change in θ_{VHP} for the other mixtures were 0.029, 0.059, and 0.056 $cm^3\ cm^{-3}$ for RZS and mixtures of CSP and CC, respectively. CP measurements indicated all mixtures remained saturated at the 30-cm depth for the 24-hour drainage period. Differences between the measured calibration equations indicate calibration is necessary for each rootzone mixture. Under these soil conditions, further specific calibration of this CP will be required to determine the absolute water content and usefulness as an irrigation tool in monitoring moisture levels of golf putting greens.

Introduction

Appropriate application and management of water is critical for turfgrass survival during the stresses of summer months. As water conservation and usage issues become more important, golf course superintendents will be forced to make judicious use of water resources. Turfgrass managers will have to justify the use and volume of water and forgo the practice of indiscriminate irrigation. For years superintendents have used many means to guide turfgrass irrigation, some methods more qualitative and adapted to quick field adjustments, while others are time consuming but provide quantitative information. An efficient and accurate method of measuring soil water content could improve water management in turfgrass systems. The use of a reliable soil moisture probe as a tool to direct irrigation may ease the decision of when to irrigate and how much water to apply.

Researchers have continually shown that efficient water management is achieved by using a reliable device to guide irrigation timing. The benefits of tensiometer guided irrigation of turfgrasses have been established (Snyder et al., 1984; Augustin and Snyder, 1984; O'Neil and Carrow, 1982; Morgan et al., 1966; Morgan and Marsh, 1965), however, the benefits have not been demonstrated on sand based putting greens. Also, due to logistical and maintenance issues, the acceptance and use of this technique by turfgrass managers has not been widely adopted. A technique that allows continuous monitoring of *in situ* soil moisture may be of practical use in the turfgrass industry.

There are various types of instruments that measure moisture content (i.e. porous blocks, thermal dissipation blocks, neutron probes, dielectric constant probes, and others), with each having positive and negative attributes. Permanently buried sensors have the potential to be valuable tools in the decision process of when to irrigate and the amount of water to apply.

A relatively new technology to measure soil moisture is the measurement of the soil dielectric constant (DC). The DC is a unit-less measurement of a solvent's ability to keep opposite charged particles apart; in this case the solvent is water (Voet and Voet, 1995). The DC of dry soil ranges from 2 to 7, while the accepted DC value for water is 80.4 at 20° C and atmospheric pressure (Miller and Gardiner, 1998; da Silva et al., 1998; Paltineanu and Starr, 1997). Due to the difference between dry soil and water, moisture content can be measured. Greater moisture contents cause higher DC values while lower DC readings indicate reduced moisture content. There are two basic types of probes that measure DC, time domain reflectometry (TDR) probes and capacitance probes (CP).

Researchers have been using time domain reflectometry (TDR) since the early 1980s for scheduling irrigation. However, little research has been specific to turfgrass. Kome (1996) reported potential water savings of 46% from irrigations scheduled based on measuring soil moisture depletion with TDR compared to evapotranspiration estimates. However, water savings have not been demonstrated on a modified sand profile construction.

Like TDR, CP measure water content based on soil DC. Similar to measurements made with a neutron probe, some CP measures soil volumetric water content (θ_v) by using an access-tube approach (Fares and Alva, 2000; Paltineanu and Starr, 1997), while other CP use a waveguide or tine approach like TDR (Seyfried and Murdock, 2001). In the access-tube approach, the probe is not in direct contact with the soil and open holes are required at measurement locations. Due to playability and maintenance disruptions, this approach is not desirable for use on golf course putting greens, whereas tine type probes could be of practical use. Tine type CP can be buried in the soil, are small (4.2 cm diameter and 10 cm long), easily integrated into automated data collection systems, and are less expensive than TDR (Seyfried and Murdock, 2001; Devitt and Morris, 1997).

Researchers have found a relationship between CP readings and other methods of measuring θ_v. Fares and Alva (2000) reported good agreement between CP readings and soil moisture content calculated from laboratory derived water release curves for a fine sandy soil. With a 1:1 relationship between θ_v calculated gravimetrically and θ_v measured by a CP, Paltineanu and Starr (1997) concluded CP could accurately measure volumetric soil water contents. However, some reports have reported factors that adversely affect CP readings. Like TDR, soil compaction, temperature and ionic strength may influence readings (de Rosny et al., 2001; Campbell, 1990). To minimize these influences, some CP measure soil salinity and temperature along with DC, allowing for more reliable moisture readings. Although only limited data exist for the use of CP in turfgrass, Starr and Paltineanu (1998) found CP to provide acceptable real-time sensitivity when measuring soil water moisture in field grown corn (*Zea mays* L.). With further research and advancements in technology, CP may prove to be an economically justifiable tool for guiding irrigation practices on golf courses.

One unknown when using CP is the possible need for calibration to particular soils. After evaluating a soil dielectric constant probe, Seyfried and Murdock (2001) concluded a separate calibration curve was necessary for each of 4 soils as soil water contents increased. Also, soil temperature and electrical conductivity affected the probe. Likewise, Whalley et al. (1992) concluded soil bulk density could affect readings of a probe based on soil dielectric measurements.

Several moisture probes currently exist, but their accuracy, dependability, and cost limit their use on a golf course. However, a dielectric constant probe for assessing water content that satisfies many of the prescribed needs has become available. The Vitel HydraProbe (VHP) (Vitel, Inc., Chantilly, VA 22021) measures soil dielectric constant, temperature, and conductivity (Figure 4.1). Based on these measurements, water content is calculated by a proprietary equation associated with the software of the probe. The algorithm is calibrated for particular soil types (i.e. soils that are predominantly sand, silt, or clay), but if this probe is to serve as a tool for water management on golf course putting greens constructed with high sand contents, refinement may be necessary.

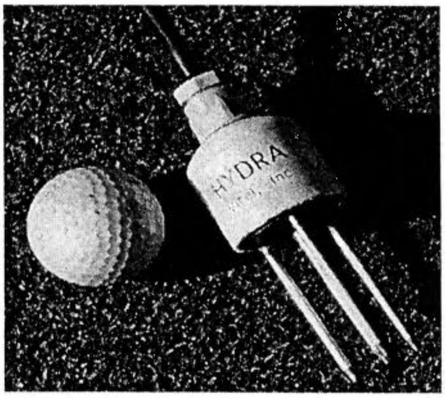

Figure 4-1. Picture of the Vitel HydraProbe (VHP).

The objective of this research was to assess the characteristics of this multisensor capacitance probe and to calibrate the capacitance probe under laboratory conditions to high sand rootzone media used for golf course putting green construction. Specific objectives included (i) developing a calibration equation based on of varying compaction levels and organic matter contents, and (ii) investigating moisture contents within a constructed USGA profile using the VHP.

Materials and Methods

Rootzone media were constructed using washed quartz sand (Golf Agronomics, Lugoff, SC 2978) commonly used for putting green construction in South Carolina. Various rootzone media were prepared using one of three amendments, Canadian sphagnum peat (CSP) (93.4% organic matter loss on ignition at 800° C), a calcined clay (CC) product (PROFILE, Aimcor Consumer Products LLC. Buffalo Grove, IL 60089), and a diatomaceous earth (DE) product (PSA, Golf Ventures, Inc., Lakeland, FL 33809). To prepare media, amendments were added to rootzone sand (RZS) on a 15% v/v basis using bulk densities of 0.13, 0.59, and 0.46 g cm^{-3} for CSP, CC, and DE, respectably. Typical particle size distribution of the RZS, individual inorganic amendments and various rootzone media are presented in Table 3.1 and physical properties are presented in Table 3.2.

Bulk density columns were constructed from 5.2 cm inside diameter (0.4 cm wall thickness) polyvinyl chloride (PVC) pipe to a length of 7.6 cm. The bottoms of the columns were covered with cheesecloth, dried in an oven to ensure that minimal moisture existed prior to filling, and weighed. Prior to wetting, all mixes were dried in an oven. In plastic bags, each mix was wetted to gravimetric water contents of 0.09, 0.12, and 0.15 g g^{-1}. Water was incorporated by kneading the required amount of water into the mixtures and allowed to reach equilibrium overnight.

Columns were packed with moist media to three levels, low, medium, and high. The low treatment was tamped by hand a total of 10 times during the filling process, the medium treatment 20 times, and the high treatment 30 times. The filling process consisted of adding a few grams of rootzone mixture to the column, the surface was tamped and scarified to reduce layering. The process was repeated until the column was filled and the appropriate total number of tamps were made. To prevent the loss of moisture, each end of the columns were covered with laboratory film (Parafilm, American National Can, Greenwich, CT 06836), laid in a horizontal position, and allowed to reach equilibrium overnight. The average bulk density for each amendment and compaction level is shown in Figure 4.2. Data were analyzed using analysis of variance with means separated using least significant difference at $P = 0.05$ (SAS Inst., Inc., 2001).

In a separate study to evaluate the effects of varying organic matter contents, columns were constructed similar to those in the bulk density study. Rootzone mixtures of sand and CSP were mixed on a volume basis using a bulk density for CSP of 0.131 g cm^{-3}. Mixtures included 100% RZS and RZS amended with CSP at 5, 15, 25, and 35% by volume. Mixes were wetted to four gravimetric water contents (0.09, 0.12, 0.15, and 0.18 g g^{-1}), identically packed (20 tamps) and measured for water content with the VHP and gravimetrically. The average bulk density for each peat concentration is shown in Figure 4.3.

To measure θ_V, the VHP was pressed into the column and measurements were read on a commercial data logger, Hydralogger (Vitel, Inc., Chantilly, VA 22021) as specified by manufactures instructions. After VHP readings were taken, columns were oven dried (105 C° overnight) and gravimetric water content, bulk density, and volumetric water content were calculated. Hereafter, volumetric water contents measured gravimetrically will be referred to as θ_V and water content measured using the VHP as θ_{VHP}. To measure water contents at saturation, columns were packed, allowed to wet from the bottom up, and measured.

Although θ_{VHP} is the dependent variable in this calculation, it was treated as the independent variable because the application was to derive actual θ_V from θ_{VHP} measurements. For the rootzone mixtures, a full model containing each amendment

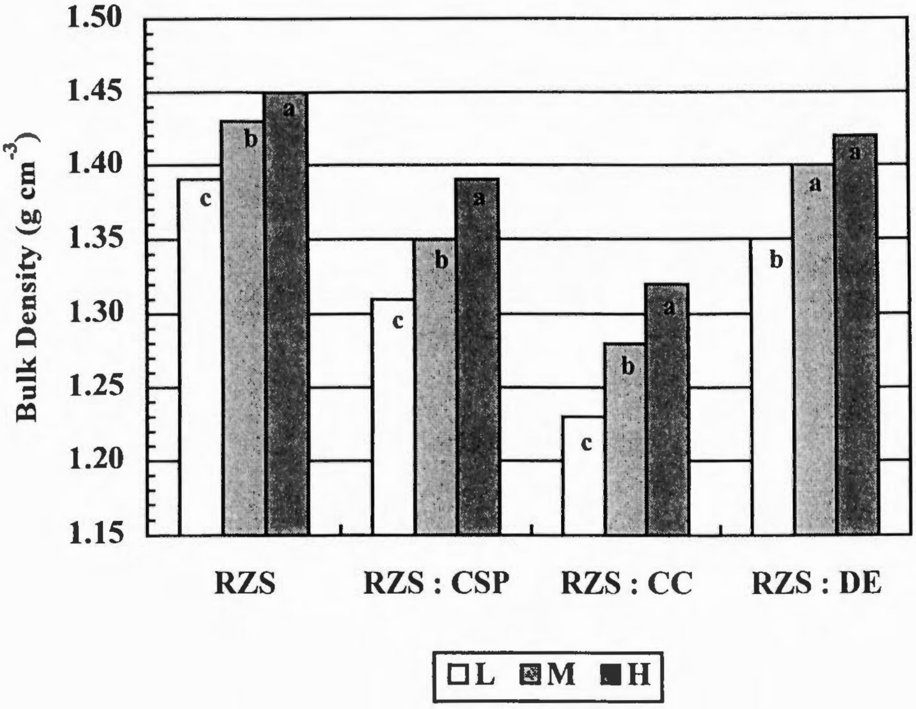

Figure 4.2 Bulk density for rootzone mixtures of rootzone sand (RZS) and RZS amended at 15% by volume of either Canadian sphagnum peat(CSP), calcined clay (CC), or diatomaceous earth (DE) compacted at three levels: low (L), medium (M), and high (H). Columns within rootzone mixtures with the same letter do not significantly differ, P = 0.05 (C.V. = 2.0).

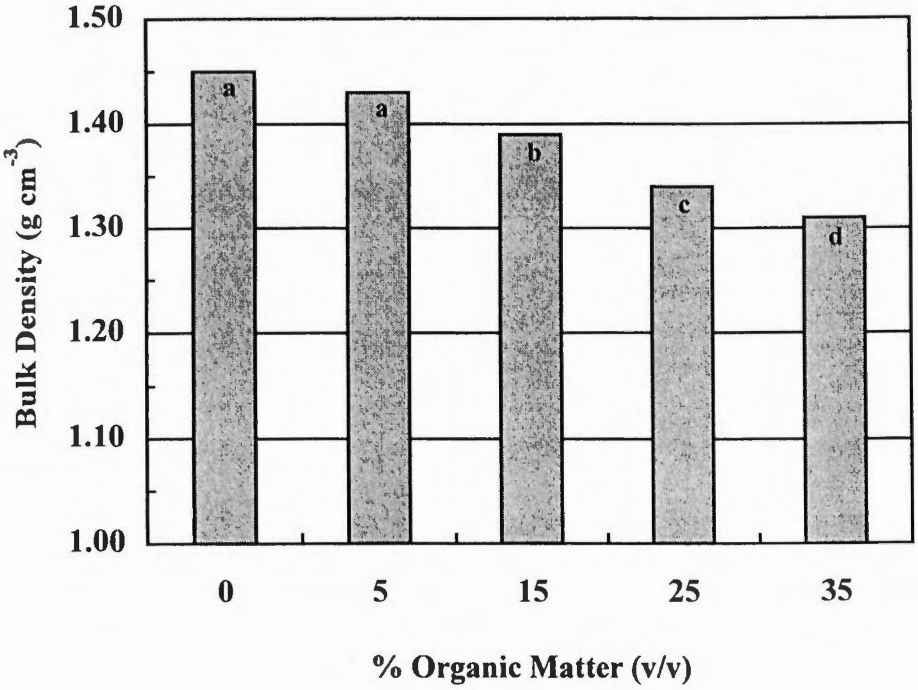

Figure 4.3 Bulk density for rootzone sand amended with various amounts of organic matter derived from Canadian sphagnum peat. Columns with the same letter do not significantly differ, P = 0.05 (C.V. = 1.9).

mixture and packing level was compared to a reduced model which combined all amendments and packing levels through a the mean square drop procedure (SAS, Inst., Inc., 2001; Ott, 1993). An F statistic was calculated to obtain an unbiased estimate of the mean square error term and data indicated the reduced equation could not be used for all rootzone mixtures. Similar analyses were performed for RZS amended with various amounts of CSP. Unlike data comparing mixtures and bulk densities, differences between organic matter contents were not detected between organic matter concentrations. Therefore, the reduced equation was used for calibration of RZS amended with CSP. Individual calibration curves were determined for each mixture (Table 4.1). Treatments in each study were replicated 3 times.

Use in a Simulated Putting Green Profile

In a process similar to Morgan et al. (1966), columns were constructed from 25.4 cm inside diameter (0.8 cm thick wall) PVC pipe (Figure 3.4). Individual columns were 40 cm high with a 1.95 cm inside diameter hole drilled at the bottom for drainage and wetting. A 10 cm layer of gravel (Table 3.1) was placed in the bottom of the columns (approximately 8.5 kg, giving a bulk density of 1.69 g cm^{-3}). Thirty centimeters of air-dry rootzone media (Table 3.1) was added in several stages. The surface of each stage was tamped and scarified before additional media was added until 30 cm was reached. No separation of the amendments during the filling process was evident.

By extending the drainpipe to an up position, columns were saturated from the bottom up to minimize entrapped air. Once wetting was complete, a 0.5 cm head was established and columns were allowed to equilibrate for 0.5 hours. To initiate drainage, the drainpipe was capped, rotated to a down position and uncapped. To reduce

Table 4.1 Linear regression coefficients of volumetric water content measured with the Vitel HydraProbe (θ_{VHP}) verses measured volumetric water content (θ_V) for rootzone sand (RZS) and rootzone media amended with Canadian sphagnum peat (CSP) and inorganic amendments, calcined clay (CC) or diatomaceous earth (DE), at 15% by volume.

Rootzone Media	Coefficients $\theta_{VHP} = \beta\theta_V + \alpha$			
	α	β	r^2	n
RZS	-0.0649 ± 0.0052	0.9445 ± 0.0282	0.959	50
RZS : CSP	-0.0617 ± 0.0025	1.0172 ± 0.0135	0.991	57
RZS : CC	-0.0604 ± 0.0029	0.9396 ± 0.0151	0.993	30
RZS : DE	-0.0435 ± 0.0038	0.9249 ± 0.0189	0.989	29

evaporation and ensure loss of water through drainage alone, columns were covered with plastic.

VHP were positioned at 5, 10, 20, and 30 cm below the soil surface and were inserted into the columns during construction. The VHP were multiplexed (AM416 Relay Multiplexer, Campbell Scientific, Inc., Logan, UT 84321) and connected to a data logger (Campbell 21X Micrologger, Campbell Scientific, Inc., Logan, UT 84321) with readings taken on one minute intervals (due to size of data set only selected intervals will be presented). Raw probe output voltages were downloaded and transformed to volumetric water content using manufacturer-supplied software (Vitel, Inc., 1994). Once VHP calculated water contents were derived, water contents were adjusted using calibration curves from compaction and organic matter studies (Table 4.1).

Results

The direct comparison between θ_V calculated gravimetrically and that determined by the VHP showed the capacitance probe technique underestimated the actual θ_V for these rootzone mixtures. Although differences in bulk density between packing levels were measured (Figure 4.2), slopes and intercepts of calibration equations for individual mixtures were not influenced by compaction treatments (Table 4.2). Regression of θ_{VHP} on the gravimetrically calculated θ_V resulted in highly significant linear relationships for each mixture (Table 4.1, Figure 4.4). Calibration data for all mixtures were well described by linear fits ($r^2 = 0.959$ to 0.993) and similarities in linear fit between several of the mixtures were measured. RZS and the CC mixtures had similar intercepts and slopes. However, the slope of the CSP mixture was higher (1.0172) than the other mixtures (0.9445, 0.9396, and 0.9249 for RZS, and mixtures of CC and DE,

Table 4.2 Probability values for predetermined contrast of compaction levels (L = low, M = medium, and H = high) when volumetric water content from the Vitel HydraProbe (θ_{VHP}) data was plotted verses measured volumetric water content (θ_V) data for rootzone sand (RZS) and rootzone media amended with Canadian sphagnum peat (CSP) and inorganic amendments, calcined clay (CC) and diatomaceous earth (DE), at 15% by volume.

		Coefficients $\theta_{VHP} = \beta\theta_V + \alpha$	
Rootzone Media	Contrast of Compaction Levels	P_α	P_β
RZS	L x M	0.2944	0.1744
	L x H	0.6639	0.5234
	M x H	0.5635	0.4822
RZS : CSP	L x M	0.1856	0.2406
	L x H	0.3215	0.4396
	M x H	0.7677	0.6990
RZS : CC	L x M	0.7738	0.7376
	L x H	0.9422	0.8918
	M x H	0.7176	0.6249
RZS : DE	L x M	0.2305	0.3186
	L x H	0.0502	0.0909
	M x H	0.4173	0.4468

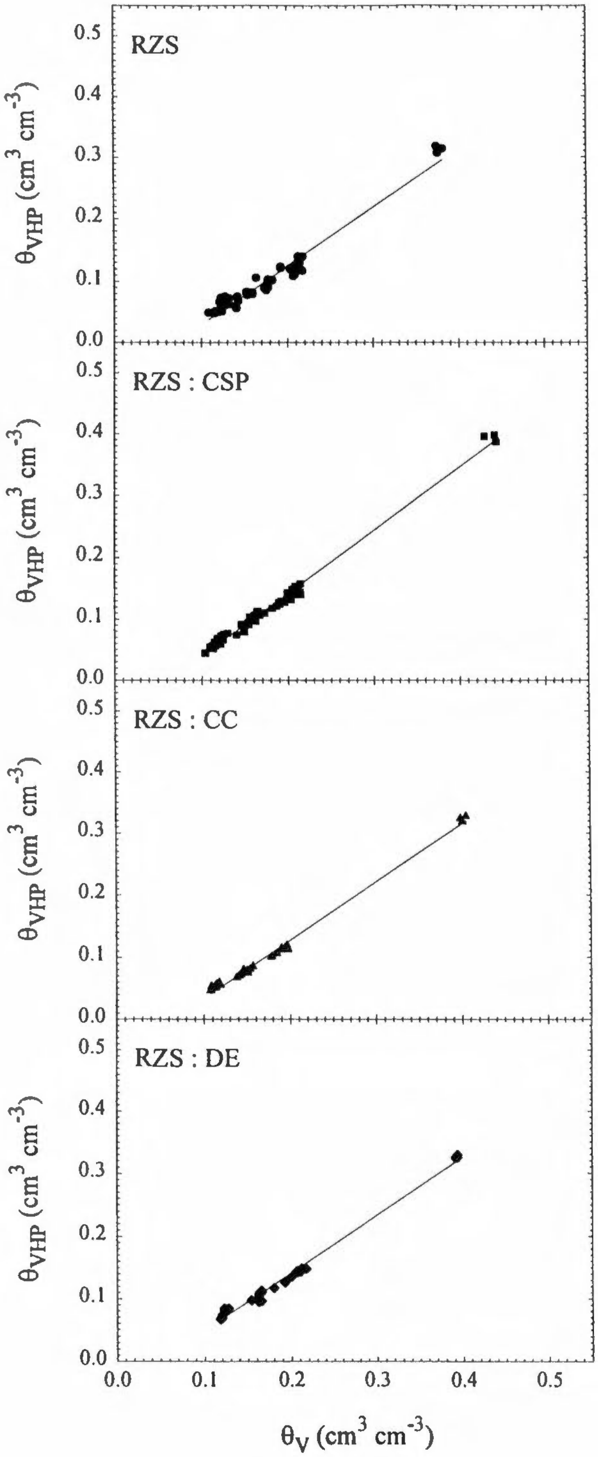

Figure 4.4 Linear regression of volumetric water content measured with the Vitel HydraProbe (θ_{VHP}) verses measured volumetric water content (θ_V) for rootzone sand (RZS) and rootzone media amended with Canadian sphagnum peat (CSP) and inorganic amendments, calcined clay (CC) or diatomaceous earth (DE), at 15% by volume.

respectively), but the intercepts of the RZS and CSP mixture were alike. Likewise, the slopes of the RZS and DE mixture were not different, but the intercept of the DE mixture was lower (-0.0435) than the other mixtures (-0.0649, -0.0617, and –0.0604 for RZS and mixtures of CSP and CC, respectively). Similar results were reported in soil substitutes amended with peat by da Silva et al. (1998) for the calibration of a TDR probe.

Use in a Simulated Putting Green Profile

The θ_{VHP} profiles illustrate the range of water contents achieved during 24 of drainage in sand-based rootzone mixtures (Figure 4.5). At 5 minutes after drainage, decreases in θ_{VHP} were measured at the 5- and 10-cm depths for all mixtures. At the 20-cm depth, a decrease (0.045 cm^3 cm^{-3}) in θ_{VHP} was only observed in the DE mixture, while at 10 min a minor decrease (0.014 cm^3 cm^{-3}) in water content was measured for the CC mixture. Continued drainage was measured at the 5- and 10-cm depths for all amendment combinations through the remainder of the drainage period. Likewise, at the 20-cm depth, continued drainage was recorded for all the mixtures with the DE combination having the greatest (0.137 cm^3 cm^{-3}) change in θ_{VHP} from initiation of drainage to 1440 min. The change in θ_{VHP} for the other mixtures were 0.029, 0.059, and 0.056 cm^3 cm^{-3} for RZS and mixtures of CSP and CC, respectively. VHP measurements indicated all mixtures remained near saturation at the 30-cm depth through the drainage period.

At the 5-cm depth, no appreciable ($<$ 0.009 cm^3 cm^{-3}) difference between the amended mixtures were detected after 1440 minutes of free drainage. Straight RZS had the lowest θ_{VHP} (0.082 cm^3 cm^{-3}) while the amended mixtures averaged 0.140 cm^3 cm^{-3}. A similar trend was observed for the 10-cm depth. These data indicate amended RZS

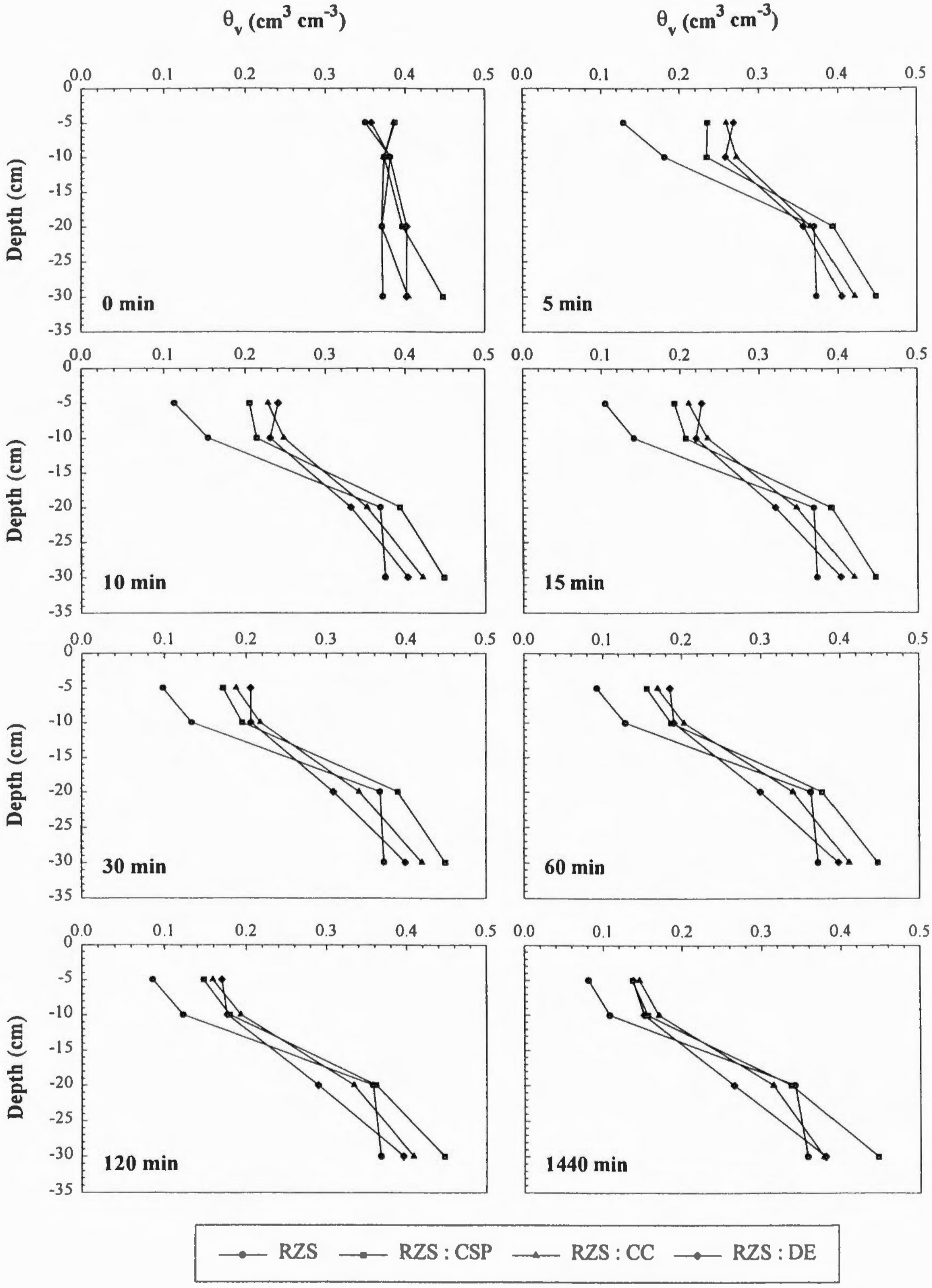

Figure 4.5 Vitel HydraProbe estimation of volumetric water content (θ_v) at 7 depths within a 40 cm rootzone for the first 24 h following drainage for rootzone sand (RZS), and RZS amended with Canadian sphagnum peat (CSP), calcined clay (CC), or diatomaceous earth (DE), at 15% by volume.

may retain 0.044 to 0.062 cm^3 cm^{-3} more water in the upper third of the rootzone. Since much of the turfgrass root growth occurs in the 10-cm (Baker and Binns, 2001; Taylor et al., 1997), amending RZS with any of these materials may aid in delaying the onset of moisture stress.

Figure 4.6 compares θ_V obtained from the relationship between tension measurements (Figure 3.11) and the water retention curve to θ_{VHP} measurements. The relationship between the two methods of measuring water content were most highly correlated for the amended RZS ($r^2 = 0.830$, 0.881, and 0.912 for mixtures of CSP, CC, and DE, respectively), while the r^2 for RZS was 0.784.

Conclusions

Published data is unavailable for field or laboratory calibration of the VHP; therefore, comparisons with previous research are not possible. In this study, raw θ_{VHP} data were underestimated by the VHP for all the tested rootzone mixtures at all the compaction and organic matter combinations. However, once VHP readings were adjusted, θ_{VHP} were in agreement with θ_V calculated by gravimetric methods. Paltineanu and Starr (1997) showed a nearly 1:1 relationship between measured θ_v and that determined by a CP.

Others have concluded moisture sensors that sample a volume of soil lose accuracy due to variations in soil bulk density (Whalley et al., 1992). Data from this study does not support this conclusion. Also, it cannot be concluded the calibration curves can be extrapolated for water contents outside the respective tested range. Additional measurements would be required to obtain the validity of the equations determined by linear regression. Data may become nonlinear below the tested range of

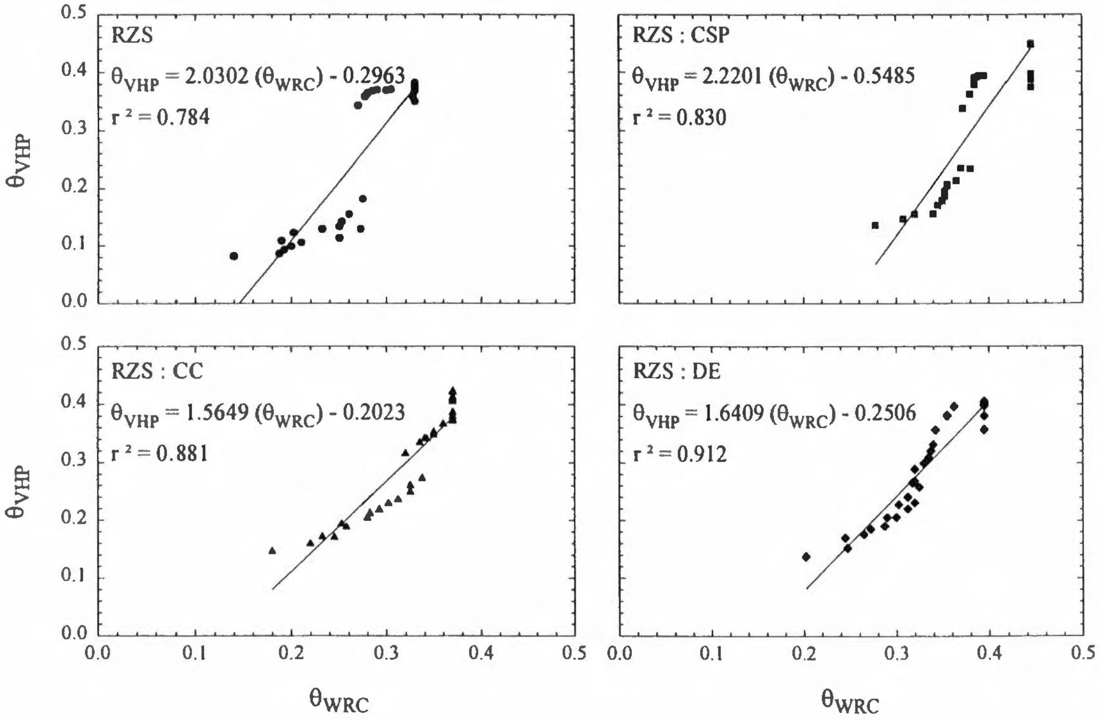

Figure 4.6 Volumetric water content estimated from the water retention curve (θ_{WRC}) verses volumetric water content measured by the Vitel HydraProbe (θ_{VHP}) for rootzone sand (RZS) and RZS amended 15% v/v with Canadian sphagnum peat (CSP), calcined clay (CC), or diatomaceous earth (DE).

water contents, as been reported for TDR measurements (da Silva et al., 1998). However, our data support the findings that moisture sensors dependent on dielectric constant readings are not independent of soil type (Seyfried and Murdock, 2001; da Silva, 1998; Anisko, et al., 1994).

With proper calibration, computer monitored systems allowing measurements of putting greens have the potential to provide rapid and reliable values of θ_v. With the advantages of CP over other techniques used to monitor soil moisture status, the possibility of directly obtaining real-time measurements of θ_v make CP an ideal instrument for guiding irrigation on golf putting greens. However, the determination of a reliable calibration curve for a particular rootzone media is critical in the design of an irrigation schedule with CP and further research is needed to demonstrate that the VHP can be used to monitor the water content of golf putting greens. Also, additional research is necessary to determine the effects of management practices (e.g. fertilization and pesticide application) on CP readings. While investigation into turfgrass water requirements and the relationship between rootzone water content and turfgrass drought response should be continued.

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CHAPTER 5

FIELD EVALUATION OF SOIL AMENDMENTS USED IN ROOTZONE MIXES OF GOLF PUTTING GREENS

Abstract

Many golf course putting greens and athletic fields have been constructed on high sand rootzone media as prescribed by the United States Golf Association (USGA). The sand is usually amended with relatively small amounts of various materials, with peat moss being the most common, to improve moisture and nutrient retention while maximizing rootzone drainage, compaction resistance, and aeration. Due to limited supplies, a trend to replace peat with inorganic soil amendments (IOSA) is occurring in the construction of new greens and athletic fields. However, little research as to the long-term (> 5 years) benefits of these materials exists. In 1997, a field study was initiated to investigate the potential of IOSA as a replacement to peat in putting greens constructed in the Southeastern United States. Plots were constructed using a rootzone sand (RZS) meeting USGA specifications alone and the RZS amended at 15% by volume with either Canadian sphagnum peat (CSP), calcined clay (CC), or diatomaceous earth (DE). Creeping bentgrass (*Agrostis palustris* Huds. X *A. stolonifera* L. 'L-93) was seeded on 8 October 1997 at 73.3 Kg ha^{-1}. Plots amended with CSP established to 95% by 6 months after seeding, which were 3 months prior to plots with either IOSA and 15 months prior for straight RZS plots. Once established and actively growing, turfgrass color for all plots was generally acceptable (≥ 7.0). The bulk density of lab packed RZS was greater

(1.61 g cm^{-3}) than the IOSA mixtures (1.49 g cm^{-3}), while CSP amended sand had the lowest bulk density (1.41 g cm^{-3}). In the upper 10-cm of field cores, significantly lower bulk densities were measured in amended plots. Organic matter contents greater than 1% by weight for plots amended with CSP and CC would explain lower bulk density measurements in this zone. Plots amended with CSP had 13 to 31% lower deceleration values than straight RZS and IOSA amended plots, indicating CSP amended plots were softer playing surfaces. Resistance to penetration in the upper 5 cm was variable for the various rootzone mixtures, however, in the lower 20 to 30 cm depths resistance to penetration ranked in the order of CC > DE > RZS > CSP. The addition of CSP to RZS provided for the earliest turfgrass establishment, excellent turfgrass color, reduced bulk densities, and lower impact absorption characteristics. Through the 3-year duration of this study, CSP was the best amendment for providing turfgrass cover and quality.

Introduction

Golfers prefer consistent, playable, putting surfaces regardless of the agronomic practices required to achieve such goals. In most cases, golf courses are rarely closed to allow sufficient turf recovery or to allow certain maintenance practices. Instead they are subjected to daily mowing, watering, and concentrated foot traffic. If not properly constructed, greens often become compacted leading to declining turfgrass growth and unacceptable playing conditions.

Soil Amendments

Putting greens are expected to last a minimum of 20 years, therefore the individual components must be durable and retain their desirable parameters (Moore, 1999). Beneficial agronomic characteristics for a putting green media include providing: (1) a proper medium for turfgrass establishment, (2) adequate infiltration, (3) resistance to compaction, (4) adequate aeration and proper water holding capacity, and (5) nutrient retention. Also, putting greens must provide a surface receptive (not excessively firm or hard) to golf shots and acceptable ball roll.

Sand is very resistant to breakdown from natural weathering and imposed degradation such as impact and abrasion as are most inorganic amendments used in putting green construction (Petrovic et al., 1997). However, peat, the most common organic amendment used, is subject to decomposition, thus, potentially compromising the long term integrity of the rootzone (Waddington, 1992). Also, peat being partially decomposed mosses, sedges, and other swamp flora, is in limited supply.

Amendments have been intensively investigated for turfgrass rootzone modification since the 1960s, though few results of long-term field trials have been reported. At the conclusion of a 10-year field study, Horn (1969) did not recommend calcined clay (CC) as a sole amendment on sandy, well-drained soil due to the water retaining ability of the sandy soil being compromised by the addition of CC. Also, hybrid bermudagrass (*Cynodon dactylon* (L.) Pres. X *C. transvaalensis* Burtt-Davey) growth and quality was reduced on plots amended with CC. Similarly, others report poor turfgrass performance when CC was the sole amendment (Bigelow et al., 1999; Minner et al., 1997; Smally et al., 1962)

While few field studies regarding CC use in turfgrass exists, published work with diatomaceous earth (DE) is even more limited. In a moisture retention study, Ralston and Daniel (1973) noted 'Penncross' creeping bentgrass (*Agrostis palustris* Huds) plots containing a DE product maintained normal growth for 15 days, while ceramic clay amended plots required watering after 5 days.

Furthermore, the effects of inorganic soil amendments (IOSA) on field bulk density (BD) and soil resistance is also limited. Higher percentages of soil solids to pore space increases bulk density. A high (>1.7 g cm^{-3}) bulk density can decrease root penetration, restrict aeration, and slow nutrient and water movement (Brady and Weil, 1999; Gliński and Lipiec, 1990). While some regard soil BD as a poor indicator of turfgrass growth (Smalley et al., 1962), others view soil BD as an important gauge for potential soil gas exchange (DePew, 2000). Gas exchange between the atmosphere and the rootzone is restricted in soils with high (e.g. 1.6 g cm^{-3}) bulk densities (Neilson and Pepper, 1990).

Measuring Soil Strength

Soil strength, also referred to as soil consistence, is a measurement of a soil's resistance to deformation. There are several methods to evaluate mechanical soil strength or firmness. One such method is to measure the soil's resistance to penetration with a penetrometer. Wood and Law (1972) used penetrometer readings to determine effects of imposed wear on soil compaction when evaluating Kentucky bluegrass (*Poa pratensis* L.) cultivars. Soil resistance varied between cultivars while increased soil compaction occurred in plots receiving wear treatments. Guertal et al. (1999) also noted increased resistance to soil penetration as traffic increased on fairway maintained hybrid bermudagrass. However, Derrick et al. (2000) reported approximately 25% reduction in soil resistance after a core cultivation to the 15 cm depth on a native soil. On a sandy soil (88% sand), Smalley et al. (1962) reported improved growth and quality of bermudagrass turf as penetration force decreased in the upper 10 cm of the rootzone. Published reports are currently unavailable on soil resistance in amended sand based rootzones. Depew et al. (1997) reported using a penetrometer in constructed sand-based athletic field rootzones, but did not include any findings.

A Clegg Impact Soil Tester (CIT) can be used to measure the impact absorption characteristics of a soil. The CIT is a lightweight, approximately 4.5 kilograms (10 pounds) for some models, portable apparatus that consists of three parts, a blunt ended hammer (also referred to as a missile), a guide tube, and a display box. Sensors in the handle of the hammer measures the peak deceleration (g_{max}) as energy is transferred from the hammer to the soil surface (Rogers and Waddington, 1990a). Therefore, the higher the g_{max}, the greater the soil firmness.

Baden Clegg developed the CIT for measuring the surfaces of sub-grades used for road construction in western Australia (Rogers and Waddington, 1990a). However, in turfgrass, the CIT has been used primarily in Europe and on athletic fields to evaluate root zone firmness (Rogers and Waddington, 1990a, b). Research indicates a decrease in maximum deceleration with increases in soil water content, thatch, and turfgrass cover (Rogers and Waddington, 1992; Dunn et al., 1994). Compared to penetrometer readings, Ford (1999) found the CIT more accurate at detecting soil firmness extremes on grassed surfaces. The use of the CIT on golf course putting greens is limited, thus, a standard to compare measurements is lacking.

Inorganic soil amendment use for golf putting green construction has increased over the last few years but long-term field performance is limited. The purpose of this study was to determine the influence of different soil amendments on turfgrass establishment, BD and soil strength. Secondly, the potential of using a CIT on sand-based rootzones to determine soil strength (or BD) was evaluated.

Materials and Methods

Plot Construction

A 0.19 ha (20,000 ft^2) bentgrass research golf green located on The Walker Course at Clemson University was established in 1997. In one section of the green, plots were established to evaluate inorganic rootzone amendments. The green consisted of a 30-cm sand rootzone placed over a 10-cm deep gravel blanket. No intermediate layer was used between the sand and the gravel. Polyvinyl chloride (PVC) sheets were installed vertically, extending 30 cm downward from the soil surface to the top of the 10-cm gravel layer, to contain individual amendments. Individual cells were 2.7 by 4.6 m (9 ft by 15 ft) and replicated 3 times in a randomized complete block design. A 10-cm corrugated drain line was installed under the gravel layer of each replication.

The fraction distribution of the rootzone sand (RZS) used for all plots is shown in Table 3-1. RZS to amendment ratio by volume included: (a) 100 % RZS; (b) 85 % RZS : 15 % Canadian sphagnum peat (CSP); (c) 85 % RZS : 15 % ceramic clay (CC); and (d) 85 % RZS : 14 % diatomaceous earth (DE) : 1 % kelp organic. The kelp organic was added as specified by the manufacturer but, is unlikely to have affected the rootzone mixture significantly since minor amounts were used and kelp is subject to rapid decomposition (Bigelow et al., 1999).

Plots were leveled to a depth of 30 cm, wetted, rolled, and on 8 October 1997 seeded with 'L-93' creeping bentgrass (*Agrostis palustris* Huds. X *A. stolonifera* L. 'L-93') at 73.3 Kg ha^{-1} (1.5 lbs 1000 ft^{-2}). The entire plot area was irrigated to promote adequate soil moisture to achieve germination. Within the first two weeks following seeding, a total of 100-8-18 kg N-P-K ha^{-1} was applied in two split applications. Throughout the next three growing seasons, plots were treated with fungicides and insecticides on a preventative and as needed basis. Also, all plots were topdressed with straight RZS and core cultivated periodically throughout each growing season to promote healthy turfgrass. Daily mowing was performed at $\approx$ 0.32 cm height with a commercial walk-behind reel mower.

Turf Density and Color

Monthly evaluations were recorded for turfgrass density and color. Density was rated as a visual percentage of the plot covered with turfgrass. Turfgrass color was visually rated on a scale of 1 to 9, 1 = brown, dead turf, 7 = minimally acceptable green color, and 9 = green, healthy turf. Data were analyzed using analysis of variance (ANOVA) and means separated by least significant difference (LSD) at $P = 0.05$.

Bulk Density

Once during the summer of 1999 and three times during the summer of 2000, bulk density measurements were made. Samples were obtained using a soil core sampler (Model 200-A, SoilMoisture Equipment Corporation, Santa Barbara, CA) and a standard golf course foot extraction hole cutter (Model 1002, Par Aide Products Company, St. Paul, MN). Samples were taken at three depths, or tiers, from the soil surface to 10 cm (1st tier), 10 to 20 cm (2nd tier), and 20 to 30 cm (3rd tier), along the same vertical cross section. Total volume of the samples was 160.23 cm^3.

The 1st tier was taken using the soil core sampler. After the sample was extracted, the upper 1.27 to 1.91 cm (turfgrass tissue and thatch) was removed and the remaining sample was stored in a moisture tight plastic bag. The 2nd and 3rd tiers were sampled using the soil core sampler and hole cutter. The hole cutter was used to cut around the hole and to the bottom of the 1st tier (10 cm). This soil was carefully placed aside for refilling after sampling and then the 2nd tier was sampled identical to the 1st tier. Similar to the 2nd tier, tier 3 was extracted by using the hole cutter to remove the upper 20 cm of soil and then the sample was taken. At the conclusion of sampling, all holes were back filled with the spoils and a laboratory prepared mix, similar to the original blend, was used to bring the surface to grade.

Two sub-samples per plot were weighed and placed in an oven at 105° C to dry. Following drying, samples were re-weighed so BD could be calculated. For comparative purposes, four soil columns per mix were packed in the laboratory and BD measured according to standard practices (Blake and Hartge, 1986). Laboratory columns mimicked RZS / amendment ratios used in the field with RZS and amendments mixed in the lab on a volume basis. Data were analyzed using the SAS general linear model procedure with means separated using least significant difference (LSD) at $P = 0.05$ (SAS Inst., Inc., 2001).

Soil Surface Strength

Soil strength was evaluated by two methods: soil surface strength (SS) using a Clegg Impact Soil Tester (Model 95049, Lafayette Instrument Company, Lafayette, Indiana) and soil resistance within the rootzone using a cone penetrometer. Soil strength readings were taken after the 2.5 kg CIT hammer was dropped four times from a height of 0.46 m, as specified by manufacturer instructions and peak deceleration (g_{max}) was recorded.

Soil profile resistance measurements were taken on 3 dates (12 October 2000, 19 October 2000, and 23 April 2001) using a cone penetrometer. Five readings per plot were recorded using a penetrometer with a 20° cone and base diameter of 1.3 cm on a 0.95 cm diameter shaft. The force (kPa cm^{-2}) required for penetrating the 5, 10, 20, and 30 cm depth was reported.

Three sub-samples were taken on each plot for SS, while five readings were made for soil resistance measurements. Data were analyzed using the general linear model procedure with means separated using LSD at $P = 0.05$ (SAS Inst., Inc., 2001).

Organic Content

Organic content for each sampling date and tier was measured by loss on ignition (800° C for 4 hours). Ten gram sub-samples were run in duplicate, averaged and data analyzed using ANOVA with means separated using LSD at $P = 0.05$ (SAS Inst., Inc., 2001).

Water Repellency

Water repellency was determined with the water drop penetration time (WDPT) test (Dekker et al., 2001; King, 1981). For each rootzone mixture and tier, a 15 to 20 g sub-sample of ground and homogenized oven dried sample was put into a ceramic crucible. Three drops of distilled de-ionized water from a medicine dropper were placed on the leveled surface. The time, in seconds, for the drops to infiltrate the soil was recorded and averaged. Water repellency was classified as described by Dekker et al., 2001 and Steenhuis et al., 2001 (Table 5.1).

Table 5.1 Classification of water repellency based on water drop penetration time (WDPT) .

WDPT (s)	Description
0 – 5	wettable; non-water repellent
5 - 60	slightly water repellent
60 - 600	moderately to strongly water repellent
600 - 3600	severely water repellent
> 3600	extremely water repellent

The relationship between organic matter content and water content on WDPT was also examined. Using a standard golf course foot extraction hole cutter equipped with a straight blade (inside edge), a core (20.3-cm long by 10.6-cm diameter) from one of the plots containing the CSP mixture was removed and brought into the laboratory. The hole cutter was disassembled such that the core remained in the metal cutting blade. The core was allowed to naturally drain with sub-samples taken at day of sampling and 7, 14, 18, 20, 24, and 28 days subsequently. A 1.1-cm diameter core was sub-sampled from the main core and drops of distilled de-ionized water from a medicine dropper were placed at 1-cm increments down the length of the sub-sample. After WDPT was determined, the sub-samples were dried in an oven (105° C) and organic matter was determined by loss on ignition (800° C for 4 hours).

Results and Discussion

Turfgrass Establishment and Color

Through the 3.5 years of this study, visual density was variable but initially, (first 6 months after seeding, MAS) plots amended with CSP and DE had 77 to 85% greater turfgrass cover than unamended plots (Figure 5.1). Likewise, plots with the CSP and DE mixture had 22 to 30% greater cover than plots amended with CC. At 6 MAS, the rooting media with CSP had 95% coverage, while it was not until 9 MAS that plots with an inorganic amendments exceeded 95% cover, and 18 MAS for plots with 100% RZS to be 90% covered. After establishment (18 MAS), visual density did not fall below 90% for plots amended with CSP (except the 24 MAS rating) and DE.

Heat stress of the summer months would thin turfgrass with the most severe reduction observed in unamended plots and plots amended with CC. In South Carolina and across the Southeast, the summer of 1999 was hot and dry. In Clemson, SC during July and August, there were 33 consecutive days when the daytime high was 32.2° C (90° F) or greater and the nighttime lows were 21.1° C (70° F) or greater 45% of the time. As a result, turfgrass thinned in all plots. At 24 MAS, only the DE amended plots had > 90% cover, while plots containing 100% RZS, CSP, and CC had 80% to 89% cover. Once conducive growing conditions of the fall and spring returned, density returned to acceptable levels. Plots with CSP had reestablished to > 90% cover by 27 MAS. A similar trend was observed during the summer of 2000.

Turfgrass color comparisons were not possible until ample cover for all treatments occurred (9 MAS). Turfgrass color is often a function of fertilization practices and therefore fluctuates through the year as nutrients are sufficiently available from fertilization and then become limiting due to plant uptake or leaching. All plots were equally fertilized through the duration of this study.

In general, turfgrass color was acceptable (≥ 7.0) for all amendments for the first 24 months following seeding (Figure 5.2). However a trend of plots containing CSP and

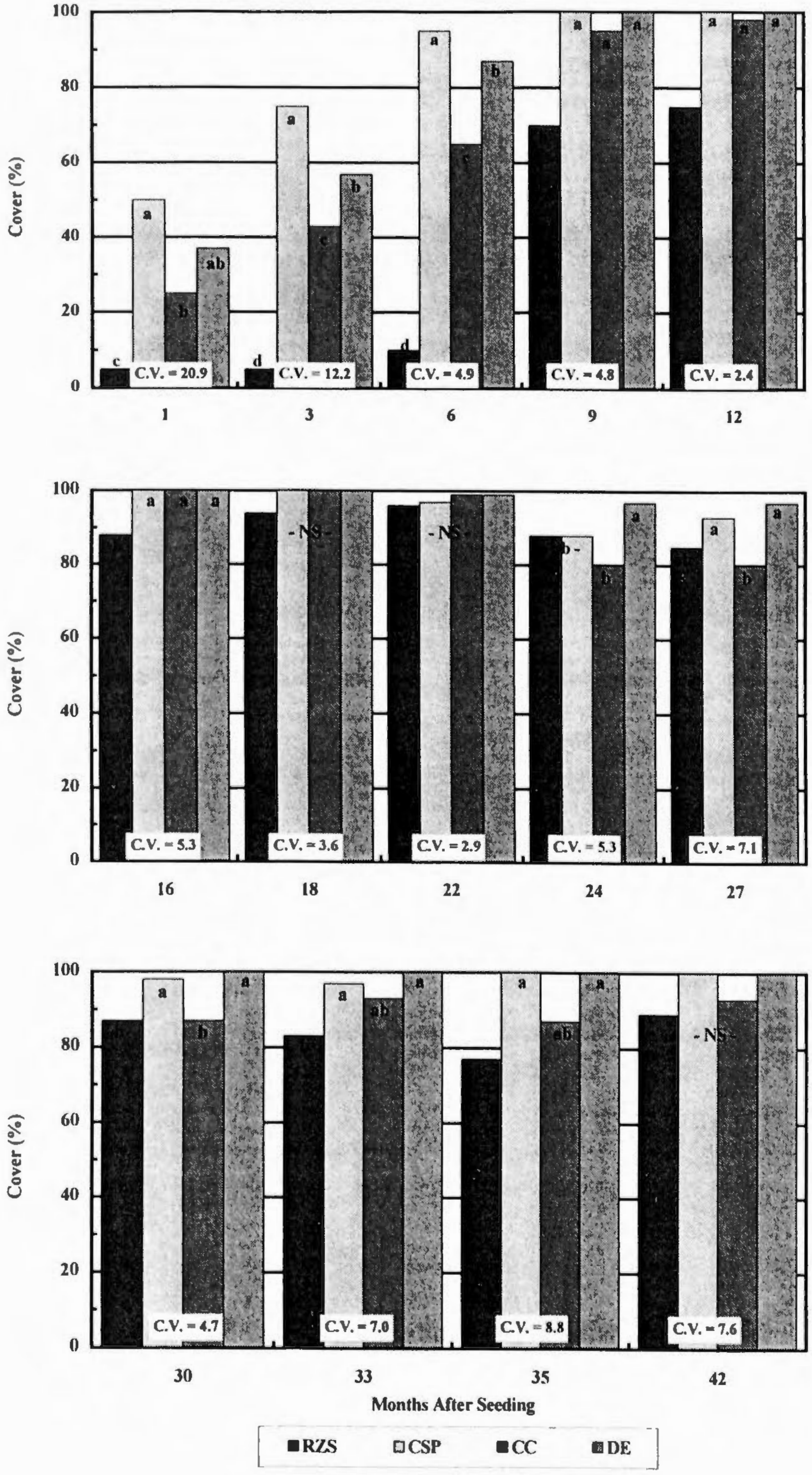


Figure 5.1 Bentgrass visual density (cover) ratings for rootzone sand (RZS) and RZS amended at 15% by volume of either Canadian sphagnum peat (CSP), calcined clay (CC), or diatomaceous earth (DE). Plots were seeded 8 October 1997. Columns within a rating date with the same letter do not significantly differ, $P = 0.05$.

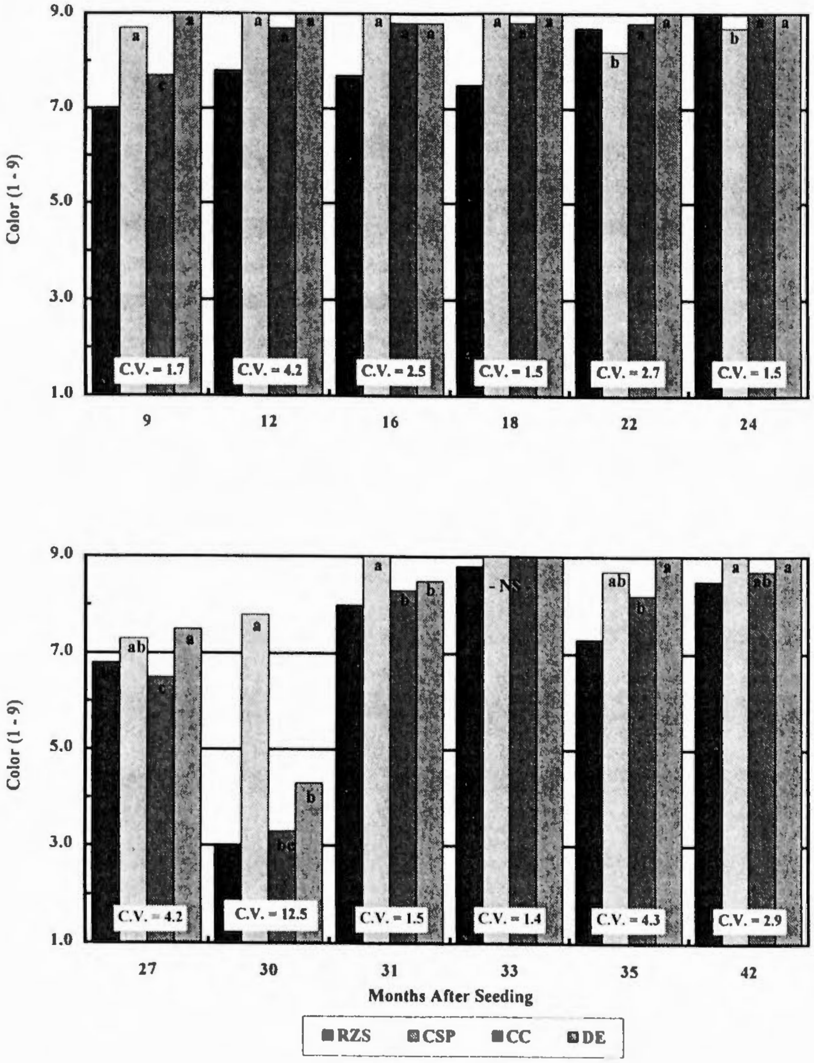


Figure 5.2 Bentgrass visual color ratings for rootzone sand (RZS) and RZS amended at 15% by volume of either Canadian sphagnum peat (CSP), calcined clay (CC), or diatomaceous earth (DE). Plots were seeded 8 October 1997. Color rated on a scale of 1 to 9 with 1 = brown, dead turf, 7 = minimally acceptable green color, and 9 = green, healthy turf. Columns within a rating date with the same letter do not significantly differ, $P = 0.05$.

DE having slightly improved color compared to CC and 100% RZS plots was observed. The 27 MAS rating was taken after 2 weeks of cold weather (two consecutive weekends of snow and freezing rain with night temperatures below freezing and daytime temperatures not exceeding 4.4° C (40° F)). The plots with CSP and DE as amendments retained acceptable color. Also, the low color ratings at 30 MAS can be attributed to an aggressive vertical mowing (1.81 cm deep and in two directions) and 2 days of drying conditions (23° C, relative humidity at 14% and average wind speeds of 20.3 to 22.9 km h^{-1}). Once climatic conditions improved, acceptable color for all plots was observed at the next rating date (31 MAS).

Bulk Density

Field measurements of BD were inconsistent and did not always follow laboratory results (Figure 5.3). However, for numerous reasons, it is not uncommon for field data and laboratory analysis to differ. In laboratory packed columns, containing no turfgrass, the addition of an amendment to RZS reduced BD with CSP having the lowest BD (1.4 g cm^{-3}). Likewise, Bigelow et al. (2000) reported lower BD in laboratory packed columns when three sand fractions were amended with peat and inorganic amendments.

Differences between amended plots were observed for all depths. In the uppermost tier, the bulk density for amended plots was 5 to 11% lower than straight RZS plots for all sampling dates in 2000. In tier 2, the bulk density was 8 to 12% higher in RZS plots than CC amended plots for 3 of the 4 sampling dates. In tier 3, similar differences were only detected at the August 1999 sampling. Differences between amendments were not measured in tier 1, while the bulk density was 7 to 9% higher in DE amended plots at the May and July 2000 sampling of tier 2 and only at the May

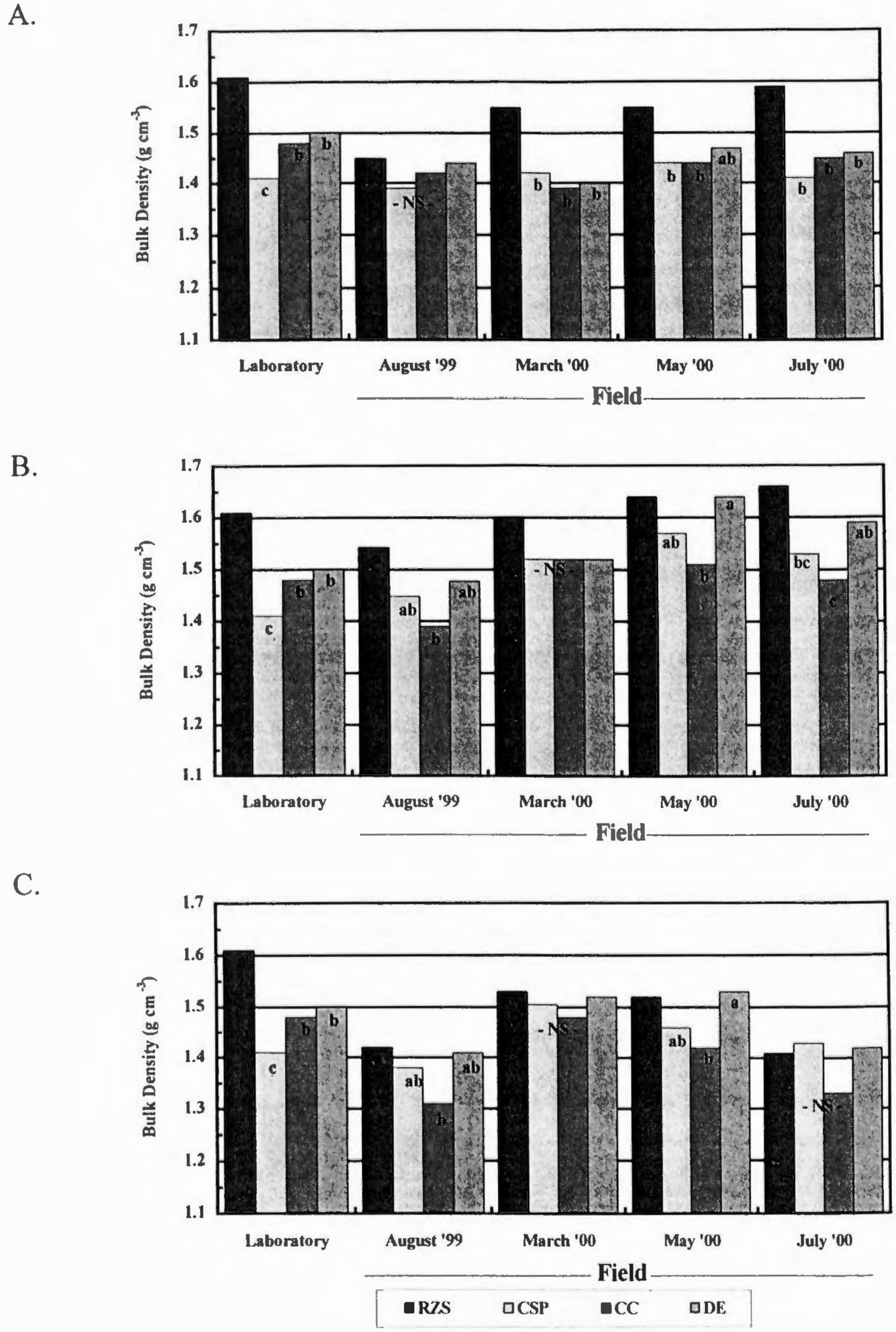


Figure 5.3 Laboratory and field bulk density measurements for rootzone sand (RZS) and RZS amended at 15% by volume of either Canadian sphagnum peat (CSP), calcined clay (CC), or diatomaceous earth (DE). In the field, bulk density measurements were taken along 3 tiers, with tier 1 (A) being form the soil surface to 10 cm, tier 2 (B) from 10 to 20 cm, and tier 3 (C) from 20 to 30 cm depth. Columns within a rating date with the same letter do not significantly differ, $P = 0.05$ (C.V. = 5.8).

sampling of tier 3.

High bulk densities ($\geq$ 1.7 g cm^{-3}) can be restrictive to root growth by posing as a physical barrier and decreasing porosity which influences water holding and oxygen exchange in the soil. BD only exceeded 1.6 g cm^{-3} for RZS and plots amended with DE on the May 2000 and July 2000 sampling of tier 2.

A trend of BD changing with depth was noticed (Figure 5.4). Although not always significant, the bulk density in tier 2 was as much as 7.5% higher than the bulk density in tiers 1 and 3. The BD of tiers 1 and 3 had 6.1 to 11.4% lower BD than tier 2 at the May and July 2000 sampling dates. Amendments had little comparative effect on BD at the lowest depths in 2000.

Organic Matter

For all treatments at all sampling dates, tier 1 had significantly greater organic matter contents than tiers 2 and 3 (Figure 5.5). For all sampling dates, greater than 1% organic matter by weight was measured in tier 1, while the most (0.85%) ever measured in tiers 2 and 3 was at the March 2000 sampling date. In the uppermost tier of plots amended with CSP and CC, organic matter contents were 0.25 to 0.95% greater than unamended plots and plots amended with DE (Figure 5.6). A similar trend of was observed in tiers 2 and 3.

Soil Strength

Surface soil strength can be affected by many factors like soil moisture, turfgrass cover, thatch, and apparently rootzone amendment. At all sampling dates, plots amended with CSP had 13 to 31% lower deceleration values than RZS plots or inorganic amended

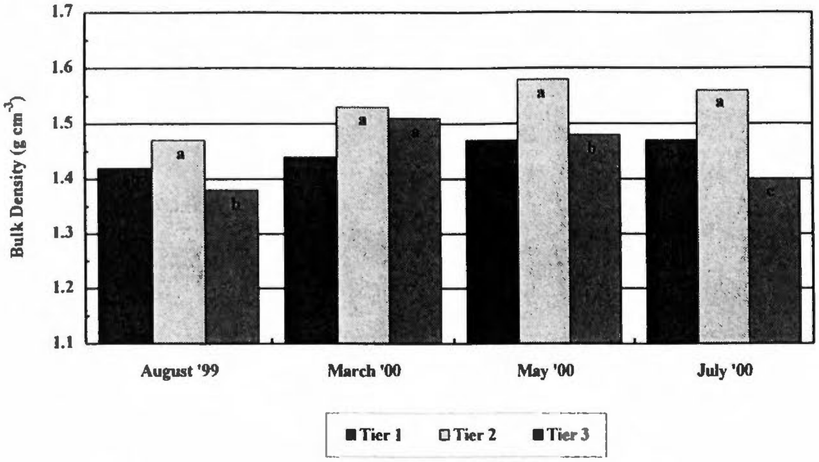


Figure 5.4 Field bulk density measurements for 3 tiers, with tier 1 being form the soil surface to 10 cm, tier 2 from 10 to 20 cm, and tier 3 from 20 to 30 cm depth. Columns within a rating date with the same letter do not significantly differ, *P* = 0.05 (C.V. = 5.8).

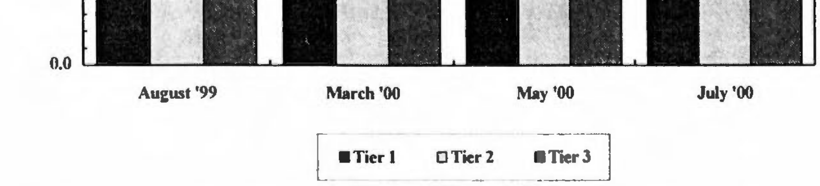


Figure 5.5 Organic matter contents for 3 tiers, with tier 1 being form the soil surface to 10 cm, tier 2 from 10 to 20 cm, and tier 3 from 20 to 30 cm depth. Columns within a rating date with the same letter do not significantly differ, *P* = 0.05 (C.V. = 32.8).

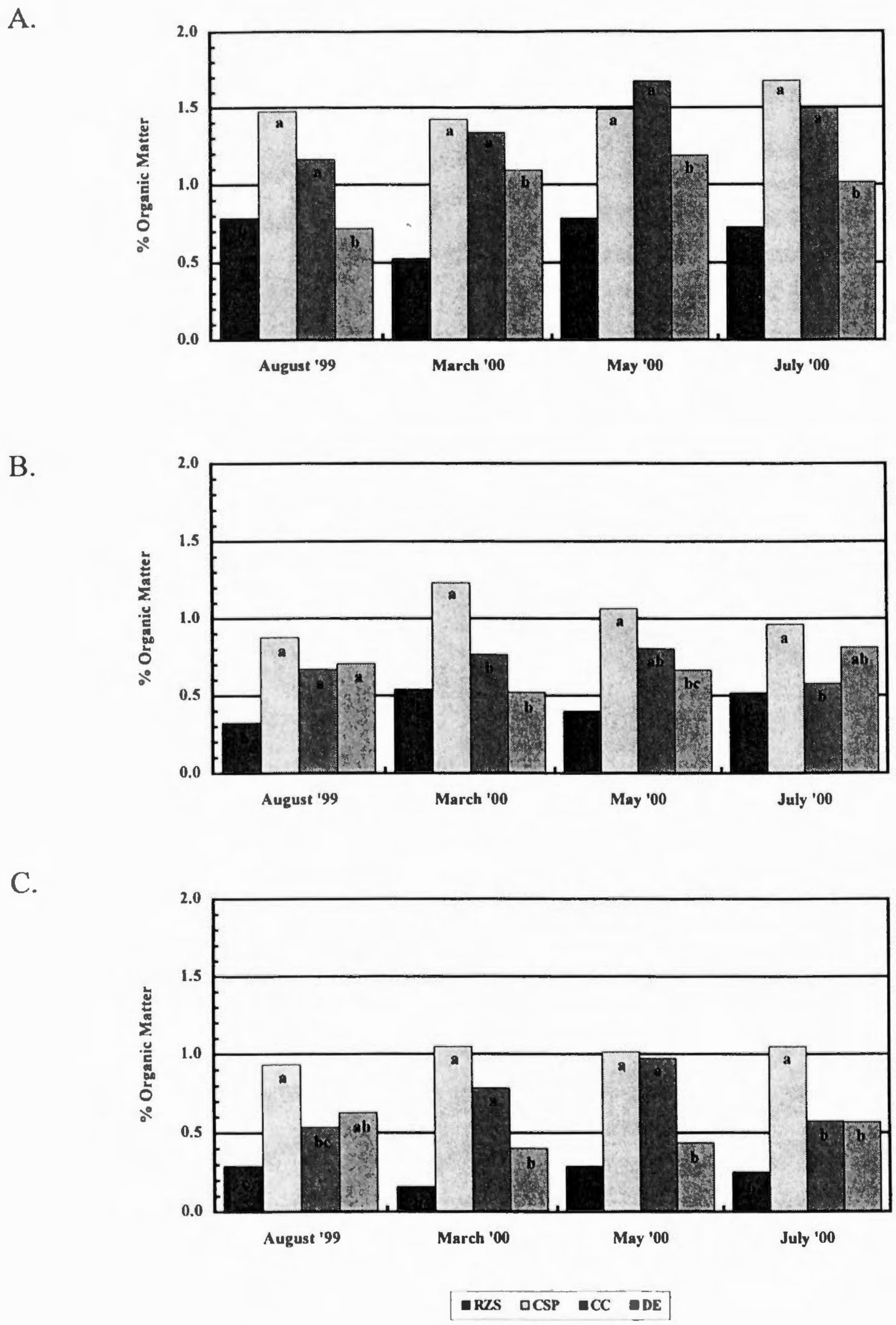


Figure 5.6 Organic matter measurements for rootzone sand (RZS) and RZS amended at 15% by volume of either Canadian sphagnum peat (CSP), calcined clay (CC), or diatomaceous earth (DE). In the field, organic matter measurements were taken along 3 tiers, with tier 1 (A) being form the soil surface to 10 cm, tier 2 (B) from 10 to 20 cm, and tier 3 (C) from 20 to 30 cm depth. Columns within a rating date with the same letter do not significantly differ, $P = 0.05$ (C.V. = 32.8).

plots (Figure 5.7). There were several instances where inorganic amended plots had lower deceleration values than RZS plots, but these were not consistent.

Resistance to penetration increased with depth (Figure 5.8). Resistance to penetration at the 5 cm depth was variable for the different amendments (Figure 5.9). At the 10 cm depth, the greatest (1273 to 1493 kPa cm^{-2}) resistance to penetration was measured in plots amended with IOSA. At the 20 and 30 cm depths, rootzone mixtures ranked in order of decreasing resistance to penetration were: CC > DE > RZS > CSP. Because organic matter is variable in time and was not sampled at the time of penetration measurements, the comparison between organic contents and soil resistance could not be made.

Water Repellency

Some degree of water repellency was measured in all rootzone mixtures at all tiers and sampling dates (Table 5.2). For all sampling dates and depths, the CSP mixture had WDPT greater than 60 s (100 to 478 s) which was considered moderately to strongly water repellent (Table 5.1). Among the other three rootzone mixtures, differences in degrees of repellency were measured between depths. In tier 1, where the highest organic matter (0.72 to 1.78%) was measured, all soils were strongly water repellent. The only exceptions were for the August 1999 and March 2000 sampling of the DE mixture, which were slightly repellent. In tier 2, straight RZS was slightly repellent at 3 of the 4 sampling dates, the exception was the July 2000 sampling with a WDPT of 106 s. Rootzone sand was wettable at the lowest depths for the March 2000 and May 2000 samplings and slightly repellent at the August 1999 and July 2000 dates. In tiers 2 and 3, both of the IOSA mixtures were wettable (WDPT < 5 s). The only exception was DE in

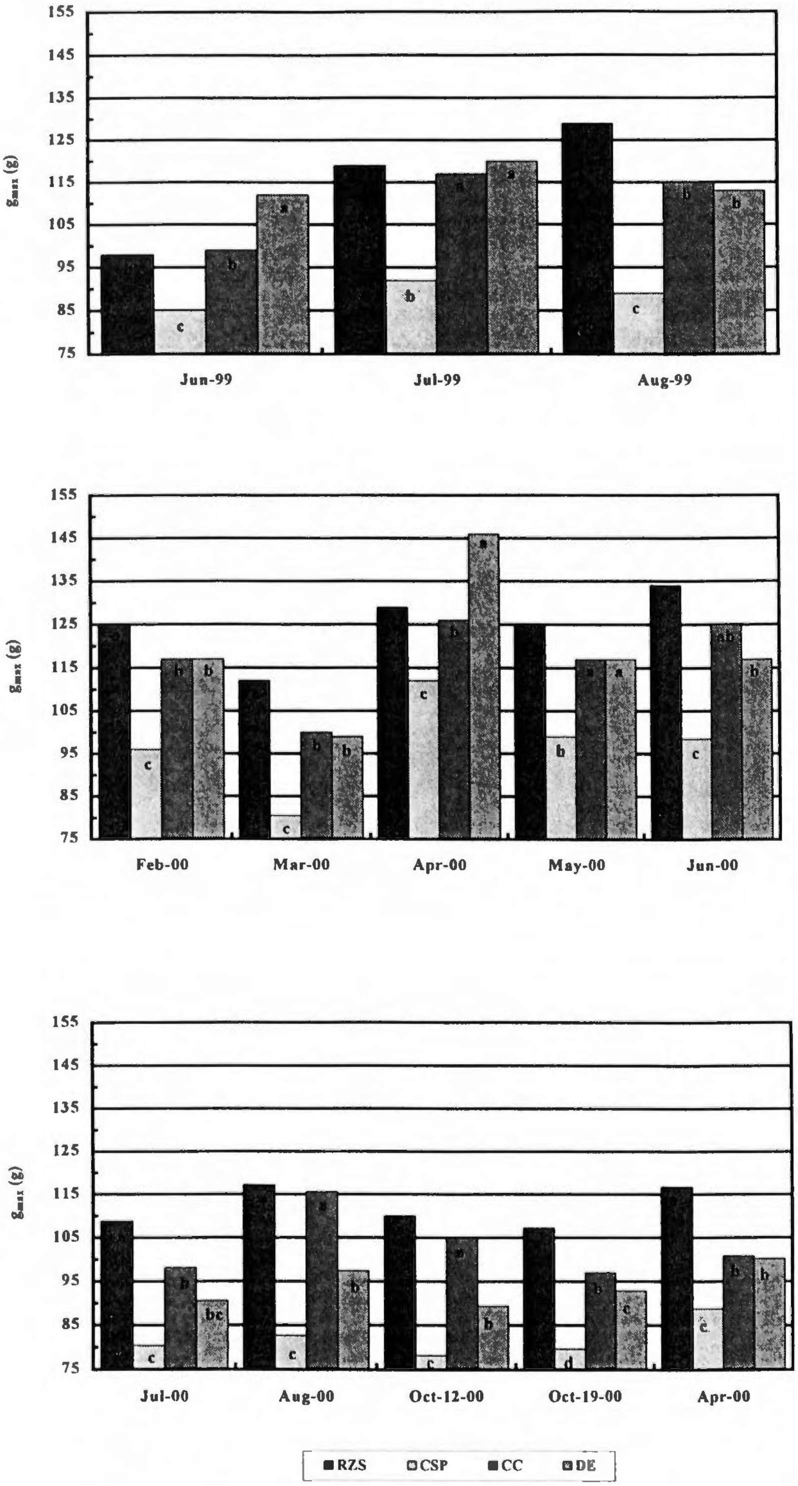


Figure 5.7 Soil surface strength for rootzone sand (RZS) and RZS amended at 15% by volume of either Canadian sphagnum peat (CSP), calcined clay (CC), or diatomaceous earth (DE). Columns within a rating date with the same letter do not significantly differ, $P = 0.05$.

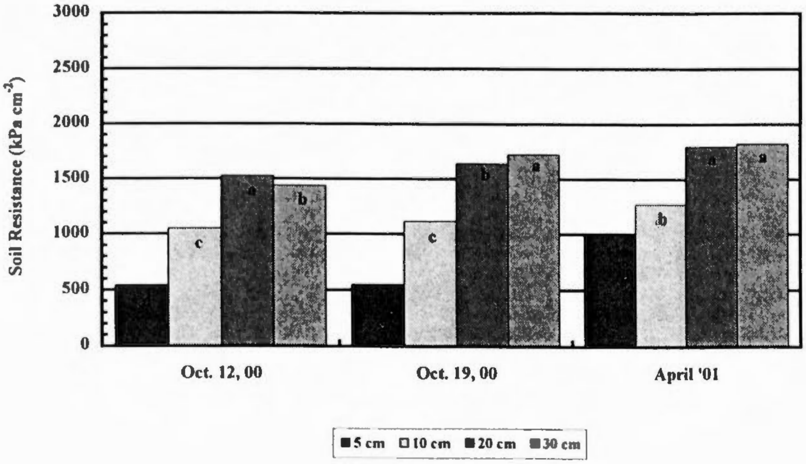


Figure 5.8 Soil resistance at four depths in a 30 cm USGA rootzone. Columns within a rating date with the same letter do not significantly differ, *P* = 0.05 (C. V. = 17.8).

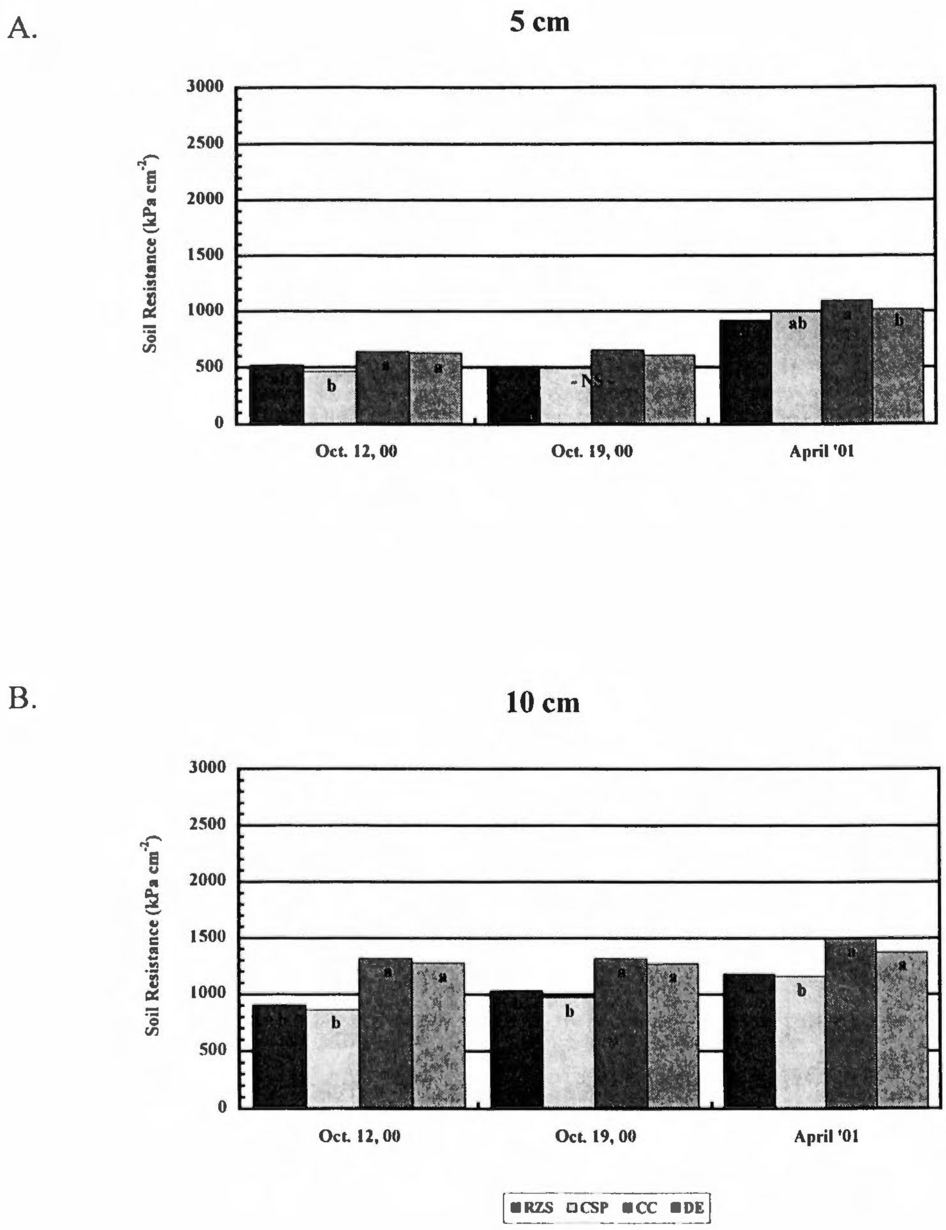
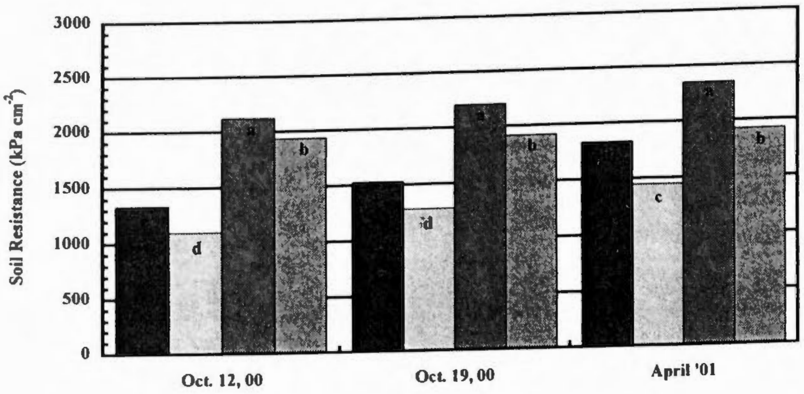


Figure 5.9 Soil resistance at four depths (A) 5 cm, (B) 10 cm, (C) 20 cm, and (D) 30 cm. Rootzone mixtures were rootzone sand (RZS) and RZS amended at 15% by volume of either Canadian sphagnum peat (CSP), calcined clay (CC), or diatomaceous earth (DE). Columns within a rating date with the same letter do not significantly differ, *P* = 0.05 (C. V. = 17.8).

C.

20 cm



D.

30 cm

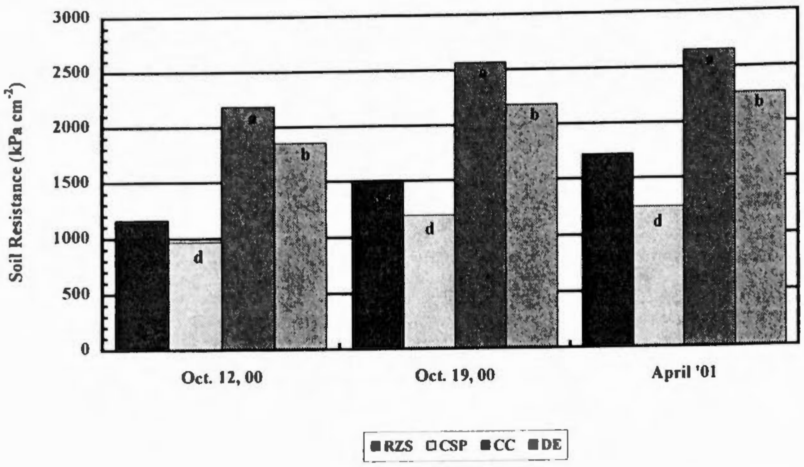


Figure 5.9 continued. Soil resistance at four depths (A) 5 cm, (B) 10 cm, (C) 20 cm, and (D) 30 cm. Rootzone mixtures were rootzone sand (RZS) and RZS amended at 15% by volume of either Canadian sphagnum peat (CSP), calcined clay (CC), or diatomaceous earth (DE). Columns within a rating date with the same letter do not significantly differ, $P = 0.05$ (C. V. = 17.8).

Table 5.2 Organic matter (OM) and water drop penetration time (WDPT) for rootzone sand (RZS) and rootzone media amended at 15% by volume of either Canadian sphagnum peat (CSP), calcined clay (CC), or diatomaceous earth (DE).

	RZS						RZS : CSP					
	Tier 1[†]		Tier 2		Tier 3		Tier 1		Tier 2		Tier 3	
Sampling Date	OM (%)[‡]	WDPT (s)[¶]	OM (%)	WDPT (s)	OM (%)	WDPT (s)	OM (%)	WDPT (s)	OM (%)	WDPT (s)	OM (%)	WDPT (s)
August 1999	0.79	203	0.32	30	0.29	7	1.57	478	0.88	314	0.93	210
March 2000	0.71	127	0.50	30	0.13	4	1.43	166	1.24	227	1.05	124
May 2000	0.78	307	0.40	54	0.29	5	1.46	364	1.07	173	1.01	100
July 2000	0.73	474	0.52	106	0.25	14	1.78	452	0.99	232	1.05	145

† Core samples (160.23 cm^3) were ground and homoginized for each tier (tier 1 from soil surface to 10 cm, tier 2 from 10 to 20 cm, and tier 3 from 20 to 30 cm depth).

‡ Organic matter (OM) was measured as % loss on ignition (800° C for 4 h).

¶ Average water drop penetration time (WDPT) of three drops of distilled de-ionized water.

Table 5.2 continued Organic matter (OM) and water drop penetration time (WDPT) for rootzone sand (RZS) and rootzone media amended at 15% by volume of either Canadian sphagnum peat (CSP), calcined clay (CC), or diatomaceous earth (DE).

	RZS : CC						RZS : DE					
	Tier 1[†]		Tier 2		Tier 3		Tier 1		Tier 2		Tier 3	
Sampling Date	OM (%)[‡]	WDPT (s)[¶]	OM (%)	WDPT (s)	OM (%)	WDPT (s)	OM (%)	WDPT (s)	OM (%)	WDPT (s)	OM (%)	WDPT (s)
August 1999	1.16	109	0.67	< 1	0.53	< 1	0.72	60	0.71	2	0.63	< 1
March 2000	1.34	142	0.77	1	0.79	< 1	1.25	27	0.52	3	0.40	< 1
May 2000	1.67	296	0.81	2	0.97	< 1	1.19	151	0.67	4	0.44	< 1
July 2000	1.49	344	0.58	1	0.57	< 1	1.02	95	0.95	6	0.57	< 1

† Core samples (160.23 cm^3) were ground and homoginized for each tier (tier 1 from soil surface to 10 cm, tier 2 from 10 to 20 cm, and tier 3 from 20 to 30 cm depth).

‡ Organic matter (OM) was measured as % loss on ignition (800° C for 4 h).

¶ Average water drop penetration time (WDPT) of three drops of distilled de-ionized water.

tier 2 for the July 2000 sampling, a WDPT of 6 s was recorded.

Interestingly, different WDPT were recorded for straight RZS and DE mixture that contained identical organic matter contents (0.52%) and were located in the same tier (2). The DE mixture was non-water repellent (WDPT = 3 s) while the straight RZS was moderately to strongly water repellent. Krammes and DeBano (1965) reported a tendency for repellency to decrease as soil size fractions decreased. The higher content of fine particles measured in the DE mixture (Table 3.1) may have influenced the water repellency characteristics.

Figure 5.10 shows the relationship between WDPT and water content in the upper 5-cm of the core removed from a field plot containing the CSP mixture. WDPT readings were not recorded below 5-cm. The trend was for WDPT to increase as water content decreased, while WDPT decreased as organic matter decreased with depth. The CSP mixture was wettable at all depths, when gravimetric water contents were greater than 0.192 g g^{-1}. However, the upper 1-cm was severely water repellent at a water content of 0.090 g g^{-1}, while water contents less than 0.022 g g^{-1} caused WDPT of 600 s at the 2 and 3-cm depths. The CSP was moderately to strongly water repellent at the 4-cm depth and slightly water repellent at 5-cm, corresponding to water contents of 0.032 and 0.026 g g^{-1}, respectively. To establish the relationship between organic matter content and water content, Figure 5.11 was constructed by plotting the average organic contents for each depth verses the mid-point of the water content where a shift in WDPT was observed. These data indicate a strong relationship ($r^2 = 0.978$) between organic matter and water content. When organic matter contents are high (> 2%), a rootzone mixture containing CSP may become severely water repellent at gravimetric water contents of 0.141 g g^{-1}.

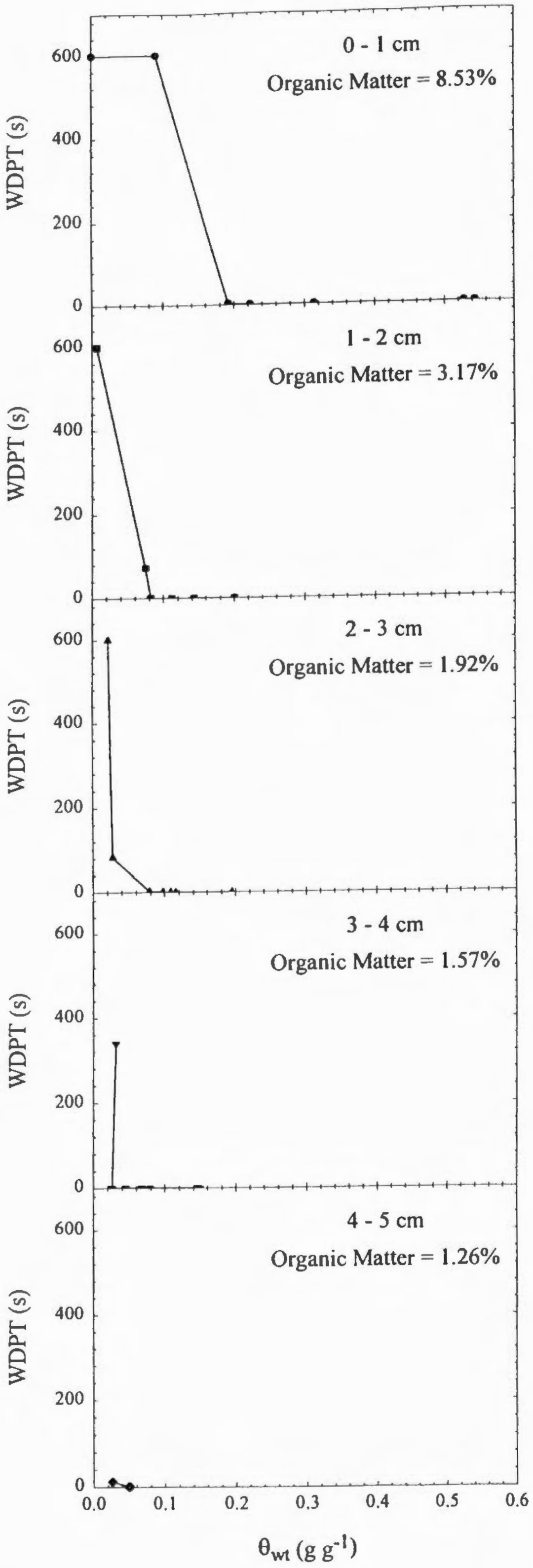


Figure 5.10 Relationship between gravimetric water content (θ_{wt}) and water drop penetration time (WDPT) for various depths of a field core from a plot constructed with rootzone sand amended at 15% by volume of Canadian sphagnum peat.

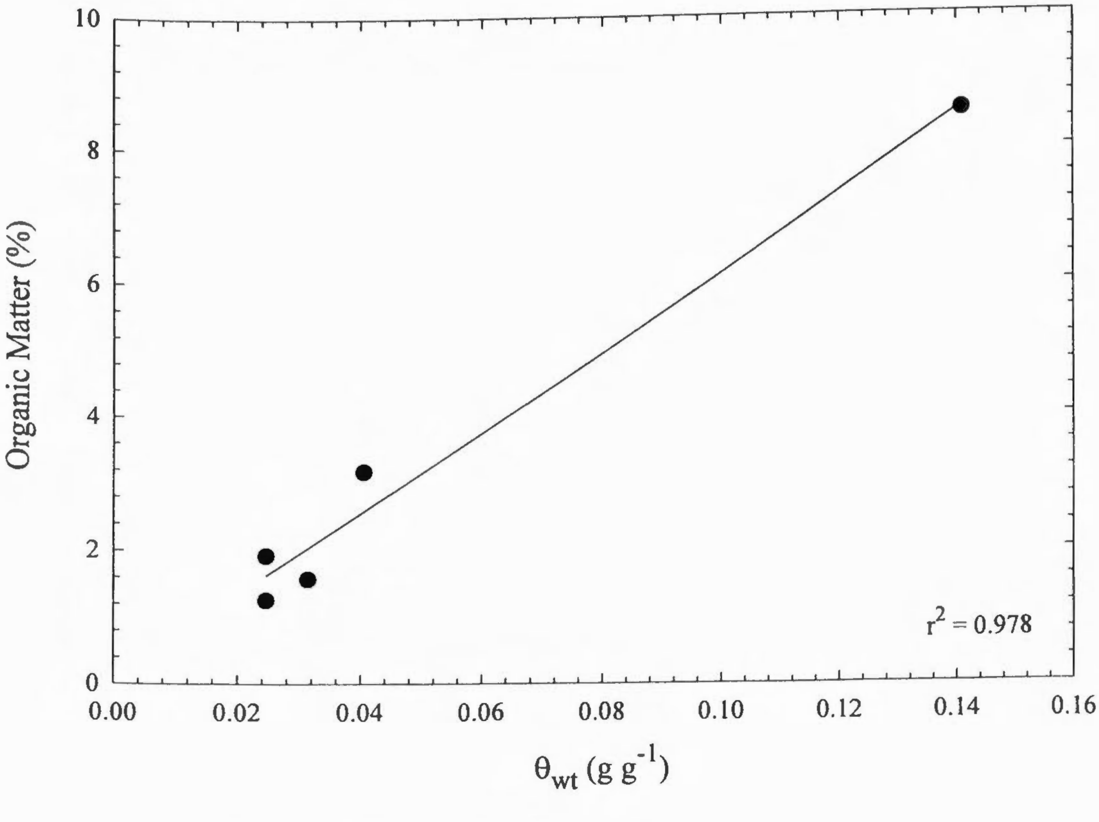


Figure 5.11 Relationship between organic matter content and gravimetric water content (θ_{wt}) for a field core from a plot constructed with rootzone sand amended at 15% by volume of Canadian sphagnum peat.

Conclusions

These data indicate for turfgrass establishment, the addition of CSP allowed bentgrass to establish 3 months sooner than RZS plots amended with either CC or DE. It is likely that the CSP retained more water at the soil surface, keeping the seed moist and allowing for improved germination. By 9 MAS all amended plots had >95% turfgrass coverage.

These results are in agreement with previous research. In field evaluations, bermudagrass quality was relatively unaffected when established on peat amended sand (Smalley et al., 1962). Likewise, Neylan and Robinson (1997) reported improved bentgrass cover 52 days after seeding for plots amended with organic components compared to the unamended plots and plots amended with porous ceramic beads. Bigelow et al. (1999) also reported greater bentgrass germination in sand amended with peat compared to CC amended sand. Others have reported poor turfgrass quality when a sandy soil was modified with CC (Joo et al., 2001; Smalley, 1962; Horn, 1969). The poor performance of CC amended sand was attributed to water bound at high tensions and therefore unavailable to the turfgrass plant, although water tension measurements were not reported.

Once established and actively growing, turfgrass color for all amended plots were acceptable and improved compared to plots with 100% RZS. Due to greater nutrient retention, improved color would be expected in amended plots (Bigelow et al., 2001). In general, this trend was observed in these field plots with the only incidences of unacceptable color attributed to climatic conditions or aggressive management practices. However, others have reported reduced color ratings in rootzone mixes containing CC

(Minner et al., 1997; Mitchell et al., 1978).

The addition of an amendment, organic or inorganic, to RZS did not always reduce the BD in cores from the field. However, lower bulk densities in the upper 10-cm could be explained through significantly greater organic matter in this zone. Soil below 10 cm may be adversely influenced by cultural practices, such as aerification, intended to benefit the rootzone. Because BD measurements did not exceed 1.7 g cm^{-3}, root growth into these depths should not have been overly restricted due to compaction. In a sandy soil with bulk densities as high as 1.77 g cm^{-3}, Smalley et al. (1962) reported no adverse effects on growth and turfgrass quality. Although turfgrass growth and cultural practices least influenced tier 3 (20 to 30 cm depth), average BD for all plots most resembled tier 1 (0 to 10 cm depth) at two sampling dates (August 1999 and May 2000).

Our surface soil strength results are in disagreement with the findings of Robinson and Neylan (2001). They reported no influence of amendment on surface firmness. However, the two IOSA used in their study were porous ceramic beads and clinoptilolite zeolite, so direct comparisons between their study and these data can not be made. It is uncertain whether the higher deceleration values associated with RZS and inorganic amended plots provides an acceptable putting green surface. Firmer greens can lead to more difficult golfing conditions, which some clubs may desire while others may not.

It appears that rootzone amendment can influence resistance to penetration, however, comparative results do not exist and future research might examine the effects of soil resistance on bentgrass roots in high sand content rootzones. Corn root elongation has been shown to be sensitive to changes in soil resistance in the range of 900 to 1600 kPa, a range measured in these plots (Gliński and Lipiec, 1990).

Interactions between organic matter and water repellency have been well documented (Karnok, et al., 1993; Karnok and Beall, 1995; Tucker, et al., 1990; Krammes and DeBano, 1965; van't Woudt, 1959), therefore higher WDPT were expected in mixtures with high organic matter contents. Among the soil amendments, the IOSA influenced water repellency characteristics in the lower two depths. Karnok and Tucker (1999) theorized that DE used as a topdressing material increased the moisture retention of water repellent soil. Research involving water repellency issues and IOSA is limited, but these data demonstrate an affect of the materials on rootzone mixtures. Future research is needed to investigate the effect of IOSA on water contact angle and the occurrence of organic coatings on the amendment surfaces.

Due to limited long-term research, the USGA does not recommend the use of IOSA in the construction of putting greens. In a RZS meeting USGA specifications, results of this research found quicker establishment times, lower bulk densities, lower surface soil strength (softer greens), and less resistance to penetration in CSP amended sand than mixtures containing IOSA. For similar reasons, others have also concluded peat to be the best amendment for putting green rootzones (Joo et al., 2001; Bigelow et al., 2000; McCoy and Stehouwer, 1998).

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CHAPTER 6

SUMMARY

Evaluation of rootzone sand (RZS) amended at 15% by volume with Canadian sphagnum peat (CSP), or inorganic soil amendments (IOSA) calcined clay (CC) or diatomaceous earth (DE) revealed that amendments had an effect on rootzone physical properties, turfgrass establishment, and capacitance probe readings. In laboratory measurements, an addition of an amendment to RZS reduced bulk density, increased total and capillary porosity, and influenced water content readings of a capacitance probe (CP). The CSP mixture had the lowest bulk density, and highest total and capillary porosity of amended mixtures. In the upper third of the rootzone, the CSP mixture contained higher water contents than the other mixtures, which indicates the peat provided greater water holding capacity and contained a greater percentage of capillary pores compared to the other amendments. Also, drainage characteristics were influence by the addition of an amendment to RZS. When an initially saturated rootzone was allowed to drain, the bulk of the downward flow of water concluded within 15 minutes, although different amounts of water drained through each rootzone mixture. The most water drained through the straight RZS and CC mixtures, while the CSP mixture held more water suggesting the peat mixture contained a greater percentage of capillary pores which was observed at a pressure of –4 kPa.

The CP underestimated water content when compared to gravimetric methods. This discrepancy could be attributed to the lack of manufacture's calibration to sand-based soils. However, measured calibration results were well describe by linear equations ($r^2 = 0.959$ to 0.993) for each mixture. Statistical analysis indicated no significant linear relationship for the various organic matter mixtures, therefore, calibration curves for each rootzone mixture were derived. However, under these soil conditions, further specific calibration of this CP will be required to determine the absolute water content and usefulness as an irrigation tool in monitoring moisture levels of golf putting greens.

In field plots of identical mixtures, bentgrass seeded into the CSP mixture established 3 months before turf in plots with IOSA and 15 months prior to straight RZS plots. Improved germination and establishment may result from improved water retention in the upper part of the rootzone. It is possible that peat retained water adjacent to the seed allowing for a favorable environment for germination and as the seedling was beginning to root, greater water contents reduced water stress and seedling mortality.

As similar to laboratory samples, lower bulk densities were associated with amended sand in field cores pulled from the upper 10-cm of the rootzone. Also in field measurements, amendments influenced surface soil strength with the addition of CSP decreasing deceleration values compared to straight RZS and the IOSA mixtures. Likewise, resistance to penetration was reduced when CSP was added to RZS. These results are an indication that the IOSA allow the sand particles to pack together, therefore, the associated increase in porosity measured in laboratory studies is due to internal pore space of the rigid amendments.

A primary objective of this research was to gain an understanding of the scope and limitations of traditional amendments (CSP) and alternative approaches (IOSA) to amending sand for use in golf putting greens. The addition of an IOSA to RZS improved establishment, total porosity, and water retention in the rootzone, compared to RZS alone. The CSP mixture retained significantly more water, which probably attributed to sooner establishment and improved turfgrass cover. From a practical aspect, the increased rate of establishment coupled with higher water retention in the upper portion of the rootzone makes CSP the most suitable amendment for putting green construction. A second objective was to investigate the potential use of a capacitance probe to measure water in a golf putting green. While the probe studied in this research has potential of being an irrigation guidance tool, further investigation is necessary before the probe can be reliably applied.

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