ROOT ZONE AMENDMENT EFFECTS ON THE QUALITY AND NUTRITIONAL STATUS OF CREEPING BENTGRASS PUTTING GREENS

By

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INTRODUCTION

The increasing number of golf courses and player demand for excellent playing surfaces have prompted extensive research directed toward the improvement of putting greens. Sand matrix root zones constitute the core of modern putting greens. Majority opinion contends that putting greens containing only sand cannot provide the physical environment turfgrasses require for rapid establishment and sustained high quality under the use intensity and cultural practices of today's putting greens. Rather, an amendment is added to the sand to reduce its bulk density, to increase moisture retention in the upper reaches of the root zone, and to increase the nutrient retention of the root zone mix in order to maintain an excellent turfgrass stand.

The putting green is the area on a golf course that most influences golfer perception of the quality of courses. Sand-matrix putting greens are expensive—construction costs can easily approach $10, 000 per 1,000 ft^2 of green and the annual maintenance cost of a 6,000 ft^2 putting green in Wisconsin can exceed $15,000. It is in this context that choice of putting green construction materials assumes permanent importance in the golf industry.

Through the years, the United States Golf Association (USGA) has developed rigorous criteria for selection of sand for putting green construction. Testing of root zone amendments occurs only indirectly. Samples of sand and organic amendments are combined in various ratios and tested for physical properties as a means of identifying a blend that satisfies USGA Green Section Standards. Absent from this testing is any indication of criteria for the selection of a suitable amendment. Consequently, the role that the amendment plays in the long-term performance and maintenance of putting greens is not clearly defined.

The present research was conducted on an experimental putting green constructed in 1992/1993 for the purpose of establishing how different types of root zone mixes affect the long-term quality of sand matrix putting greens. Treatment variables include seven different amendments, six organic and one inorganic, and three sands. The objectives of the research are: (1) to continue evaluation of the influences of the amendments on the quality and fundamental characteristics of the greens, and (2) to determine whether or not the amendments significantly influence the N, P, and K nutrition of creeping bentgrass (*Agrostris palustris* Huds.).

LITERATURE REVIEW

Golf putting greens can be built in many different ways. Methods ranging from using only native soil to only pure sand have been proposed and used through the years; some more successfully than others. In 1960, the United States Golf Association (USGA) Green Section Staff first published specifications for the construction of putting greens. Three revisions of the original specifications have been published, most recently in 1993.

Putting Green Construction

Prior to World War II, putting greens were primarily constructed with soil native to the site of the green. But as early as 1916, sand and manure were used to amend the native soil (Hudson, 1985). Eventually, putting green root zone mixes evolved into standard 1-1-1 (sand-soil-peat) volume ratios.

During the 1950s, a tremendous growth in the popularity of golf occurred. Green use intensity increased accordingly and it quickly became apparent that the construction of that time did not provide greens that could hold up to increased traffic. Davis (1950, 1952) observed that the better greens had greater total porosity than poorer greens, probably due to differences in compaction. As a result, he proposed that soils be modified with coarse sands to bring the total sand content to 50%. Garman (1952) reported that the standard 1-1-1 mix did not possess adequate permeability under compacted conditions. He suggested a mix of sand, soil, and peat that contained 8.2% clay by weight and 20% peat by volume. This mix had a permeability of 0.8 inch per hour, a rate four times that of the 1-1-1 mix.

On the basis of the work by Davis, Garman, and other researchers in the 1950s, the USGA established its first putting green specifications in 1960. These specifications called for a root zone mix with a minimum total porosity of 33% and a permeability of between 0.5 to 1.5 inches/hour (USGA Green Section Staff, 1960). Subsequent revisions of the USGA Specifications followed in 1973 and 1989 (USGA Green

Section Staff, 1973, 1989). Each of the revisions resulted from new studies that provided some of the rationale behind the revisions.

Tables 1 through 4 contain the 1993 USGA Specifications for material for greens construction (USGA Green Section Staff, 1993). These specifications have been and continue to be those most widely used in the golf course industry (Snow, 1993).

USGA Specifications call for four distinctive layers in an "ideal" green: the subgrade, the overlying gravel layer, the intermediate sand layer, and the overlying root zone mixture. Drainage tile, which is a component of these specifications, is incorporated into the gravel layer.

The subgrade's purpose is to facilitate water movement to the drainage system and does not need to conform to the proposed finished grade. The subgrade should be established 16 to 20 inches below the proposed surface grade and should be thoroughly compacted to prevent further settling.

Selection of gravel for the 4-inch gravel layer is based on particle size (Table 1), the recommended range being between 0.25 inch (6 mm) and 0.375 inch (9 mm). Gravel meeting the criteria in Table 2 negates the inclusion of an intermediate sand layer, whose purpose is to prevent migration of the root zone mix into the gravel bed. This will not occur if the bridging factor between the gravel and the root zone mix is satisfied.

Table 1. Particle size description of gravel and intermediate layer materials.

Material	Description
Gravel:	
Intermediate layer is used	Not more than 10% of the particles greater than 1/2 inch (12 mm)
	At least 65% of the particles between 1/4 inch (6 mm) and 3/8 inch (9 mm)
	Not more than 10% of the particles less than 2 mm
Intermediate layer material	At least 90% of the particles between 1 and 4 mm

Table 2. Size recommendation for gravel when intermediate layer is not used.

Performance factors	Recommendation
Bridging factor	$D_{15(gravel)} \leq 5 \times D_{85(root\ zone)}$
Permeability factor	$D_{15(gravel)} \geq 5 \times D_{15(root\ zone)}$
Uniformity factors	$D_{90(gravel)} / D_{15(root\ zone)} \leq 2.5$
	No particles greater than 12 mm
	Not more than 10% less than 2 mm
	Not more than 5% less than 1 mm

Table 3. Particle size distribution of USGA root zone mix.

Name	Particle diameter	Recommendation (by weight)	
Fine gravel	2.0 to 3.4 mm	Not more than 10% of the total particles in this range, including a maximum of 3% fine gravel (preferably none)	
Very coarse sand	1.0 to 2.0 mm		
Coarse sand	0.5 to 1.0 mm	Minimum of 60% of the particles must fall in this range	
Medium sand	0.25 to 0.50 mm		
Fine sand	0.15 to 0.25 mm	Not more than 20% of the particles may fall within this range	
Very fine sand	0.05 to 0.15 mm	Not more than 5%	Total particles in this range shall not exceed 10%
Silt	0.002 to 0.05 mm	Not more than 5%	
Clay	Less than 0.002 mm	Not more than 3%	

Table 4. Physical properties of the root zone mix.

Physical properties	Recommended range
Total porosity	35 to 55%
Air-filled porosity (at 40 cm tension)	15 to 30%
Capillary porosity (at 40 cm tension)	15 to 25%
Saturated conductivity:	
Normal range	6 to 12 inches/hour (15 to 30 cm/hour)
Accelerated range	12 to 24 inches/hour (30 to 60 cm/hour)
Organic matter content (by weight)	1 to 5% (ideally 2 to 4%)

When used, the intermediate layer is spread to a uniform thickness of 2 to 4 inches over the gravel drainage blanket. The particle size specification calls for 90% of the particles to be between 1 and 4 mm.

The 12-inch root zone mixture is predominantly sand mixed with an organic material. The USGA Specifications have stringent requirements for the particle size distribution of the root zone mix sand. A minimum of 60% of the particles must be of the course or medium sand size fraction (0.25 to 1.0 mm) according to Table 3. Recommended porosity and saturated conductivity levels for the root zone mix are also included in these specifications.

An important objective in the design of golf putting greens is to create a root zone that will retain sufficient plant available water to prevent the onset of moisture stress during daytime hours. The USGA Specifications approach this objective in two ways. One employs the principles of water retention in soils consisting of layers of different textures. The second is that of amending the sand-matrix root zone with water-retentive amendments.

Perched Water Table

Soil texture discontinuities are an important feature in USGA putting greens. They result in "perching" of water within the root zone mix. In sports turf literature, the term perched water table has been used to describe the effect coarse-textured layers have on water relations of the finer soil mixture in the root zone layer (USGA Green Section Staff, 1989). In reality, coarse-textured layers underlying finer-textured layers do not cause a positive water pressure and, thus, a water table to build-up above them. Perched water table terminology is probably inappropriate (Taylor et al., 1993).

Perched water table theory revolves around unsaturated flow in soils. The role of unsaturated flow is dependent upon the thickness of water films surrounding soil particles; thicker water films allow faster flow rates than thinner films, due to the differences in water potential. Where the continuity of water films is disrupted, as at the interface between a fine-textured soil and a underlying coarse-textured soil, unsaturated flow is slowed or may stop altogether. This can result in temporary perching of water. Water does not move across the interface until the water potential in the above soil builds to a level sufficient to overcome the attraction between the water and the fine-textured soil.

Root Zone Mix Amendments

The USGA Specifications only define that the root zone mix include "a fibrous organic amendment" that contains 85% or more organic matter. Amendments are added to the sand matrix to improve plant-soil relationships and to minimize turf management problems. Extreme variability in peats and other organic amendments can exist, which may influence the performance of a root zone mix. Waddington (1992) states that the effectiveness of amendments depends on their individual properties, the amount of amendment added, the properties of the soil to which they are added, and the uniformity of mixing with the soil.

Peat is the most popular organic amendment used to improve soil properties. Bethke (1988) reported that commercial peats vary considerably in water and organic matter contents, stage of decomposition, ash content, pH, and water retention. Fibrous peats in any stage of decomposition are preferred over sedimentary and woody-type peats. Amendments are normally used at rates of 5 to 20% by volume or 1 to 5% by weight. Higher rates may alter many of the physical and chemical properties of the root zone mixture to the point that organic matter characteristics predominate. Lucas et al. (1965) listed the following benefits of peats:

1. Increased moisture holding capacity of sand soils;
2. Increased infiltration into fine-textured soils;
3. More friable and better aerated soils;
4. Decreased bulk density and improved root penetration;
5. Increased buffer capacity of soils (increased cation exchange capacity, CEC);
6. Increased microbial activity;
7. Serves as a slow-release source of plant nutrients;
8. Makes certain elements, such as Fe and N, more available.

By-products of the forest industry, such as sawdust and bark have also been used to modify soils. Shepard (1978) reported that N immobilization stunted the growth and caused discoloration of creeping bentgrass when either oak sawdust or pine bark was added to sand. Mazur et al. (1975) reported that bark was not as stable as peat and deteriorated after a 13-month period. Ammoniated rice hulls and sludge composts have also been used as sand amendments. Johns (1976) found no difference in infiltration, water holding capacity, CEC, or root growth when rice hull-amended sand was compared to sand amended with peat moss. McCoy (1992) reported that a composted sludge added to sand increases saturated conductivity and available water in proportion to the amount of sludge compost added.

Inorganic amendments such as calcined clay, vermiculite, calcined diatomites, clinoptilolite zealite, and polyacrylamides have been marketed as soil amendments over the years. Long-term field trials have yet to establish any of these materials as substitutes for a good organic amendment. Hummel (1993) states that inorganic amendments, polyacrylamides, and reinforcement materials are not recommended at this time for use as amendments.

Assessment of Putting Green Quality

Turfgrass researchers employ a combination of visual and physical methods for judging effects of research variables on putting green quality.

Visual Assessment

Turgeon (1991) states that the quality of turf is a function of its utility, appearance and, in the case of sports turf, its playability during the growing season. Golf greens should provide sufficient ball-holding capacity for properly directed approach shots and true putting to the hole from any position on the green. Standardized methodology for characterization of playability does not exist. Emphasis is therefore placed on visual quality assessment.

Skogley and Sawyer (1992) state that turfgrass quality cannot be measured in the same manner as other agricultural crops. The quality of turfgrass is not measured by yield, color, or nutritive value of fruit or forage. Rather, quality is a measure of aesthetic appeal, durability, density, ease of establishment and maintenance, and perhaps, longevity or hardiness. Resistance to or tolerance of diseases and insects is also a desirable quality of turfgrass.

The most widely used and accepted method of recording turfgrass quality data is the visual quality rating system. The visual method of rating or scoring takes into consideration the color, density, and uniformity of stand, or overall appeal, as judged by an evaluator. The quality scale is generally based on values 1 to 9, with 1 representing a completely dead or dormant turfgrass stand, while 9 indicates the very best stand possible. The top quality possible for a given species of turfgrass needs to be fixed in the mind of the evaluator as it is upon this level that quality scoring is based.

The most visible determinants of turfgrass quality include density, texture, uniformity, and color. Density is a measure of the number of aerial shoots per unit area. The extremely high density of creeping bentgrass provides an excellent playing surface on greens. Highest densities are obtained when greens are closely mowed (1/8 to 5/32 inch), receive adequate amounts of fertilizer and water, and are protected from disease-causing organisms, insects and other pests.

Texture is a measure of the width of the leaf blades. A fine-textured turfgrass, such as creeping bentgrass, has narrow leaves. Density and texture are related in that, as density increases, texture becomes finer.

Uniformity is an estimate of the even appearance of a turf stand. Unlike texture and density, uniformity cannot be measured accurately; it is influenced by features such as differences in texture, density, turfgrass species composition, color and mowing height.

Color is a measure of the light reflected by turfgrass. Different species and cultivars vary in color from light to very dark green. Color is the main tool golf course managers use in deciding the frequency of fertilizer N application.

The functional quality of turfgrass is determined not only by some of the visual characteristics already discussed, but also by other characteristics, such as rigidity, elasticity, resiliency, yield, verdure, rooting, and recuperative capacity.

Physical Assessment

Infiltration rate is an important component of putting green quality since heavy rainfalls or irrigation cycles are a common occurrence on golf courses. A putting green that cannot dispose of large volumes of water in a short period of time is subject to surface ponding, which greatly increases the chance of injury to or disease occurrence in the turf and disrupts play. The USGA recommends an infiltration rate of at least 6 to 12 inches/hour on greens located in climates similar to that of Wisconsin (USGA Green Section Staff, 1993).

The USGA has also made recommendations on preferred porosity percentages for putting green root zone mixes. Their 1993 specifications suggested a total porosity of 35 to 50%, comprised of an air-filled porosity of 15 to 30% and a capillary porosity between 15 to 25%.

The ability of a root zone mix to retain moisture at or near the soil surface is also critical in determining putting green quality. When the root zone mix is unable to hold enough moisture, the putting green will be prone to localized dry spot that results in an unsatisfactory turf stand. In 1989, the USGA defined moisture retention as the gravimetric expression of water content at a potential of -40 mb. The 1993 USGA Specifications for green construction do not list a recommended value for moisture retention, but the 1989 specifications recommend 12 to 18% by volume. Given that the specified depth of the root zone mix is 12 inches (30 cm), moisture retained at -30 mb is a more realistic measure.

As indicted by the ongoing discussion, the development of putting green specifications by the USGA focused on physical properties. The effects of different types of construction and construction materials on turfgrass nutrition were largely ignored.

Amendment Effects on N, P, and K Status

Literature on the nutrient status of putting greens has been mostly limited to research reports on amounts of nutrients needed to obtain optimum turf growth and assessments of critical soil nutrient levels needed to avoid nutrient deficiencies. Research on the effects of root zone amendments per se on the nutrient status of putting greens is very much lacking.

Environmental issues, such as nitrate contamination of groundwater, have prompted determination of the fate of nitrogen applied to putting greens. Nitrate leaching from turfgrass sites has been proposed as a major source of nitrate contamination of groundwater in suburban areas where turfgrass culture is the major land use (Flipse et al., 1984).

The fate of fertilizer N applied to turfgrass has generally been studied as a series of isolated components rather than a complete system. As Petrovic (1990) points out, only Starr and DeRoo (1981) have attempted to study in its entirety the fate of N applied to turfgrass. However, their results are limited to a narrow set of conditions (i.e., cool-season turfgrass, unirrigated, sandy loam soil).

In Petrovic's review (1990) of the fate of nitrogenous fertilizers, he reports that the amount of fertilizer N recovered in the turfgrass (clippings, shoots, and roots) varies from 5 to 74%, depending on factors such as N source, rate and timing of application, species of grass, and other site-specific conditions. Sheard et al. (1985) reported that 60% of the fertilizer N applied in the form of urea was recovered in the season long clippings of a 'Pencross' creeping bentgrass green grown on an unamended sand putting green when fertilized at a N rate of 240 to 287 kg/ha/yr.

Petrovic (1990) also reported that the extent of NO_3^- leaching from N fertilization of a turfgrass site is highly variable. Some researchers have reported little or no leaching, whereas others have suggested that as high as 80% of the fertilizer N applied maybe leached as NO_3^- (Nelson et al., 1980). Sheard et al. (1985) observed that creeping bentgrass sand greens lost only 1.2 to 2.0% of applied N in the drainage water (N rate of 242 to 390 kg/ha/yr). Brown et al. (1982) noted that 22% of NH_4-NO_3-N leached as NO_3-N in the drainage water when N was applied in February at 103 kg/ha (three times the normal rate for bermuda grass greens in Texas). Factors cited as influencing the degree of leaching included soil type, irrigation, N source, N rates, and season of application.

Researchers in Germany (Hardt et al., 1993) measured leachate N on a peat-amended putting green seeded to a blend of fine fescues and bentgrasses. They reported that the highest value of N recovery in drainage water was 13%. This occurred when fertilized at the rate of 80 g N $m^{-2}yr^{-1}$ (more than twice of what is currently applied on German golf courses). At average German golf course fertilization rates of 20 and 40 g N $m^{-2}yr^{-1}$ (200 and 400 kg/ha/yr), the researcher reported very low levels of leachate that did not contain significant amounts of nitrate.

Literature pertaining to the P and K status of amended sand-based creeping bentgrass putting greens is almost non-existent. Much of the nutrient research on creeping bentgrass putting greens has been carried out on straight sand putting greens and not amended root zone mixes. Paul (1981) reported that 3 ppm of bicarbonate-extractable P in straight sand was the critical level for growth of creeping bentgrass. Christians et al. (1979) demonstrated that P was not limiting to bentgrass growth or quality at 2 ppm Bray-1 P. The level of soil P in which no further increases in levels of tissue P was observed was a Bray-1 P level of 24 ppm (Waddington et al., 1978).

Average tissue levels of K for creeping bentgrass was reported (Waddington and Zimmerman, 1972) to be 38.6 g/kg. They found the average tissue P for creeping bentgrass to be 7.6 g/kg. Jones (1980) suggested nutrient content sufficiency ranges for turfgrass. The ranges proposed for N, P, and K were 27.5 to 36.0, 3.0 to 5.5, and 10.0 to 25.0 g/kg, respectively. Turner and Hummel (1992) note that wide ranges in tissue N, P, and K levels have been reported and reflect differences in turfgrass species and cultivars.

The ultimate goal of this project is to establish criteria for the selection of amendments for blending with sand to create root zone mixes for golf putting greens. The project consists of laboratory, greenhouse, and field studies. Results of the laboratory characterizations of a wide array of organic amendments, their performance in simulated greens in the greenhouse, and the establishment year performance of putting greens constructed at the O.J. Noer Turfgrass Research and Education Facility will be presented in a companion thesis.

The objectives of the present phase of the study were: (1) To continue field assessment of various root zone amendment effects on putting green quality and the factors involved in determining putting green quality and (2) to determine amendment effects on the status of N, P, and K in root zone mixes.

METHODS

The golf putting green used in this research consists of 10 treatments (different root zone mixes) replicated four times in a randomized complete block design. Individual plots are 8 x 8 foot cells isolated by 6-mil plastic sheeting and containing observation wells for measurement of soil moisture and root development. After completion of construction in May 1993, the plots were seeded to 'Pencross' creeping bentgrass (*Agrostris palustris* Huds.).

Most of the root zone mixes containing an amendment were blended on a 80/20 (80% sand, 20% amendment) volume basis. The quantity of fermented rice hulls available at the time of mixing limited the ratio of this root zone mix to 83/17. Additionally, financial considerations limited the blending of the Isolite amendment to the top 6 inches of the 12-inch root zone mix, where blending was on a 80/20 basis. The 10 treatments and their basic physical properties determined according to USGA protocols are shown in Table 5. Characteristics of the six root zone amendments appear in Table 6, and the particle size distributions of the three sands in Table 7. The Greensmix and Lycon sands meet USGA Specifications, while the WPL sand, that

Table 5. Laboratory measures of bulk density, porosity, and saturated conductivity (Ksat) of compacted root zone mixes.

Sand	Amendment	Bulk density	Porosity Total	Porosity Capillary†	Porosity Non-capillary†	Ksat
		$g\ cm^{-3}$	%	%	%	$in\ hr^{-1}$
Greensmix	Canadian sphagnum	1.45	45.3	15.6	24.7	32.5
	Michigan sphagnum	1.48	44.2	13.9	30.3	40.7
	Reed sedge peat	1.57	40.8	15.4	25.4	14.0
	Wisconsin peat	1.59	40.0	11.0	29.0	31.3
	Iowa peat	1.61	39.2	16.5	22.7	10.5
	Fermented rice hulls	1.62	38.9	7.2	31.7	41.4
	Isolite	1.55	41.5	13.2	28.3	38.2
WPL	Canadian sphagnum	1.20	54.7	46.0	8.7	1.6
Lycon	Canadian sphagnum	1.50	43.4	17.4	26.0	25.2
Greensmix	None	1.74	34.3	4.9	29.4	41.7

† At 40-cm tension.

Table 6. Characteristics of organic amendments used in putting green root zone mixes.

Organic amendment	Total ash	HMP fiber†	H_2O retention By volume	H_2O retention By weight	C:N ratio	Bulk density	Salt pH	CEC pH 7
	---------- % ----------					$g\ cm^{-3}$		$cmol(+)/kg^{-1}$
Canadian sphagnum peat	6.65	76.6	52.1	464	54.9	0.13	4.0	116
Michigan sphagnum peat	5.45	80.9	52.5	392	53.5	0.13	2.9	141
Reed sedge peat	15.4	51.2	59.8	279	53.0	0.21	6.2	121
Wisconsin peat	16.9	74.7	32.8	432	50.0	0.18	3.3	74.6
Iowa peat	35.6	31.7	43.6	254	16.7	0.29	5.5	872
Fermented rice hulls	23.4	83.3	65.6	138	104	0.23	4.9	23.6

† Hexametaphosphate pre-treatment.

Table 7. Particle size distributions of sands used in putting green root zone mixes.

Particle size range	Particle size designation	Greensmix sand	Lycon sand	WPL sand
mm		-------------	% by weight	----------
> 2.0	Gravel	< 0.1	0	2.7
2.0 to 1.0	Very coarse sand	5.0	4.8	13.7
1.0 to 0.5	Coarse sand	49.6	22.5	13.6
0.5 to 0.25	Medium sand	44.7	54.0	16.4
0.25 to 0.125	Fine sand	0.8	18.1	26.6
0.125 to 0.05	Very fine sand	0	0.4	15.6
< 0.05	Silt plus clay	0	0.2	11.4

sieved from coal-fired electrical plant bottom ash, does not. The WPL sand contains nearly equal amounts of material in all of the sand fractions. The particle size distribution of the gravel used as a sub-layer in the construction of the green used for the present study appears in Table 8.

Coefficients were calculated for USGA recommended performance factors using the size distributions of the sand and gravel used to build the putting green. The pea gravel used in this study as a sub-grade layer met all three of the performance factors specified by the USGA in Table 2, even when the WPL sand was used in the root zone mix. The Greensmix and Lycon sands met the USGA's recommendation for maximum gradation index of ≤6.67 and for a uniformity coefficient of ≤2.65. The WPL sand, with a maximum gradation index of 30.29 and a uniformity coefficient of 6.55, did not satisfy these criteria.

Routine Measurements and Management Practices

Observations made in 1994 and 1995 included weekly turfgrass quality ratings of the ten treatments, three measures of moisture retention per year, and annual determination of water infiltration rates. In 1995, quality ratings for trafficked and untrafficked conditions were recorded after half of each individual green was subjected to simulated traffic through the use of a roller outfitted with golf shoe spikes. Based on the numbers of spikes on the rollers and a typical golf shoe, one pass with the traffic simulator equates to about 40 rounds of golf.

Table 8. Particle size distribution of gravel used in subgrade.

Particle size range	Gravel used in study
mm	% by weight
> 9.5	0
9.5 to 6.3	29.7
6.3 to 4.75	63.1
4.75 to 3.35	6.5
3.35 to 2.00	0.4
< 2.00	0.3

Root zone moisture measurements were made at 2-, 4-, 6-, 8-, and 10-inch (5-, 10-, 15-, 20-, and 25-cm) depths through the use of a time-domain reflectometer (TDR) unit. By measuring the time required for a pulsed wave to travel down and back a wave guide, the cable-tester instrument is able to measure the apparent dielectric constant. This constant is related to the volumetric water content through the use of an empirical equation (Topp et al., 1980):

$$\theta = -5.3E\text{-}02 + 2.92E\text{-}02Ka - 5.5E\text{-}04Ka^2 + 4.3E\text{-}06Ka^3$$

where θ is the volumetric water content and Ka is the apparent dielectric constant.

Infiltration rates were determined using a single 3.75-inch (9.53-cm) diameter cup cutter driven into the putting green surface to a depth of approximately 2 inches. Water to a depth of 1.5 inches was maintained in the cylindrical core cutter with a Marriot bottle and fitted with a buret that, through calibration, permitted observation of the volume of water infiltrating the soil. On any given occasion, the infiltration rate of a particular root zone mix is high initially and falls with time until a fairly constant value is reached. Madison (1971) states this value is usually reached within 30 minutes of the start of infiltration. In the present study, measurements were continued until successive infiltration rates were within 0.5 inch/hour of one another. The time required ranged from 30 minutes to 2 hours.

Routine management practices consisted of mowing six times a week at 5/32 inch (8 mm). The greens were on a preventative fungicide application program and irrigated regularly to prevent moisture stress. The entire green was topdressed with pure sand seven times in 1995 and four times in 1994. The green was aerified for the first time in September 1995 with 3/4-inch hollow tines. Plugs were removed and the green was subsequently topdressed with pure sand. Selected plots with extensive localized dry spot were treated monthly with Naiad, a wetting agent, and topdressed with Profile, a porous ceramic material, following core cultivation in 1995.

Urea, 15-0-30, 18-4-10, 11-32-0, and 0-0-50 fertilizers were rotationally applied over the two years of this study. Fertilization rates for 1994 and 1995, respectively, were 3.4 and 3.8 lb N, 0.8 and 1.5 lb P_2O_5, and 2.5 and 3.1 lb K_2O/1000 ft^2 (M). Frequency of fertilization was guided by bentgrass color. Additionally, 1 lb N/M as Milorganite was applied in November 1995.

Nutrient Analyses

Chemical measurements made during 1994 included bentgrass clipping nutrient content, and soil organic matter, pH, P and K levels. In 1995, cation exchange capacity (CEC), exchangeable cations and solution K, and labile P levels were measured as well. Five sets of creeping bentgrass clippings were collected and analyzed for nutrient content in 1995.

Tissue contents of nutrients other than N were measured by way of plasma emission spectrophotometry. Cation exchange capacity was determined in duplicate samples using 1 M NH_4Cl (pH 7.0), methanol and 1 M KCl in a modification of the leaching tube method described by Gillman et al. (1983). Available P and K were determined in Bray-1 extracts by way of colorimetry and flame photometry, respectively (Liegel et al., 1980). Available P was also determined in Bray-2 extracts by way of colorimetry (Liegel et al., 1980). Soil samples taken in May 1994 to a depth of 6 inches were analyzed for pH, % organic matter, Bray-1 P, and K. Soil samples were taken in October 1994 at 0 to 2, 2 to 4, 4 to 6, and 6 to 8 inches and analyzed for pH, Bray-1 P, Bray-2 P, and K.

The 1994 soil samples were also analyzed for DTPA-extractable (Lindsay and Norvell, 1969) Fe, Zn, Cu, and Mn.

Nitrogen Recovery

Mini-plots were created for the purpose of determining root zone amendment effects on short-term fertilizer uptake by the creeping bentgrass. Steel frames (22 x 22 x 6 inches) were installed on each of the replicate greens containing the six organic amendments. The frames were installed to facilitate the collection of clippings by matching the width of the frames to that of the mower. Low-tension lysimeters were then installed at 8- and 12-inch depths in order to track fertilizer nitrogen. The lysimeters were constructed of 4-inch diameter plastic funnels in which a plastic disc was glued to the top surface opening. Fiberglass wicking ran through 3/4-inch circular opening in the disc and continued through the funnel and the connecting Tygon tubing. The tubing was directed to 1-L plastic bottles, where the leachate was collected. The total length of the fiberglass wick was 15 cm. On July 10, 1995, 0.5 lb N/M was applied as ^{15}N depleted ammonium sulfate. The lysimeters were pumped and leachate collected about every 4 days. Clippings were collected daily for 3 weeks, and subsequently weighed and analyzed for total nitrogen concentration and ^{15}N content.

Soil samples from the six organic amendments treatments were collected prior to and at the conclusion of the study and analyzed by way of the Kjeldahl method for organic and inorganic N. Crown and stem material was separated from the roots and subsequently weighed and analyzed for N content via the Kjeldahl procedure. Water inputs (rainfall + irrigation) were measured on a daily basis throughout the course of the study on each individual replicate green to quantify differences in water applied via the irrigation system.

Phosphorus Nutrition

Measures of solution and labile P provided the basis for assessing the effects of root zone amendments on bentgrass P nutrition. Labile P levels of the root zone mixes were measured using iron oxide impregnated filter paper (Ransome, 1989). After a 24-hour equilibrium period, labile P was determined for root zone mix samples previously treated with 0, 10, 20, 40, or 80 mg kg^{-1} of P applied as KH_2PO_4. Solution P was estimated using $Sr(NO_3)_2$ as the extractant (Wiethölter, 1983).

Syringes were filled with 10.0-g (O.D.) samples of each of the 10 root zone mixes and 10 mL of KH_2PO_4 was added successively in the amounts of 0, 0.1, 0.2, and 0.3 mg P L^{-1} to examine the relationship between soil Bray-1 P and solution P levels. After a 24-hour equilibrium period, 10 mL of distilled water was added to each of the syringes and the Bray-1 extract was used to measure soil P.

Potassium Nutrition

Duplicate 50.0-g (O.D.) samples of root zone mix were placed into each of three syringes. Leaching was as follows: Syringe 1 was leached with 3 x 25 mL of 0.004 M $Sr(NO_3)_2$; Syringe 2 with 5 mL 350 mg/kg of K as KH_2PO_4 followed by 3 x 25 mL 0.004 M $Sr(NO_3)_2$; and Syringe 3 with 5 mL 700 mg/kg K followed by 3 x 25 mL 0.004 M $Sr(NO_3)_2$. Duplicate 10.0-g (O.D.) samples were weighed from each leached sample and placed into syringes. One syringe was leached with 25 mL 1 N NH_4OAc (pH 7.0) to extract exchangeable K. The other syringe was leached with 25 mL 0.004 M $Sr(NO_3)_2$ to obtain an estimate of solution K. All K analyses were by way of flame photometry.

All statistical analysis performed in this study were by way of CoStat Version 3.0 (CoHort Software, P.O. Box 19272, Minneapolis, MN 53419).

RESULTS AND DISCUSSION

Quality ratings taken during 1994 and 1995 and corresponding day of year are shown in Appendix Tables A-1 through A-3. These visual ratings incorporate the color, density, and uniformity of the creeping bentgrass. Means of the 1994 and 1995 quality ratings are given in Table 9.

Table 9. Putting green quality rating means for 1994 and 1995.

Sand	Amendment	1994	1995	1995 (traffic imposed)	Paired T-test of 1995 means † (p = 0.05)
Greensmix	Canadian	7.98	8.03	7.73	NS ‡
	Michigan	7.89	8.12	7.78	0.26
	Reed sedge	8.00	8.19	7.80	0.22
	Wisconsin	7.96	8.23	7.95	0.10
	Iowa	8.11	8.27	7.96	0.26
	Rice hulls	6.15	7.63	7.48	NS
	Isolite	6.75	7.73	7.43	NS
Greensmix	None	6.89	7.82	7.61	0.12
WPL	Canadian	7.89	8.11	7.83	0.29
Lycon	Canadian	8.02	8.14	7.76	NS
Duncan's LSD (p = 0.05)		0.29	0.24	0.36	

† Traffic vs. no traffic.

‡ NS = not significant.

Season means (Table 9), as well as weekly quality ratings for 1994 (Table A-1), show that the fermented rice hull, Isolite, and pure sand treatments were significantly lower in quality than the seven remaining treatments. Statistical examination revealed that there were no significant differences among the five peat treatments even though the Iowa and Wisconsin peats do not meet the USGA standard of containing more than 85% organic matter. In fact, the Iowa peat contains only 64% organic matter (Table 6).

Quality ratings for selected treatments during the 1994 season are shown in Figures 1 and 2. Figure 1 shows the ratings for the Iowa peat treatment, the organic amendment with the highest season mean quality ratings, the ratings for the pure sand green and for fermented rice hulls, the green with the lowest mean quality ratings. After about May 20, the Wisconsin peat green had consistently higher quality ratings. The gradual rise in the quality ratings for the fermented rice hulls and pure sand greens reflects greater uniformity in the bentgrass stand as a result of spring overseeding and intensive use of a wetting agent on the rice hull green. Although the WPL sand does not meet USGA standards, quality ratings for the treatment did not significantly differ from those of the Greensmix and Lycon sand greens (Fig. 3)

The 1995 quality ratings continued to show some of the same trends that were observed in 1994. Quality of the fermented rice hull, Isolite, and pure sand greens continued to be significantly lower throughout the 1995 growing season than for the remaining seven treatments. The Iowa peat and Wisconsin peat greens continued to

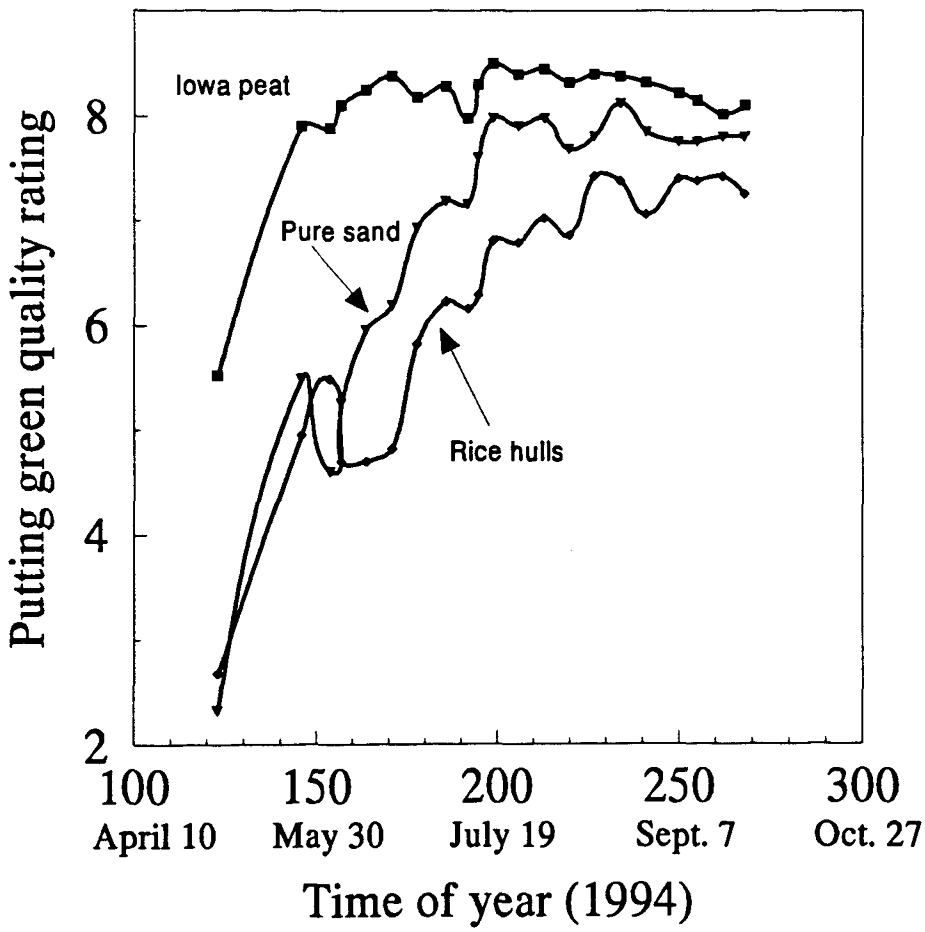

Figure 1. Daily quality ratings for three root zone mixes contrasting in quality during 1994.

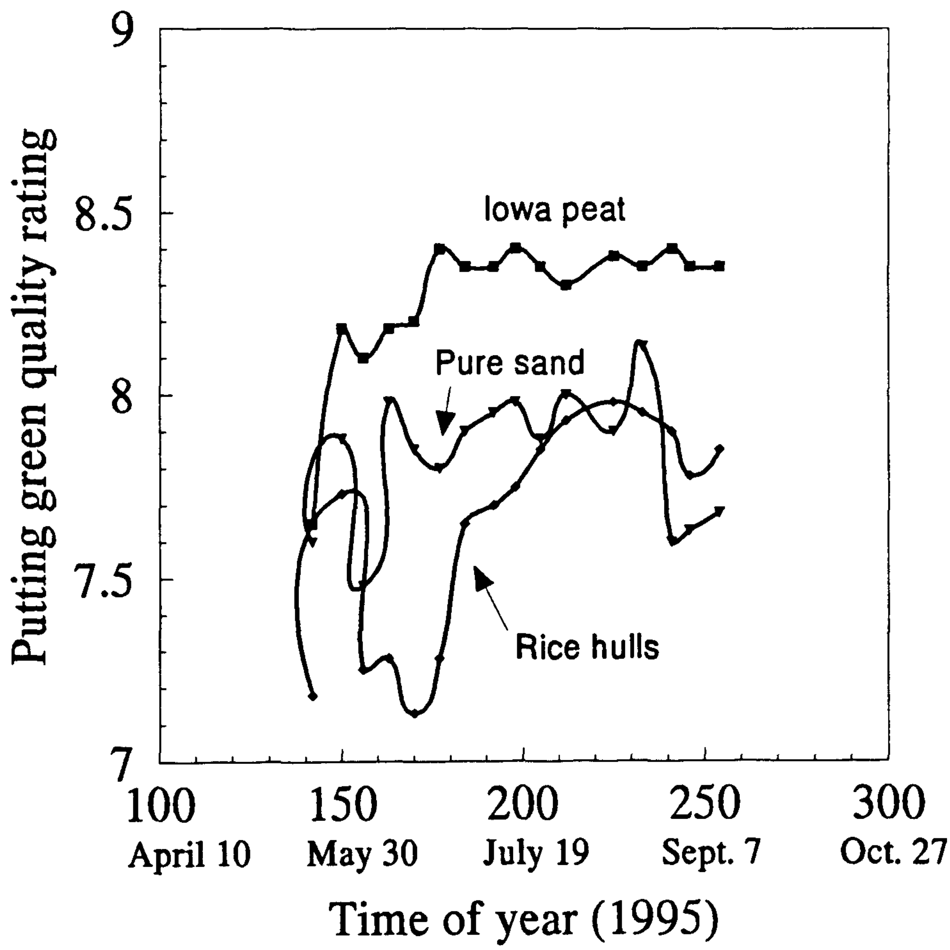

Figure 2. Daily quality ratings for three root zone mixes contrasting in quality during 1995.

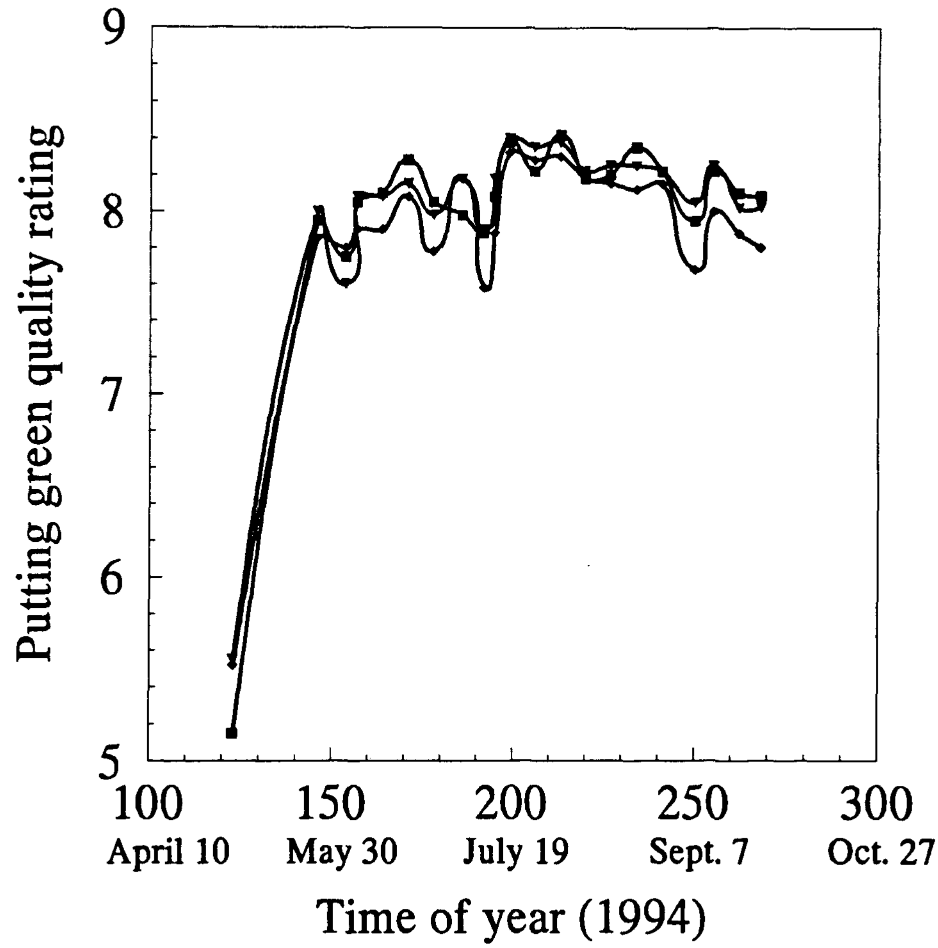

Figure 3. Sand effects on putting green quality.

produce excellent quality turfgrass, and, in fact, were the two highest rated treatments during the majority of the growing season.

Quality ratings in 1995 for the same three treatments in Figure 1 appear in Figure 2. The root zone mix containing fermented rice hulls had the lowest mean quality rating among the 10 different treatments in 1995. The gradual increase in the quality ratings for rice hull treatment in early summer appears to coincide with the institution of a wetting agent application program which began in early June in an attempt to overcome the presence of localized dry spot (LDS).

The Canadian sphagnum peat treatment did not perform as well in 1995 when compared to the other peat amendments. For example, on day 246 (September 3), the Canadian sphagnum peat treatment ranked seventh out of 10 treatments, with a quality rating of only 7.95, compared to the highest rating of 8.38 that the Iowa peat treatment received (Table A-2). This occurrence is of interest since Canadian sphagnum peat is considered to be the premier organic amendment by the golf course industry. Part of the explanation for the decreased quality of this treatment can be attributed to the development of LDS on one of the replicated greens. In the course of investigating amendment influence on fertilizer N fate, water inputs were measured on a daily basis. During a 14-day period without rain, daily temperatures in excess of 85°F and strong, southerly winds, one of the Canadian peat plots received only an average of 32% of the 0.25 inch of irrigation water being applied. This led to dry-down of the plot and, in a matter of only 3 days , the appearance of severe LDS. This, in turn, significantly reduced moisture retention in the root zone (Fig. 4). This phenomenon persisted for the remainder of the 1995 season and the quality ratings reflect this occurrence. Eliminating the Canadian sphagnum peat replicate suffering from extensive LDS resulted in the mean quality rating increasing from 8.03 to 8.14 for 1995. This increased its ranking form seventh to fifth.

Trafficking by a roller outfitted with metal golf shoe spikes was instituted in 1995 in an attempt to realistically simulate the effects of mowing equipment and golfer traffic on quality. One-half of each of the plots was subjected to traffic. This procedure facilitated side-by-side comparison of trafficked and non-trafficked quality on the individual plots. Quality ratings dropped by an average of 3.4% among the 10 treatments. A paired T-test of quality ratings with and without trafficking revealed that only the four treatments with lowest mean quality ratings (Canadian peat, rice hulls, Isolite, and pure sand) did not have statistically significant lower quality ratings when trafficking was imposed (Table 9).

Table A-4 shows the number of simulated golf rounds and the date on which these rounds were imposed during 1995. Although a total of only 6,520 simulated rounds of golf were imposed, and it is commonplace for golf courses to have between 20,000 and 40,000 rounds played each year, there was a definite decline in quality between trafficked and untrafficked areas. Because the traffic was imposed in a very short time frame (less than 1 hour), this high intensity made up for a deficit of total rounds because rounds on a golf course are spread out over time periods as long as 14

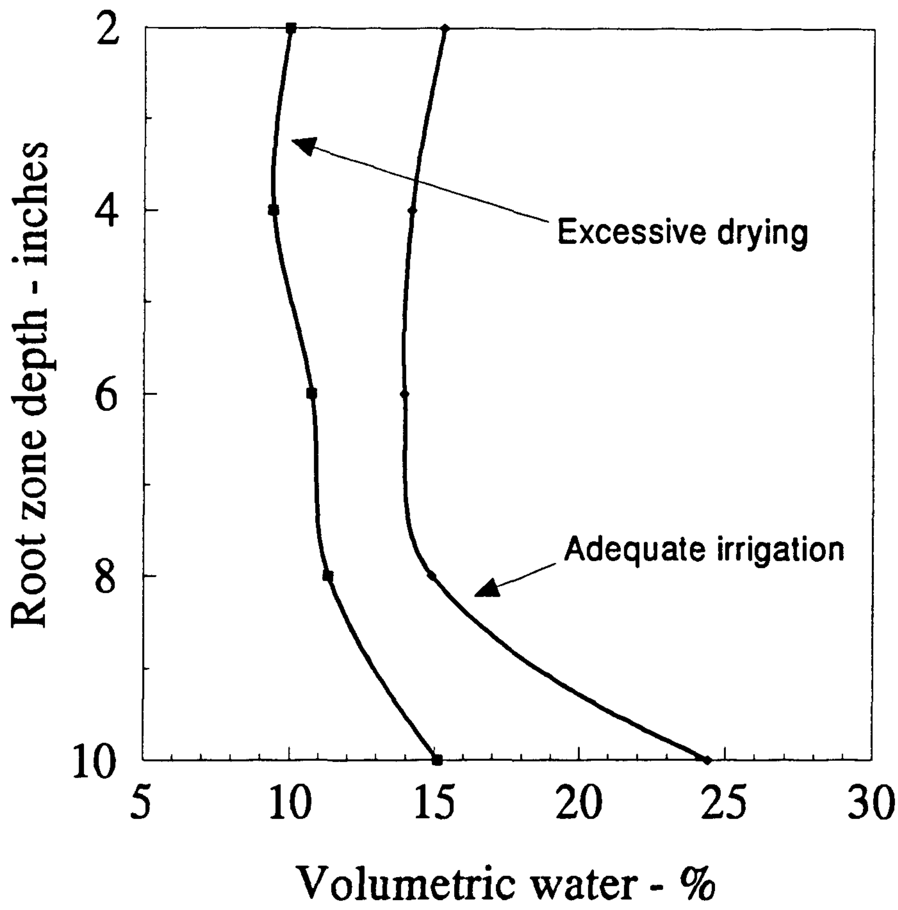

Figure 4. Effect of excessive drying on the subsequent moisture retention by a root zone mix constructed with Canadian sphagnum peat.

or 15 hours per day. The most significant result of imposing traffic in 1995 was the development of an extensive surface algal layer that persisted throughout the season, even after trafficking ceased in early August. The untrafficked portions of the plots also experienced algae, but not nearly to the extent of the trafficked areas.

Table 10 contains observations of percentage algal coverage, LDS, and the presence of turf thinning on day 225 (August 13). Surface compaction and its accompanying increase in surface wetness had a dramatic effect on the amount of algae growth. Without traffic, algal growth was evident on 3 to 32% of the total area of the individual plots, the actual amount depending on the root zone mix composition. These percentages increased dramatically as a result of trafficking—to as much as 92% coverage with algae for the Isolite root zone mix. It is important to point out that these plots are in full sunlight and not tucked in a shaded area. Algal growth was lowest on the WPL sand treatment, perhaps due to the fact that this root zone mix has a pH of about 8.6. Treatment means for pH over three sampling dates can be found in Table A-5. Explanations for differences in algal coverage for the other treatments are not readily apparent as a relationship between percent moisture retention in the top 2 inches of the root zone mixes and the appearance of algae was not observed.

Localized dry spot (LDS), which appears as irregularly shaped areas of wilted or dead turfgrass, was a problem with the rice hull, Isolite, and straight sand greens. Localized drying in the Canadian peat treatment was on but one of the four replications and, as pointed out previously, arose from a set of unique circumstances. Miller

Table 10. Root zone mix effects on the presence of algae, localized dry spot (LDS) and turf thinning.

Root zone mix	Algae coverage		LDS	Turf thinning
	No traffic	Traffic		
	-------------- % --------------			
Canadian peat	3	66	Yes	Yes
Michigan peat	18	69	No	Yes
Reed sedge peat	6	50	No	Yes
Wisconsin peat	7	49	No	Yes
Iowa peat	6	69	No	Yes
Rice hulls	8	65	Yes	No
Isolite	32	96	Yes	Yes
WPL sand	4	48	No	No
Lycon sand	10	69	No	Yes
Pure sand	7	61	Yes	Yes
Duncan's LSD ($p = 0.05$)	15	34		

and Wilkenson (1979), Tan (1982), and Tucker et al. (1990) suggest an organic coating similar to fulvic acid on sand particles as a possible explanation for the occurrence of LDS.

Thinning of the 'Pencross' creeping bentgrass greens as a result of algae invasion occurred in isolated areas on all but the rice hull and WPL sand treatments. No attempt was made to quantify the relationship between the area of the greens invaded by algae and turf thinning.

Volumetric Moisture Retention

Average volumetric moisture measurements for 1994 and 1995 are shown in Tables 11 and 12. These measurements were obtained through the use of time-domain reflectometry and represent the average amount of moisture retained across the five depths (2, 4, 6, 8 and 10 inches) measured for each individual green. Treatment and depth volumetric means for all six measurements taken over the course of 1994 and 1995 are found in Tables A-6 and A-7, respectively. All 10 treatments retained less moisture in 1995 than in 1994. Possibilities for this occurrence include time of measurement after irrigation, amendment decomposition, sand topdressing, and loss of organic matter, at least near the putting green surface. Soil analyses of the top 4 inches of root zone mix in 1993 revealed the presence of an average of 1.3% organic matter (OM). By August 1995, this percentage dropped to 0.8 (Table 13). This reduction may be due in part to repeated topdressing with pure sand. By April 1996,

Table 11. Root zone volumetric moisture means for 1994.

Root zone mix	June 10	June 20	July 15	Mean ± SD
	------------------------------	% volume	------------------------------	
Canadian peat	19.86	18.19	16.11	18.1 ± 7.0
Michigan peat	18.93	16.93	14.48	16.8 ± 2.2
Reed sedge peat	20.52	19.84	17.15	19.1 ± 1.8
Wisconsin peat	18.19	16.86	14.75	16.6 ± 1.7
Iowa peat	19.86	19.46	17.58	19.0 ± 1.2
Rice hulls	13.62	12.15	10.59	12.1 ± 1.5
Isolite	17.23	15.86	14.08	15.7 ± 1.6
WPL sand	39.33	38.59	34.18	37.9 ± 2.8
Lycon sand	24.87	23.39	21.37	23.2 ± 1.8
Pure sand	18.08	16.36	14.04	16.2 ± 2.0
Duncan's LSD ($p = 0.05$)	2.26	2.01	2.38	

Table 12. Root zone volumetric moisture means for 1995.

Root zone mix	June 1	July 15	Aug. 28	Mean ± SD
	------------------------------ % volume ------------------------------			
Canadian peat	11.77	14.28	15.14	13.7 ± 1.8
Michigan peat	11.74	15.04	11.47	12.7 ± 2.0
Reed sedge peat	14.04	17.81	16.91	16.2 ± 2.0
Wisconsin peat	10.83	15.07	12.89	12.9 ± 2.1
Iowa peat	14.34	18.25	16.62	16.4 ± 2.0
Rice hulls	8.33	9.79	8.93	9.0 ± 0.7
Isolite	11.21	12.93	9.96	10.3 ± 1.5
WPL sand	30.62	34.65	34.66	33.3 ± 2.3
Lycon sand	17.17	20.65	18.22	18.7 ± 1.8
Pure sand	10.84	13.17	11.03	11.7 ± 1.3
Duncan's LSD ($p = 0.05$)	2.02	2.45	2.73	

Table 13. Changes in root zone mix organic matter percentages.

Root zone mix	Oct. 1993 0 to 3 inches	May 1994 0 to 6 inches	Aug. 1995 0 to 4 inches	April 1996 0 to 4 inches
	-------------------------	% organic matter	-------------------------	
Canadian peat	1.6	0.7	0.7	1.1
Michigan peat	1.2	0.7	0.7	1.0
Reed sedge peat	0.6	1.0	0.9	1.2
Wisconsin peat	1.1	0.8	0.6	0.8
Iowa peat	1.8	1.2	1.5	1.5
Rice hulls	1.3	0.6	0.6	0.6
Isolite	0.1	0.3	ND†	0.3
WPL sand	1.8	1.9	ND	1.6
Lycon sand	1.2	0.8	ND	0.7
Pure sand	0.5	0.2	ND	0.2
Duncan's LSD ($p = 0.05$)	0.6	0.2	0.3	0.2

† ND signifies not determined.

the depth of sand topdressing was approximately 1 inch. This alone could account for a reduction in OM in the top 4 inches from 1.3 to 1.0%.

There was a strong relationship between water retained and average quality ratings in 1994 and 1995 (Fig. 5 and 6). The treatment containing WPL sand deviated from this linear relationship in both 1994 and 1995. The presence of 11.4% fine-sized particles within this sand resulted in this root zone mix being able to retain much larger amounts of water than the nine remaining treatments (Table 7). Excluding the WPL treatment, the Iowa peat mix retained the highest amount of water and had the highest quality ratings. The Isolite, fermented rice hulls, and pure sand greens continued to hold the least amounts of water in 1995. Their continually lower quality ratings reflect their inability to hold enough moisture to produce a high-quality putting green. Not surprisingly, these were also the greens most prone to development of LDS.

Imposing traffic on the green caused even more moisture to be retained in the top 4 inches of the root zone mixes (Fig. 7), even though average moisture retention through the root zone as a whole declined. This occurrence may help explain the development of the extensive algal layer as an appropriate environment was clearly present. Algae, being phototropic, can only thrive on or near the soil surface. Algae persistence therefore requires a nearly continually moist soil surface. Unlike the Iowa peat treatment, the water retention at greater depths of the Isolite root zone mix

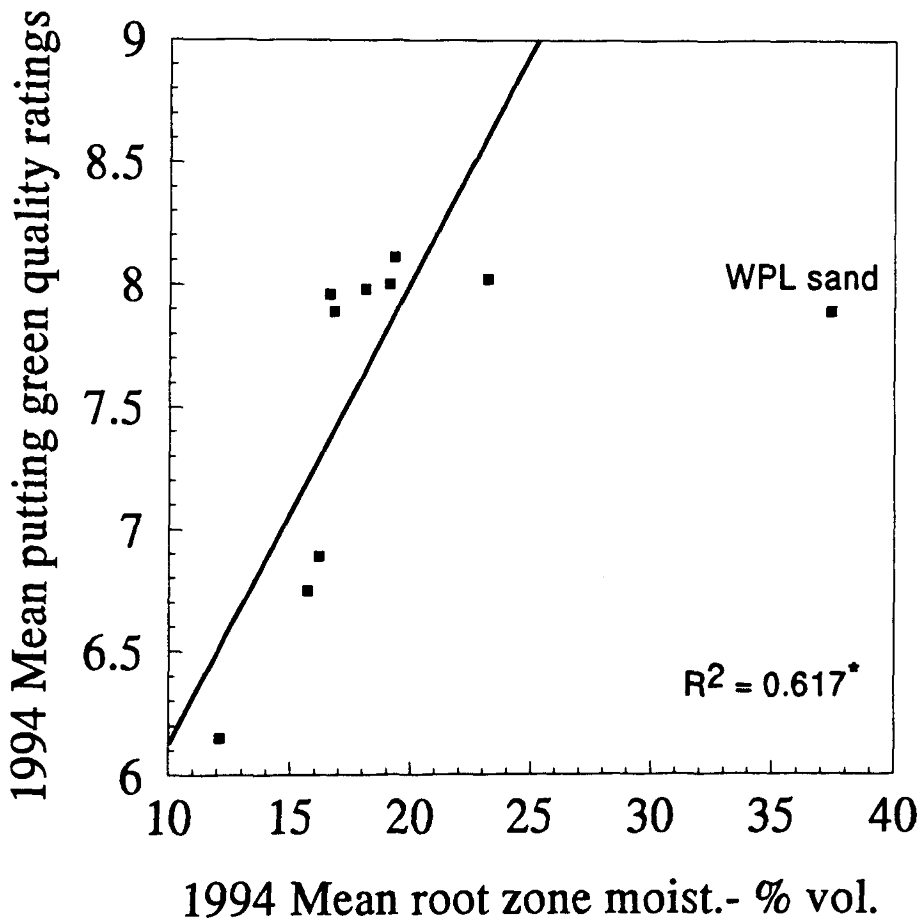

Figure 5. Relationship between root zone moisture retention putting green quality for 1994.

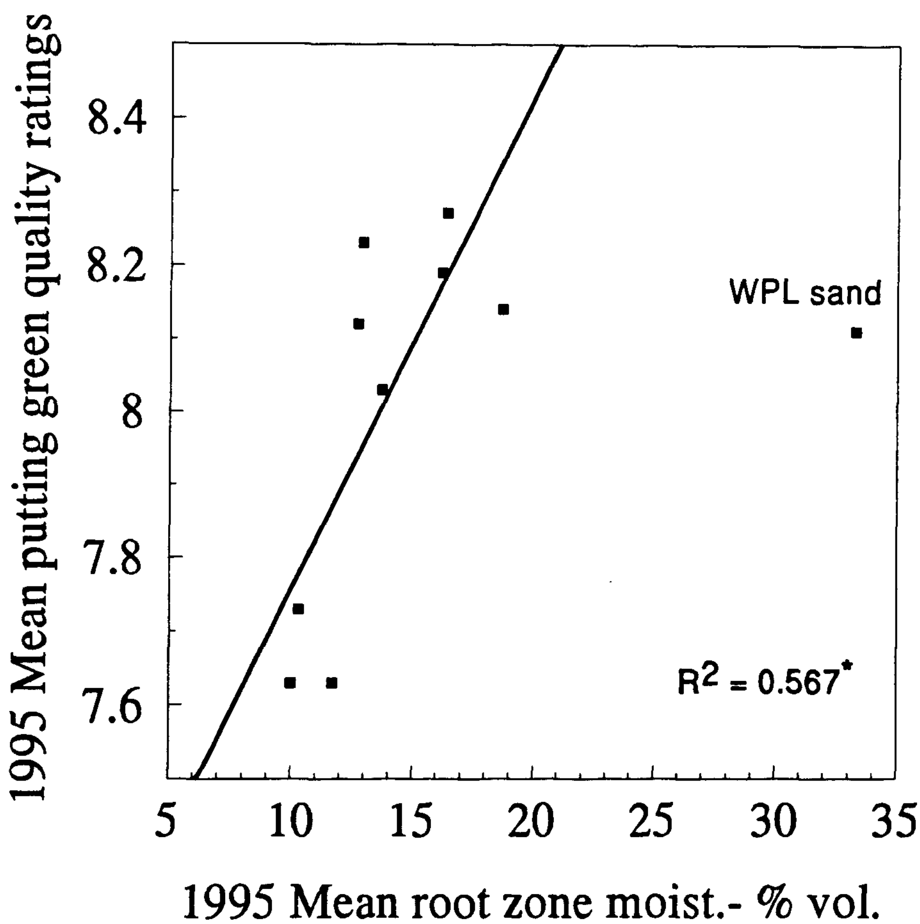

Figure 6. Relationship between root zone moisture retention putting green quality for 1995.

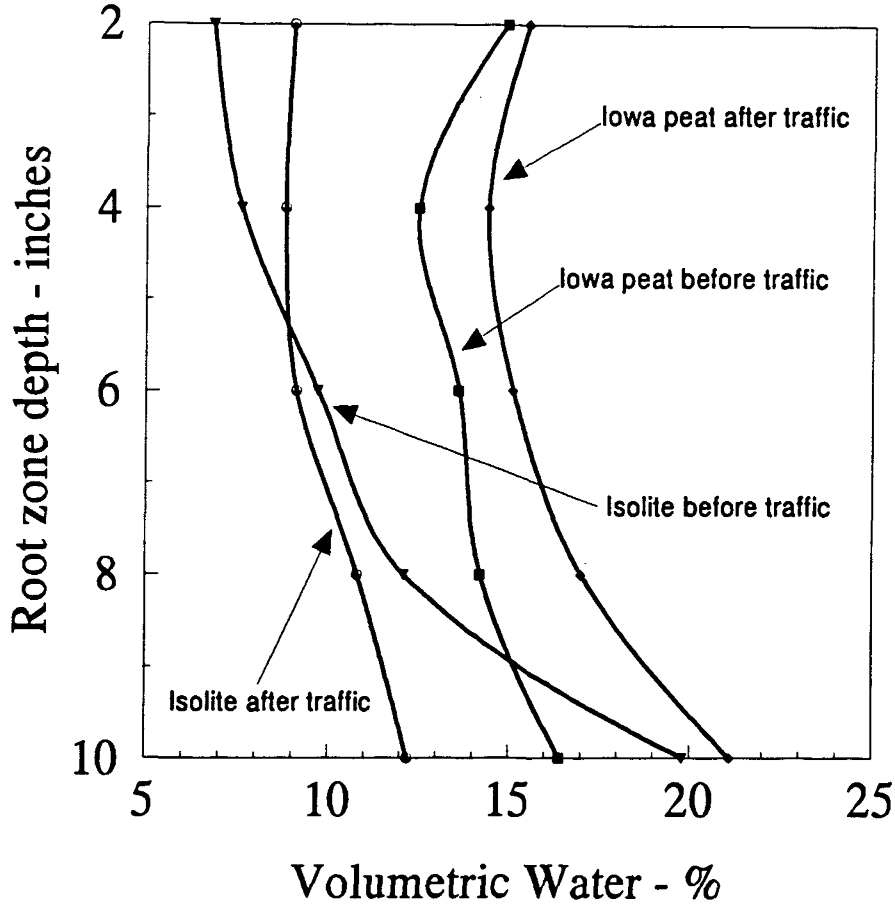

Figure 7. Effects of traffic on moisture retention by Iowa peat and Isolite root zone mixes.

decreased after the imposition of trafficking, although water retention in the top 5 inches of the root zone mix increased (Fig. 7).

Root zone mix organic matter content proved to be a good indicator (R^2 = 0.819) of volumetric moisture retention (Fig. 8). As would be expected, the curvilinear relationship suggests that the higher the root zone organic matter, the higher the amount of moisture retention. Amendment fiber content was also a good indicator of volumetric moisture retention (Fig. 9). This is evidenced by comparing the root zone mixes prepared with Canadian sphagnum peat and Iowa peat. The Canadian peat contains nearly 77% fiber and the Iowa peat 32% fiber. Their respective levels of moisture retention (Table 12) were 13.7 and 16.4%. A highly significant negative correlation (R^2 = 0.963) existed between root zone mix organic matter and amendment fiber content (Fig. 10). This strong relationship may be due to the fact that as fiber content increases, bulk density of organic amendment decreases, resulting in less organic matter being added on a mass basis to the root zone mix when blended on a volume basis (Table 6).

Evidence for the "perched water table" in USGA golf putting greens is apparent in the root zone moisture contents at the five depths of measurements (Table 14). On average, volumetric moisture contents at the 2-, 4-, 6-, 8-, and 10-inch depths were 13.6, 13.5, 14.7, 16.7, and 19.6%, respectively. Thus, moisture retention at 6 inches was 8.1%, greater than at 2 inches. The increase averaged 22.8 and 44.1%, respectively, at the 8- and 10-inch depths.

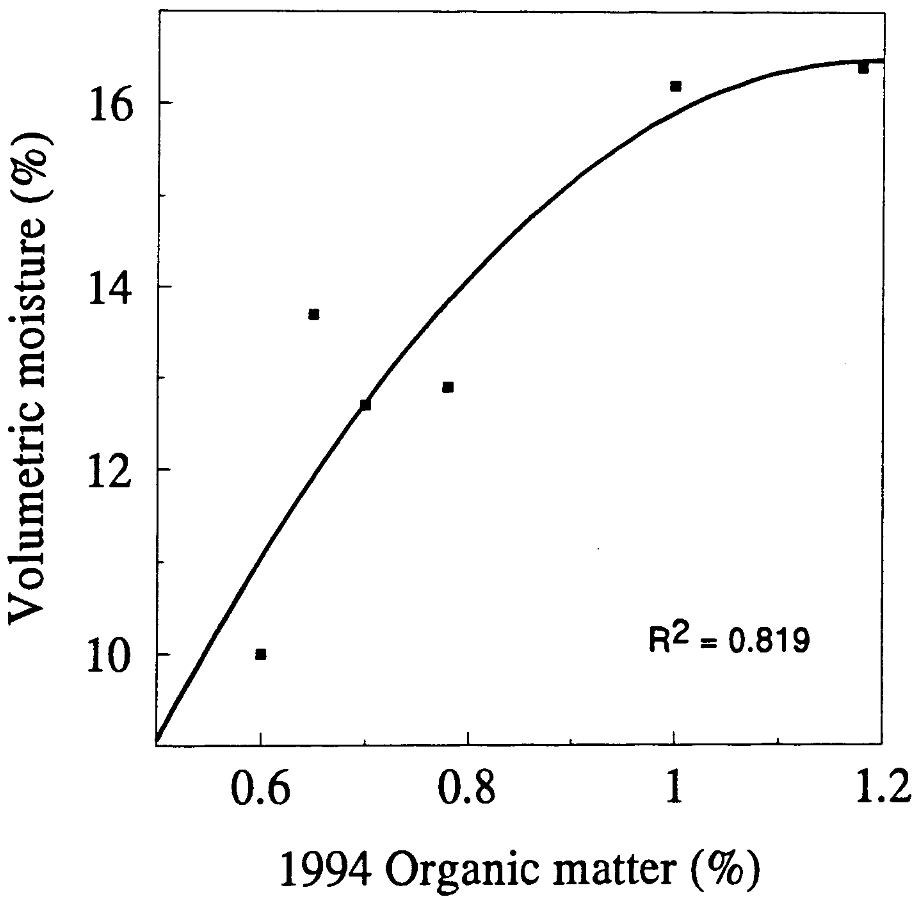

Figure 8. Relationship between root zone moisture retention and organic matter content.

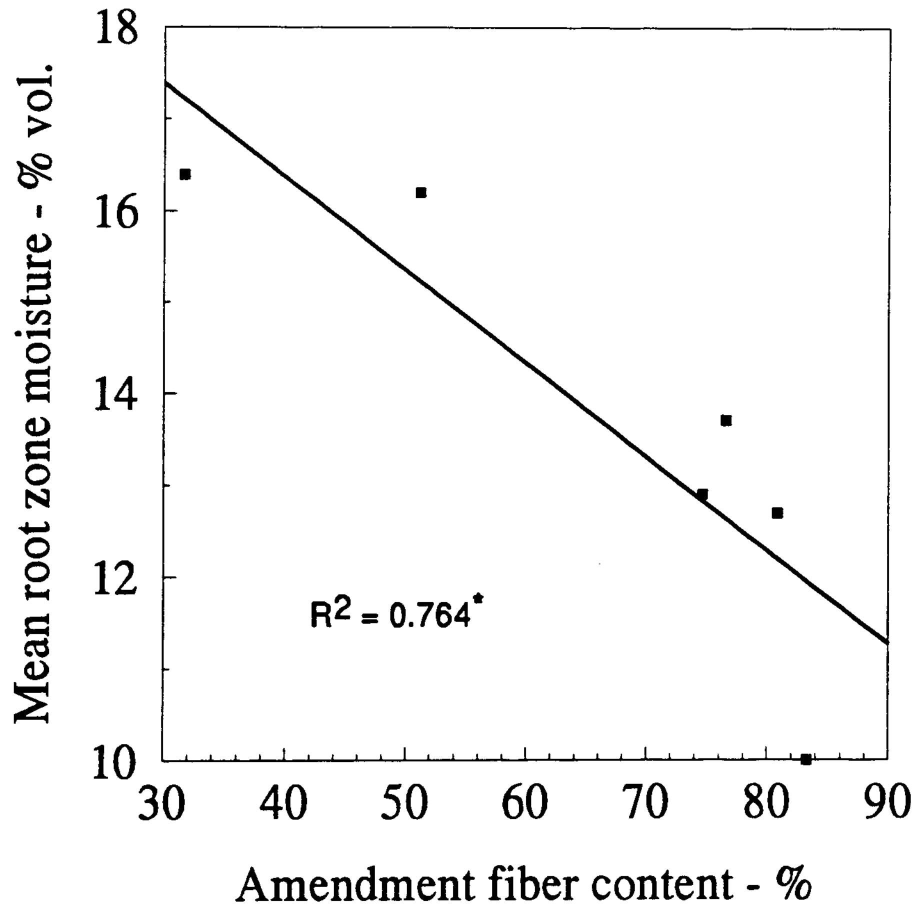

Figure 9. Relationship between root zone moisture retention and organic amendment fiber content.

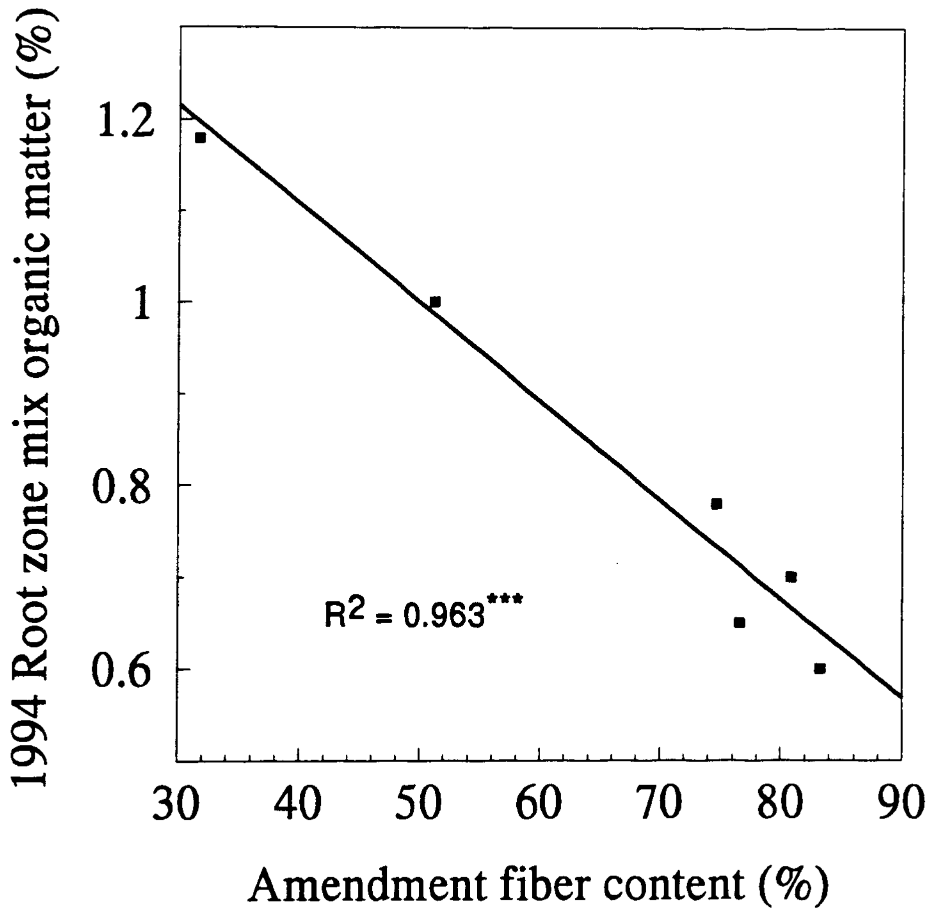

Figure 10. Relationship between root zone amendment fiber content and root zone mix organic matter content.

Table 14. Volumetric moisture for 1995, averaged by depth for all ten root zone mixes.

Depth	June 1	July 10	August 28
inches †		% volume	
2	12.1	15.2	13.4
4	12.3	14.5	13.6
6	13.4	15.9	14.9
8	15.1	18.2	16.8
10	17.5	22.1	19.2
Duncan's LSD (p=0.05)	1.4	1.7	1.9

† Depth of time-domain reflectometer (TDR) probe.

Infiltration Rate

Putting green infiltration rates for 1994 and 1995 are presented in Table 15. With the exception of the WPL sand green, all infiltration rates declined from 1994 to 1995. Some of the treatments experienced as much as a four-fold reduction in infiltration rate. This dramatic reduction in infiltration rates can be attributed to the green's continuing maturation as well as surface compaction due to trafficking. Although 1995 infiltration rates were substantially lower than 1994, only the Isolite treatment (5.1 inches/hour) did not meet the USGA's recommendation of 6 to 12 inches/hour for our climate. No ponding of water, which is the major concern of low infiltration rates, has ever been observed on any of the treatments, even after a heavy rain or irrigation cycle. The low infiltration rates measured on the WPL sand green in 1994 and 1995 were expected, since this sand does not meet USGA specifications. Its particle size distribution is roughly equal across all size fractions (Table 7), a factor that results in reduced porosity and favors compaction.

Rooting Depth

Rooting depth was examined as a possible factor affecting putting green quality. However, with the exception of the WPL sand treatment, all of the treatments had creeping bentgrass roots that extended through the full 12 inches of the root zone mix. The fact that the WPL sand contains 11.4% silt and clay-sized particles (Table 7) and that water retention became greater at the 8- rather than the 10-inch depth (Table A-6),

Table 15. Putting green infiltration rates for 1994 and 1995.

Root zone mix	1994 mean ± SD	1995 mean ± SD
	---------- inches/hour	----------
Canadian peat	26.6 ± 2.4	14.8 ± 9.2
Michigan peat	33.9 ± 7.4	9.4 ± 3.6
Reed sedge peat	24.7 ± 2.7	12.9 ± 5.9
Wisconsin peat	33.8 ± 10.2	7.8 ± 4.9
Iowa peat	16.1 ± 1.0	13.1 ± 6.5
Rice hulls	36.2 ± 6.9	16.4 ± 6.0
Isolite	27.8 ± 2.7	5.1 ± 1.3
WPL sand	7.1 ± 1.4	7.6 ± 3.9
Lycon sand	32.0 ± 7.6	11.3 ± 5.4
Pure sand	42.2 ± 8.1	22.1 ± 11.1

suggests that particle migration and accumulation occurred above the perched water. This could account for the restricted root development observed at that depth.

Root Zone Amendment Effects on N

Bentgrass clipping N data for the 1994 and 1995 sampling dates, as well as yearly averages, are presented in Table 16. Fertilizer nitrogen applications are found at the bottom of the table for reference purposes. Lower average percent N levels for 1995 than 1994 are attributed to differences in the proximity of sampling in relation to fertilizer application. Although statistical differences for clipping percent N exist for each individual sampling date, there was not one treatment in which the percent N in the creeping bentgrass clippings consistently exceeded that of the other treatments. Hence, any differences in clipping percent N for these seven amendment treatments were not apparent. This is believed to be a result of the practice of making light, frequent applications of N fertilizers, to avoid surges in top growth. Timing of N fertilizer applications for both years was based on need indicated by bentgrass color.

Fertilizer N Recovery

During the 28 days following application of 0.5 lb N/M as ^{15}N depleted ammonium sulfate, significantly more clippings were removed from the reed sedge and Iowa peat greens than from the Canadian peat greens (Table 17). One reason for these differences in growth may be due to the fact that the reed sedge and Iowa peat root zone mixes retain 19% more moisture than does the Canadian peat mix (Table 12).

Table 16. Root zone mix influences on bentgrass clipping N concentrations in 1994 and 1995.

	1994			1995				
Root zone mix	6/6	7/5	8/29	6/12	6/26	7/10	7/24	8/28
	% N							
Canadian peat	3.97	4.09	4.49	3.43	3.59	3.67	3.66	4.21
Michigan peat	3.91	3.93	4.52	3.06	3.38	3.65	3.55	4.23
Reed sedge peat	3.87	4.08	4.51	3.28	3.26	3.70	3.61	4.15
Wisconsin peat	3.92	3.95	4.63	3.52	3.55	3.81	3.78	4.13
Iowa peat	4.00	4.23	4.78	3.27	3.59	3.63	3.72	4.42
Rice hulls	3.80	3.89	4.35	3.48	3.51	3.84	3.70	4.15
Isolite	3.86	4.08	4.33	3.29	3.38	3.65	3.31	4.02
WPL sand	3.70	3.80	4.49	3.30	3.34	3.58	3.40	3.99
Lycon sand	4.14	3.99	4.57	3.05	3.49	3.58	3.53	4.14
Pure sand	3.83	4.05	4.85	3.43	3.48	3.62	3.34	4.01
Duncan's LSD (p=0.05)	0.28	0.26	0.37	0.35	0.24	0.19	0.27	0.24

Date	Fertilizer N application, lb N/M	Date	Fertilizer N application, lb N/M
5/3/94	0.50	4/22/95	0.50
6/1/94	0.50	5/22/95	0.33
6/27/94	0.20	6/2/95	1.00
7/12/94	0.20	7/7/95	0.50
7/27/94	0.50	8/9/95	0.50
8/8/94	0.50	9/8/95	0.50
8/30/94	0.50	10/9/95	0.50
9/25/94	0.50	11/6/95	1.00

Table 17. Short-term amendment effects on bentgrass responses over 28 days to a July-10th application of 0.5 lb N/M as ^{15}N depleted ammonium sulfate.

Root zone amendment	Clipping weight	N	Total N taken up	Fertilizer N taken up	Fertilizer N recovered
	lb/Mx10^3	%	------- lb/Mx10^6	---------	%
Canadian sphagnum peat	0.47	4.41	7.00	1.10	16.95
Michigan sphagnum peat	0.49	4.49	7.38	1.39	20.10
Reed sedge peat	0.55	4.51	8.37	1.46	18.82
Wisconsin peat	0.52	4.58	7.93	1.42	19.09
Iowa peat	0.54	4.50	8.25	1.44	19.13
Rice hulls	0.50	4.38	7.32	1.38	20.11
Duncan's LSD (p = 0.05)	0.07	0.07	0.67	0.12	0.71

There was a weak (non-significant) dependency ($R^2 = 0.570$) of clipping N concentration on clipping weights. A stronger relationship was not expected during this time of year due to temperature moderation of bentgrass growth rates. During the 28-day test period, maximum daily air temperatures ranged from 78.7 to 96.5°F and had a mean of 81.4°F. Bentgrass growth rates are noticeably suppressed at air temperatures above 75°F. Temperature stress days, calculated as maximum daily temperature above 75°F, totaled 290 over the 28-day period.

Fertilizer N recoveries in the bentgrass clippings ranged from 16.95 to 20.11% (Table 17). Recovery of fertilizer N was significantly lower for the Canadian peat root zone mix than for all others. This is understandable given that this treatment had the lowest clipping weight and one of the two lowest clipping N concentrations.

Although leachates collected at the 8- and 12-inch depths of the root zone mixes contained undetectable amounts of ^{15}N, nitrogen mobility did appear to play a significant role in fertilizer N recovery. Nitrogen mobility, herein, expressed as the lb N/M/inch of leachate collected at the 8-inch depth (Table 18) was implicated as a major contributor to treatment effects on fertilizer N recovery (Fig. 11). The greater the mobility of N, the lower the fertilizer N recovery values.

Because bentgrass roots extended throughout the 12-inch depth of the root zone mixes, the N leaching to the 8-inch depth was still positionally accessible for uptake. Studies on bentgrass rooting have repeatedly shown that 90% or more of the roots reside in the top 4 inches or so of the soil. Thus, while N is still positionally available

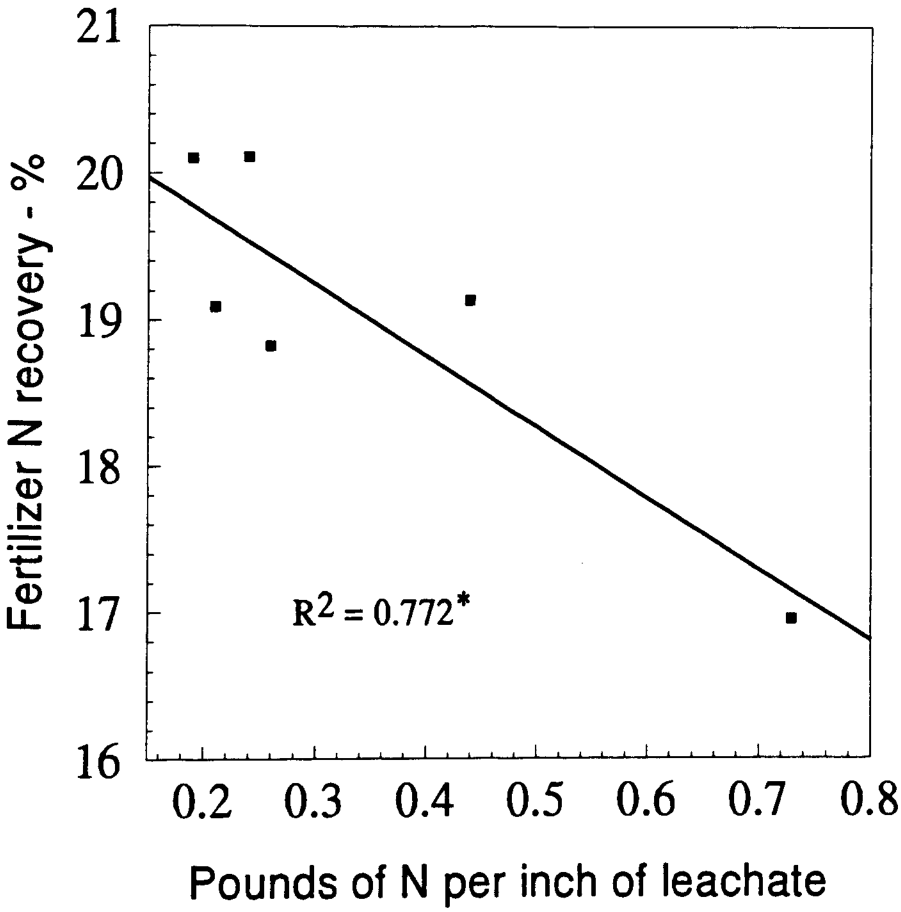

Figure 11. Relationship between pounds of N per inch of leachate and bentgrass fertilizer N recovery.

at the 8-inch depth, it is accessed by only a few percentages of the total root mass. From this perspective, N leaching to the 8-inch depth can be viewed as having the potential of significantly impacting on fertilizer N recovery in clippings.

The total amount of water applied (irrigation + rainfall) did not differ significantly among the root zone mix treatments (Table 18). However, the differences recorded were found to account for 84% of the treatment effects on N detected in leachate at the 8-inch mix depth (Fig. 12). This strongly implies that inherently non-uniform irrigation over the 28-day test period accounted in large part for root zone amendment effects on fertilizer N recovery.

The amounts of N at the 12-inch root zone depth (i.e., entering the underlying pea gravel) were extremely small (Table 18), amounting to less than 2% of the mean amount of N collected at the 8-inch depth. On the surface, one might conclude that this is indirect evidence that significant N losses occurred via denitrification as the N moved into the 8- to 12-inch zone, that with the perched water table. When the 12-inch leachate data are converted to lb N/inch of leachate, the resulting values range from 0.56 to 1.53 lb N/inch of leachate. These are higher than the values of 0.21 to 0.73 lb N/inch of leachate collected at the 8-inch root zone depth. Thus, these data discount the notion that significant amounts of denitrification occurred at depth in the experimental putting greens.

Root and crown samples were collected before and after the onset of this study. Analyses of the root and stem material showed no treatment differences in terms of

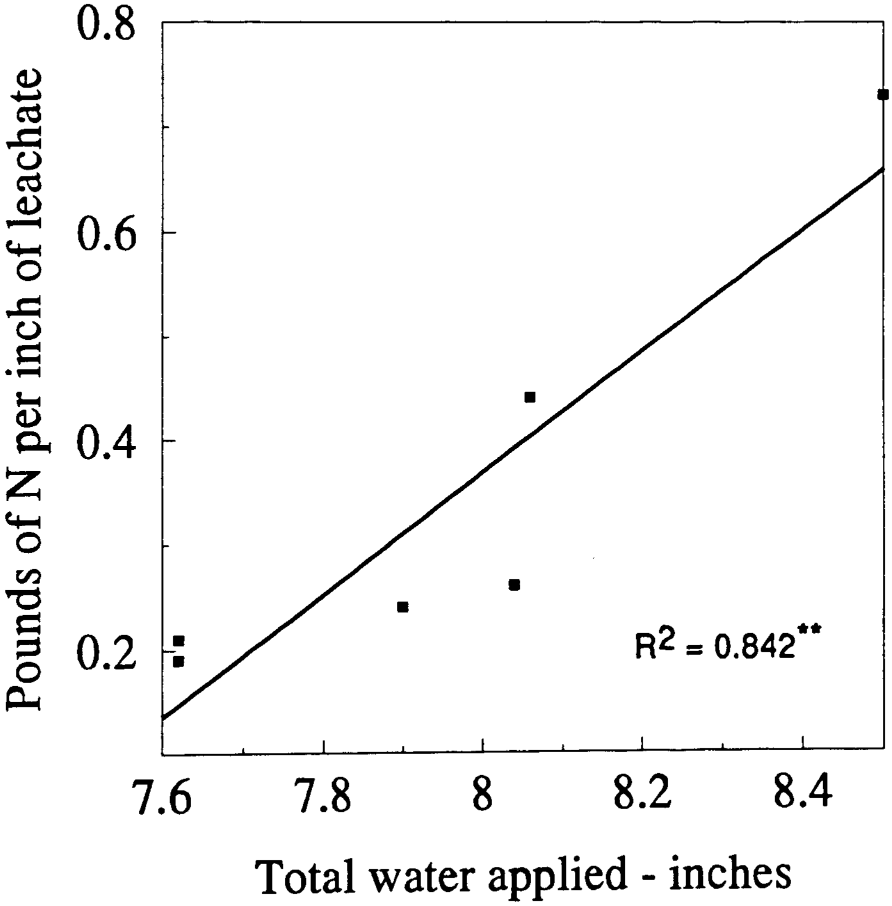

Figure 12. Relationship between total water applied (irrigation + rainfall) and pounds of N per

weight or total N content. Financial constraints limited tracking of ^{15}N-depleted ammonium sulfate to only the creeping bentgrass clippings and leachates. Significant amounts of fertilizer N would not be expected in the crown and stem material, since published values for fertilizer N recovery in root and crown tissue is typically <10% (Petrovic, 1990). Additionally, root systems are declining and not increasing in size at this time of year, making it even less remote that a large amount of fertilizer N would be found in the creeping bentgrass root and crown tissue. Amendment effects on any N transfers and storage among the various soil and plant N pools were not examined.

Root Zone Amendment Effects on P

Clipping analyses for P revealed that clippings taken from the plots whose root zones were amended with Iowa peat consistently had the highest levels of P (Table 19). The Iowa peat clippings contained significantly more P than the clippings from the fermented rice hulls and Michigan sphagnum peat greens on four or more of the sampling dates. The greens containing Wisconsin peat also produced clippings that contained relatively high P levels. Of interest is the fact that the Wisconsin and Iowa peat amendments also produced the two highest-rated greens in terms of quality ratings in 1995.

There was a statistically significant relationship (R^2 = 0.428*) between early season Bray-1 P soil test and bentgrass clipping P (Fig. 13). A stronger relationship would not be expected root zone mixes containing calcareous sands.

Table 19. Root zone mix influences on bentgrass clipping P concentrations in 1994 and 1995.

Root zone mix	1994			1995				
	6/6	7/5	8/29	6/12	6/26	7/10	7/24	8/28
	% P							
Canadian peat	0.50	0.61	0.42	0.39	0.44	0.47	0.47	0.58
Michigan peat	0.52	0.54	0.40	0.31	0.43	0.45	0.52	0.57
Reed sedge peat	0.56	0.60	0.43	0.38	0.42	0.45	0.54	0.58
Wisconsin peat	0.58	0.60	0.45	0.41	0.46	0.47	0.59	0.60
Iowa peat	0.58	0.68	0.53	0.43	0.48	0.48	0.60	0.65
Rice hulls	0.61	0.59	0.38	0.37	0.40	0.45	0.32	0.57
Isolite	0.55	0.65	0.43	0.42	0.41	0.46	0.52	0.55
WPL sand	0.54	0.58	0.45	0.42	0.43	0.45	0.58	0.59
Lycon sand	0.62	0.61	0.45	0.42	0.45	0.46	0.53	0.55
Pure sand	0.59	0.60	0.45	0.41	0.41	0.44	0.47	0.54
Duncan's LSD (p=0.05)	NS †	0.07	0.05	0.08	0.04	0.03	0.11	0.07

Date	Fertilizer P application, lb P/M	Date	Fertilizer P application, lb P/M
5/3/94	0.30	7/7/95	0.05
6/27/94	0.02	8/9/95	0.05
8/30/94	0.05	10/9/95	0.05
5/22/95	0.44	11/6/95	0.15
6/2/95	0.10		

† NS = not significant.

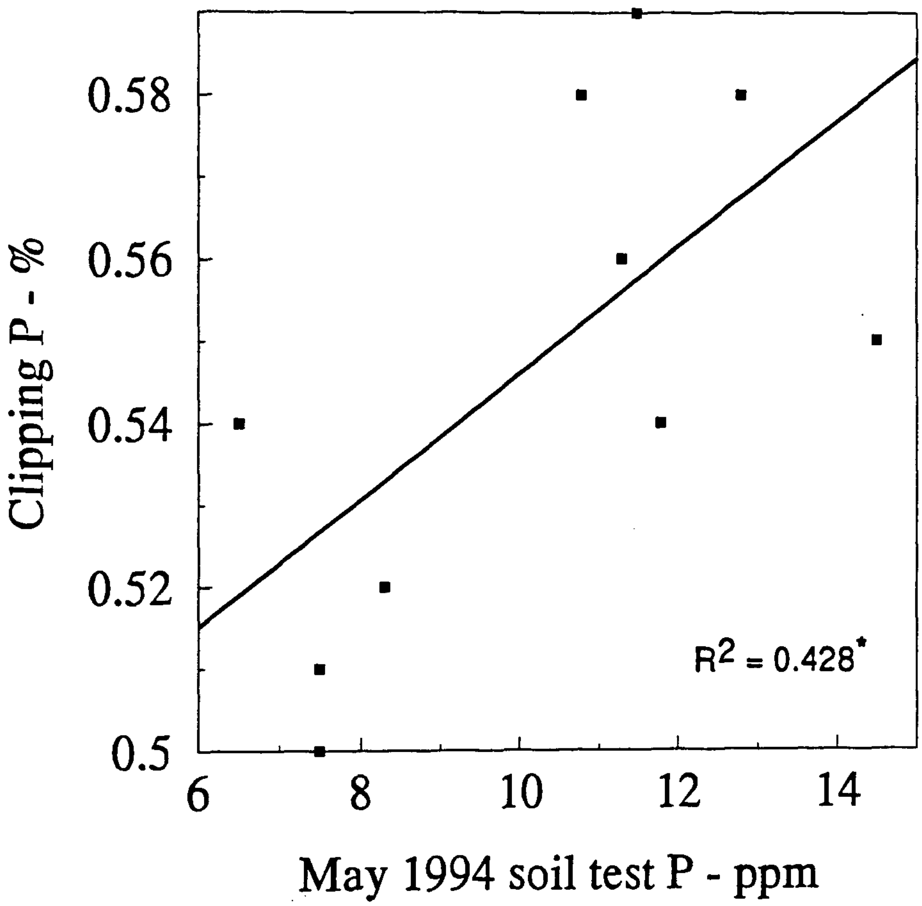

Figure 13. Relationship between bentgrass clipping P content and Bray-1 soil test P.

Soil test analyses from two sampling dates (Table 20) in 1994 revealed that the Iowa peat and Isolite amendments maintained the highest levels of Bray-1 P. To explore whether or not the use of a more acidic extracting solution would yield different results for available P levels in these calcareous sand root zone mixes, soil Bray-2 P was also measured. The greatest change in soil test P occurred with the WPL sand treatment. Using Bray-2 as an extract resulted in a mean test P level for the WPL sand treatment of 62.7 ppm, 55 ppm more than was extracted with the Bray-1 solution. For the nine other root zone mixes, the Bray-2 extract removed an average of only 8.2 ppm more P than did the Bray-1 extract. When the WPL sand was not considered, a good correlation (R^2 = 0.881) was obtained between Bray-1 and Bray-2 available P levels (Fig. 14).

Analyses of the available P throughout the four 2-inch increments showed that 48 and 50% of the available P measured was located in the top 2 inches of the root zones for the Bray-1 and Bray-2 extraction methods, respectively (Table 21). Some 20 to 24% of the P was found at the 2- to 4-inch depth. Amounts of soil test P at this depth were 25 to 74% greater than at the 4- to 6- and 6- to 8-inch depths. This is evidence that topically applied fertilizer P had migrated into the 2- to 4-inch depth of the root zone mixes.

Soil test samples taken in August 1995 of the six organic amendment treatments revealed that the Iowa peat treatment contained significantly more available P than the other five amendment root zone mixes (Table 22). Treatment and depth means of pH,

Table 20. Soil analyses for 6-inch depth samples collected in May and October 1994.

	May 1994 0-6 inches			October 1994 (0-2 inches)+(0-4 inches)+(0-6 inches)/3			
Root zone mix	pH	Bray-1 P	K	pH	Bray-1 P	Bray-2 P	K
		------- ppm ------			---------------- ppm --------------		
Canadian peat	7.8	7.5	33.8	7.7	7.2	13.3	29.2
Michigan peat	7.7	8.3	28.8	7.8	4.9	13.7	29.6
Reed sedge peat	8.0	11.3	35.0	7.9	9.5	16.8	26.3
Wisconsin peat	7.8	10.8	43.8	7.5	6.1	13.4	33.3
Iowa peat	8.0	12.8	37.5	7.5	12.9	20.9	26.3
Rice hulls	7.7	7.5	30.0	7.4	5.9	14.7	33.3
Isolite	7.8	14.5	46.3	7.7	10.8	21.8	40.0
WPL sand	8.7	6.5	41.3	8.5	7.1	62.7	39.2
Lycon sand	8.0	11.8	36.3	7.8	7.0	15.9	26.7
Pure sand	7.8	11.5	33.8	8.0	5.8	13.0	29.6
Duncan's LSD ($p = 0.05$)	0.2	2.7	12.6	0.2	4.3	22.7	14.0

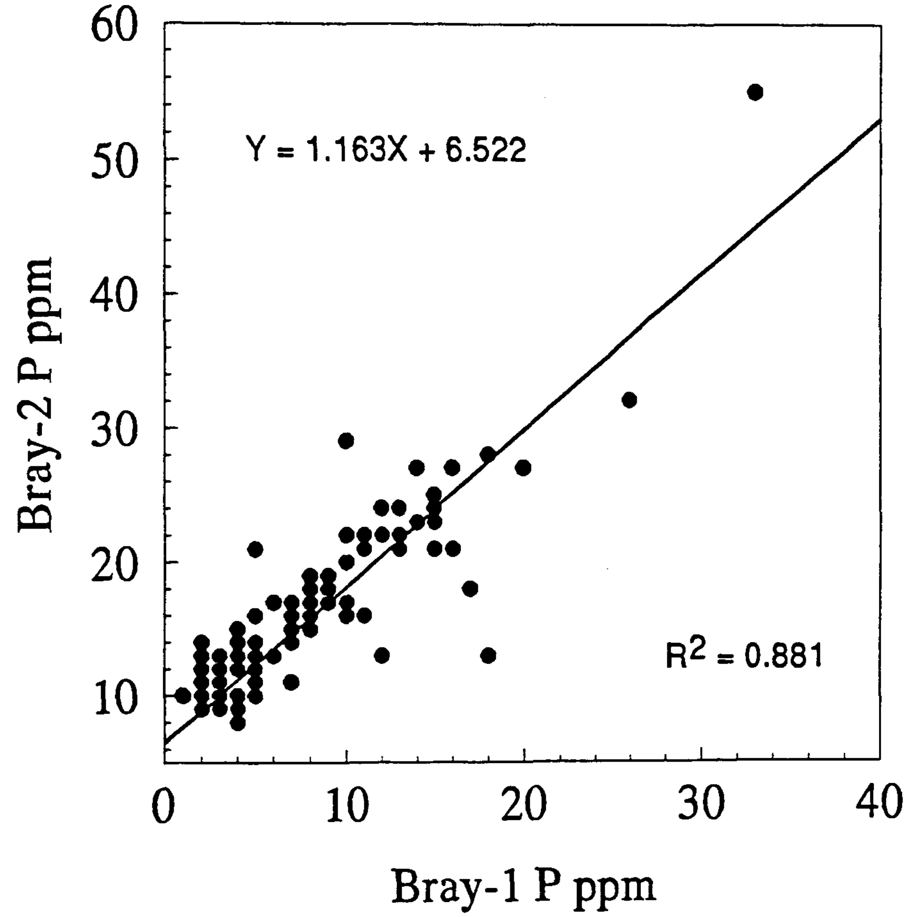

Figure 14. Relationship between Bray-1 and Bray-2 soil P levels for all root zone mixes.

Table 21. October 1994 soil analyses averaged by sampling depth over all root zone mixes.

Sample depth	pH	Bray-1 P	Bray-2 P	K
inches		-------	ppm	-------
0 to 2	7.61	13.1	37.0	48.3
2 to 4	7.82	6.82	13.8	24.6
4 to 6	7.90	3.93	11.1	21.1
6 to 8	7.98	3.90	11.0	20.6

Table 22. Soil Bray-1 P for three sampling dates.

Root zone mix	May 1994 0 to 6 inches	Aug. 1995 0 to 4 inches	April 1996 0 to 4 inches
	ppm		
Canadian peat	7.5	7.5	11.0
Michigan peat	8.3	7.8	11.5
Reed sedge peat	11.3	9.8	14.8
Wisconsin peat	10.8	9.0	14.8
Iowa peat	12.8	15.3	18.3
Rice hulls	7.5	8.3	14.8
Isolite	14.5	ND †	13.8
WPL sand	6.5	ND	10.3
Lycon sand	11.8	ND	11.3
Pure sand	11.5	ND	10.3
Duncan's LSD (p = 0.05)	2.7	3.3	3.9

† ND = not determined.

Bray-1 P, Bray-2 P, and K levels for the four 2-inch increments sampled in October 1994 are presented in Table A-9.

An intensive effort to investigate amendment and sand type effects on the status of P in root zone mixes was undertaken in 1995. Phosphorus in the amounts of 0, 10, 20, 40, and 80 mg kg^{-1} was added to the root zone mix samples and allowed to equilibrate over 24 hours. Phosphorus concentrations were then obtained by way of four different methods. These included soil test P via Bray-1 and Bray-2 extractions, labile P, and solution P (Table A-10).

Regressions of the amount of fertilizer P added on soil test P were performed for each of the different amendments to obtain estimates of the amounts of fertilizer P_2O_5 required to increase the soil test by 1 mg kg^{-1}. Ignoring the atypical WPL sand not likely to be used for putting green construction, the ratios average 2.6 and 2.7 mg P_2O_5 kg^{-1}/mg soil test P kg^{-1} for the Bray-1 and Bray-2 tests, respectively. In practical terms, either number can be used to calculate fertilzer P needs. For the Bray-1 test, the root zone mix treatment ratios of fertilizer P_2O_5 to soil test P ranged from a low of 2.1 for the Isolite treatment to 10.6 for the WPL sand (Table 22). For practical purposes, the treatments might be placed into three groups. One would be P_2O_5/soil test P values of 2.1 to 2.8; the Canadian, Michigan, Wisconsin, rice hulls, Isolite, Lycon, and Greensmix pure sand treatments comprise this group. The second group, with P_2O_5/soil test P ratios of 3.1 to 3.5, includes the reed sedge and Iowa treatments. The WPL sand and its P_2O_5/soil test P ratio of 10.6 stands alone.

The ratios of fertilizer P_2O_5 to soil test P covered a much smaller range when the P extractant was Bray-2 (Table 23). The major change in the ratios when shifting from the Bray-1 to Bray-2 extract occurred for the WPL sand. The Bray-2 extract removed more than nine times more P from the WPL sand treatment than did the Bray-1 extract. This resulted in the ratio of P_2O_5 to soil test P being reduced from 10.6 to 3.1. There were no distinct groupings of the treatments with regard to the amounts of fertilizer P_2O_5 needed to bring about a unit change in Bray-2 P.

These ratios of fertilizer P_2O_5:soil test P have management implications with regard to establishment of adequate levels of soil test P and the rate of buildup of soil P over time. Amendment type greatly influenced changes in the amounts of labile P present when the root zone mixes were fertilized with 0, 10, 20, 40 or 80 mg P kg^{-1} (Fig. 15). Although all started out with comparable labile P concentrations, the Wisconsin and reed sedge peats attained 0.5 mg L^{-1} of labile P when only 10 mg kg^{-1} of fertilizer P was added, while the Iowa and Isolite treatments did not approach this level until 80 mg kg^{-1} of fertilizer P were added. These results indicate that root zone mixes containing different amendments require different rates of phosphorus applied in the form of fertilizer to achieve a particular level of labile P.

The level of soil Bray-1 P necessary to maintain a solution P level of 0.05 ppm ranged from 4.9 ppm for the pure sand treatment to 32.9 ppm for the WPL sand treatment (Table 24). These differences are attributed to the fact that the pure sand treatment contains very little colloidal material to which phosphorus can adsorb. With

Table 23. Estimates of the amounts of phosphate (P_2O_5) required to increase soil Bray-1 and Bray-2 P by 1 mg kg^{-1}.

	Soil test P	
Root zone mix	Bray-1	Bray-2
	mg P_2O_5 kg^{-1}/mg soil test P kg^{-1}	
Canadian peat	2.6	2.2
Michigan peat	2.3	2.6
Reed sedge peat	3.5	2.8
Wisconsin peat	2.5	2.9
Iowa peat	3.1	2.0
Rice hulls	2.4	2.4
Isolite	2.1	3.0
WPL sand	10.6	3.6
Lycon sand	2.8	3.1
Pure sand	2.5	2.1

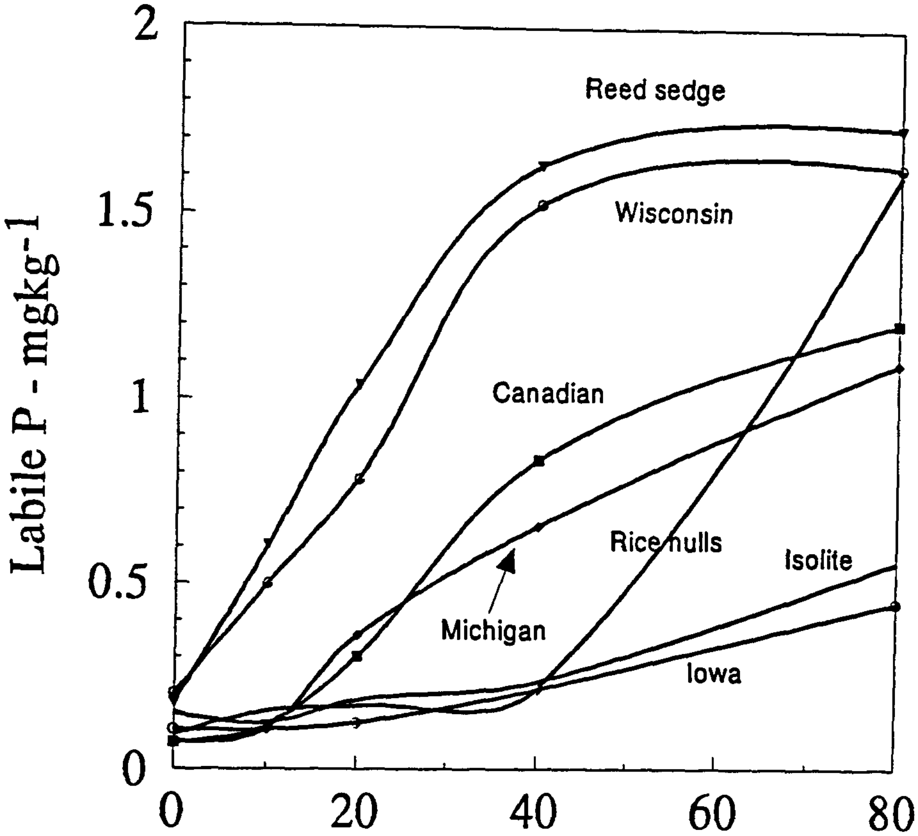

Figure 15. Amendment effects on the relationship between labile P levels and the amount of P added to the root zone mixes.

Table 24. Root zone mix composition effects on soil P status.

Sand	Amendment	Bray-1 P at 0.05 ppm solution P	P buffer power †
		----------- ppm (soil) ---------	
Greensmix	Canadian	16.4	23.2
	Michigan	20.1	8.9
	Reed sedge	19.7	28.9
	Wisconsin	16.9	4.2
	Iowa	31.8	23.0
	Rice hulls	27.2	5.3
	Isolite	10.3	5.5
	None	4.9	9.8
WPL	Canadian	32.9	14.1
Lycon	Canadian	13.6	8.4

† P buffer power = Δ Bray-1 P/Δ solution P.

the presence of a substantial amount of fine-sized soil particles, and the presence of recently precipitated $CaCO_3$, the WPL sand treatment provides an ideal environment for the adsorption of large amounts of phosphorus.

The P buffer power of each of the 10 different root zone mixes was calculated and appears in Table 24. These values were arrived at by dividing the change in soil Bray-1 P by the change in measured solution P. The Canadian, reed sedge and Iowa peats had a noticeably greater P buffer power than any of the other nine remaining root zone mixes. This occurrence is defined by these treatments' propensity to maintain a very low solution P level in relation to the large amount of P that is adsorbed onto its peat particles.

There was a strong relationship (R^2 = 0.831***) between the amounts of fertilizer P added and solution P, the amount of P extracted by way of $Sr(NO_3)_2$ from the seven different amendment root zone mixes (Fig. 16). Not including the rice hulls treatment strengthened this relationship further (R^2 = 0.968). The three root zone mixes containing Canadian sphagnum peat and either Greensmix, WPL, or Lycon sand were also examined to determine sand effects on solution P (Fig. 17). The strong relationship observed (R^2 = 0.742***) was strengthened even further (R^2 = 0.948) by not considering the WPL sand treatment.

There was a more than four-fold difference in solution P between the WPL sand and rice hulls treatments when 80 ppm of fertilizer P was added. This can be explained by differences in adsorption capacities between the two root zone mixes.

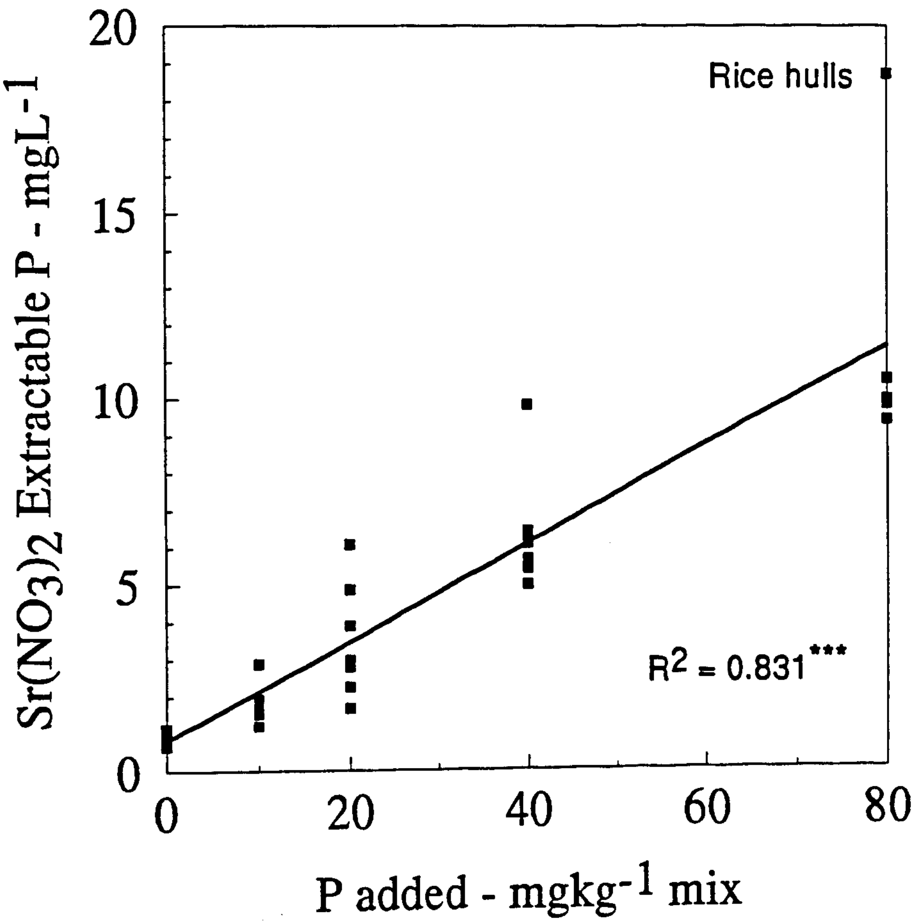

Figure 16. Amendment effects on $Sr(NO_3)_2$ extractable P.

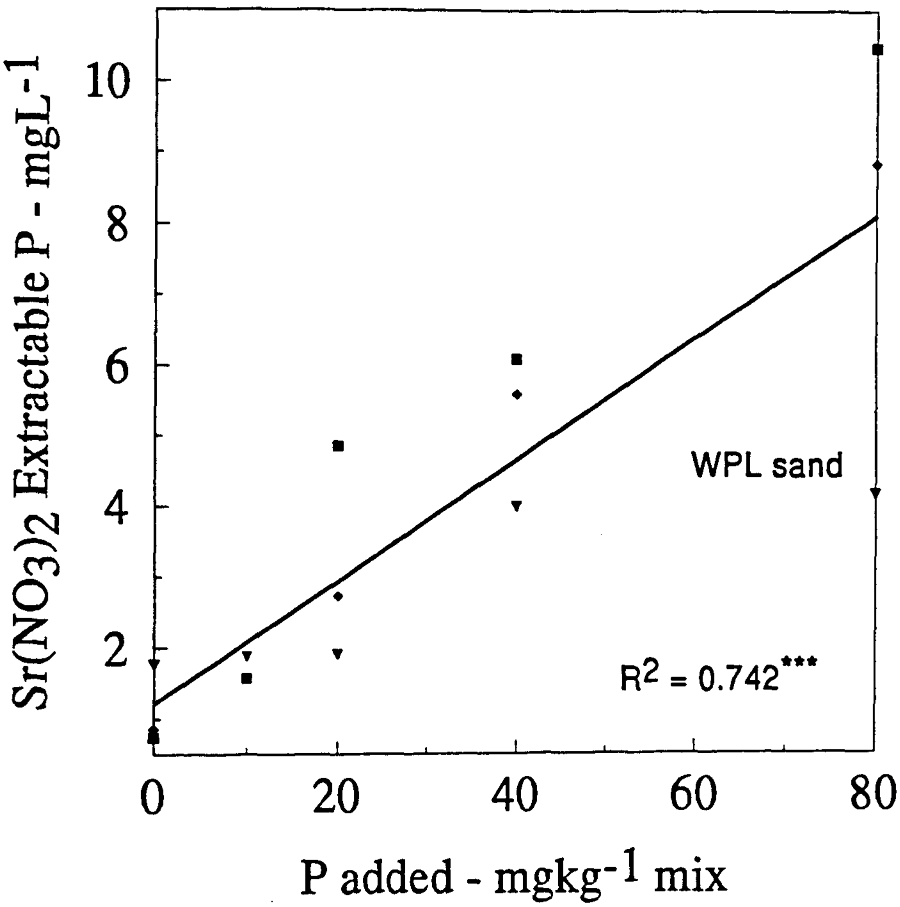

Figure 17. Sand effects on $Sr(NO_3)_2$ extractable P.

When 80 ppm of fertilizer P was added to the rice hull treatment, this exceeded its P adsorption capacity and, as a result, 18.7 ppm of solution P was measured. The WPL sand appeared to be undergoing a phase change from P adsorption to precipitation. The amount of solution P extracted was a nearly constant 4.2 ppm with additions of 40 and 80 mg P kg^{-1} of mix (Fig. 15).

Root Zone Amendment Effects on K

Significant differences in amendment effects on bentgrass clipping K were not observed during the five sampling dates in 1995 (Table 25). The only significant difference in clipping K in 1995 resulted on the last sampling date. In this instance, the straight sand root zone mix produced a significantly higher percentage of K in the bentgrass clippings than the root zone mix containing Lycon sand. Differences in clipping K by date simply reflect time of clipping collection with respect to the amount of application of fertilizer K (Table 25).

Analyses for soil K in samples collected during 1994 are shown in Table 20 (page 67). The May soil samples revealed that the only statistically significant difference between treatments was that between the Isolite root zone mix and the rice hull and Michigan sphagnum peat treatments. Regression analysis revealed that for a select group of treatments there was a weak (non-statistically significant) relationship between root zone mix CEC and soil test K (Fig. 18). On the second soil sampling date in 1994, cores from the 0- to 2-, 2- to 4-, 4- to 6-, and 6- to 8-inch soil depths were collected and analyzed for available K levels (Table A-9). Statistical analyses

Table 25. Root zone mix influences on bentgrass clipping K concentrations in 1994 and 1995.

Root zone mix	1994			1995				
	6/6	7/5	8/29	6/12	6/26	7/10	7/24	8/28
	% K							
Canadian peat	2.91	3.19	2.52	2.41	1.81	2.50	1.64	2.28
Michigan peat	3.11	3.16	2.52	2.12	1.86	2.52	1.81	2.31
Reed sedge peat	3.19	3.10	2.43	2.32	1.80	2.40	1.79	2.20
Wisconsin peat	3.30	3.11	2.50	2.54	1.86	2.52	2.00	2.27
Iowa peat	3.16	3.19	2.66	2.31	1.83	2.39	1.84	2.22
Rice hulls	2.95	2.94	2.31	2.38	1.81	2.34	1.89	2.33
Isolite	3.12	3.26	2.41	2.76	1.79	2.52	2.02	2.35
WPL sand	3.05	2.92	2.44	2.67	1.89	2.44	2.00	2.18
Lycon sand	3.37	3.15	2.45	2.65	1.82	2.41	1.77	2.09
Pure sand	3.48	3.30	2.64	2.67	1.90	2.45	1.82	2.41
Duncan's LSD (p=0.05)	NS †	0.15	0.15	NS	NS	NS	NS	0.27

Date	Fertilizer K application, lb K/M	Date	Fertilizer K application, lb K/M
5/3/94	0.11	6/2/95	0.46
6/1/94	0.83	7/7/95	0.23
6/27/94	0.09	8/9/95	0.23
7/2794	0.83	9/8/95	0.83
8/3094	0.23	10/9/95	0.23
4/22/95	0.83		

† NS = not significant.

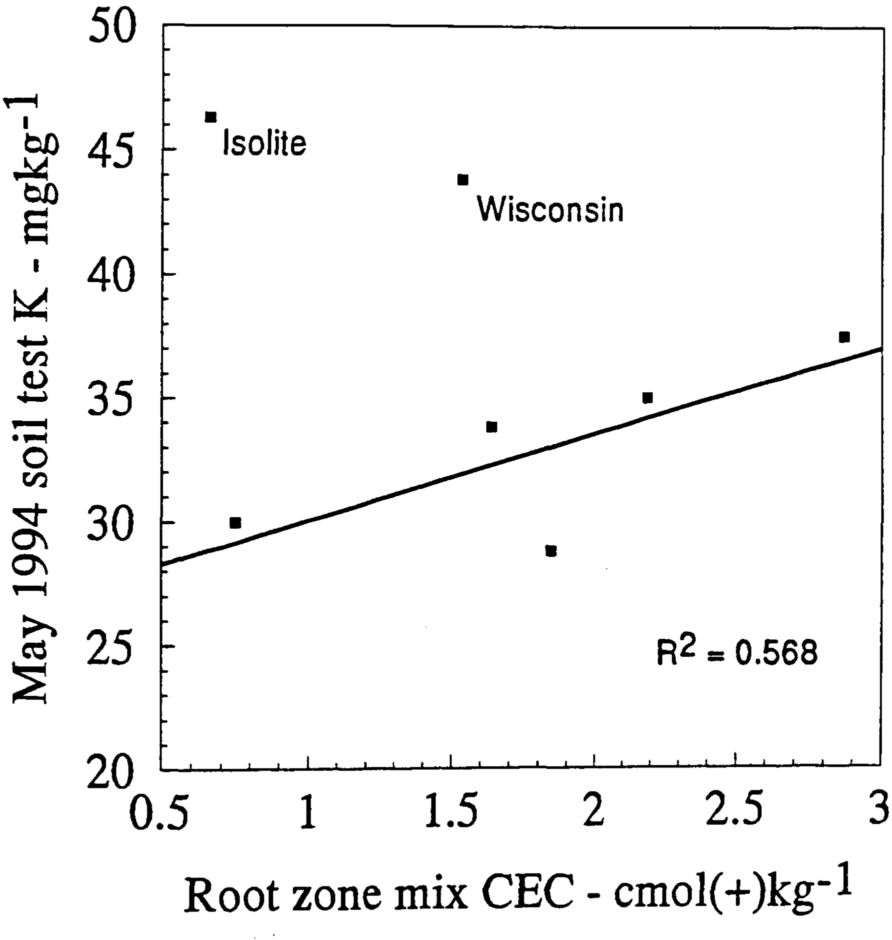

Figure 18. Amendment effects on the relationship between root zone mix CEC and soil test K.

revealed no significant differences between treatment and corresponding depth. Mean K concentrations for the four depths indicated that the Isolite treatment had significantly greater amounts of available K than five other treatments. However, since the greens containing no amendment did not contain significantly lower amounts of available K than the greens containing Isolite, it is difficult to conclude that amendment type affected retention of available K. In fact, no significant relationships were found between soil test K and root zone mix CEC, pH or water retention.

Available K levels for the four different depths of all ten treatments are presented in Table 21 (page 69). The top 2 inches of the root zone mix contained about twice as much available K as the other three 2-inch depth increments combined. While this could indicate that there was little K leaching during the growing season, it provides no solid evidence that K is not constantly being leached out of the root zone. Soil test K at the 6- to 9-inch depth in October 1993 averaged 28.5 ppm. This suggests a K loss rate of about 7.9 ppm in 12 months. Treatment and depth means for K for all 10 treatments are contained in Table A-9. Treatment soil test K levels from three samplings over the course of 2 years is shown in Table 26.

Early season soil test K was not a useful predictor of clipping K concentration (Fig. 19). This might be expected, given the fact that fertilizer K was applied five times during the season (Table 25).

When the amounts of potassium present in the exchangeable and solution forms within the various root zone mixes were compared, two distinct groupings of

Table 26. Soil K levels for three sampling dates.

Root zone mix	May 1994 0 to 6 inches	Aug. 1995 0 to 4 inches	April 1996 0 to 4 inches
	ppm		
Canadian peat	33.8	23.8	50.0
Michigan peat	28.8	31.3	51.3
Reed sedge peat	35.0	20.0	47.5
Wisconsin peat	43.8	31.3	41.3
Iowa peat	37.5	23.8	46.3
Rice hulls	30.0	28.8	51.3
Isolite	46.3	ND †	58.8
WPL sand	41.3	ND	63.8
Lycon sand	36.3	ND	33.8
Pure sand	33.8	ND	46.3
Duncan's LSD (p = 0.05)	12.6	9.2	11.7

† ND = not determined.

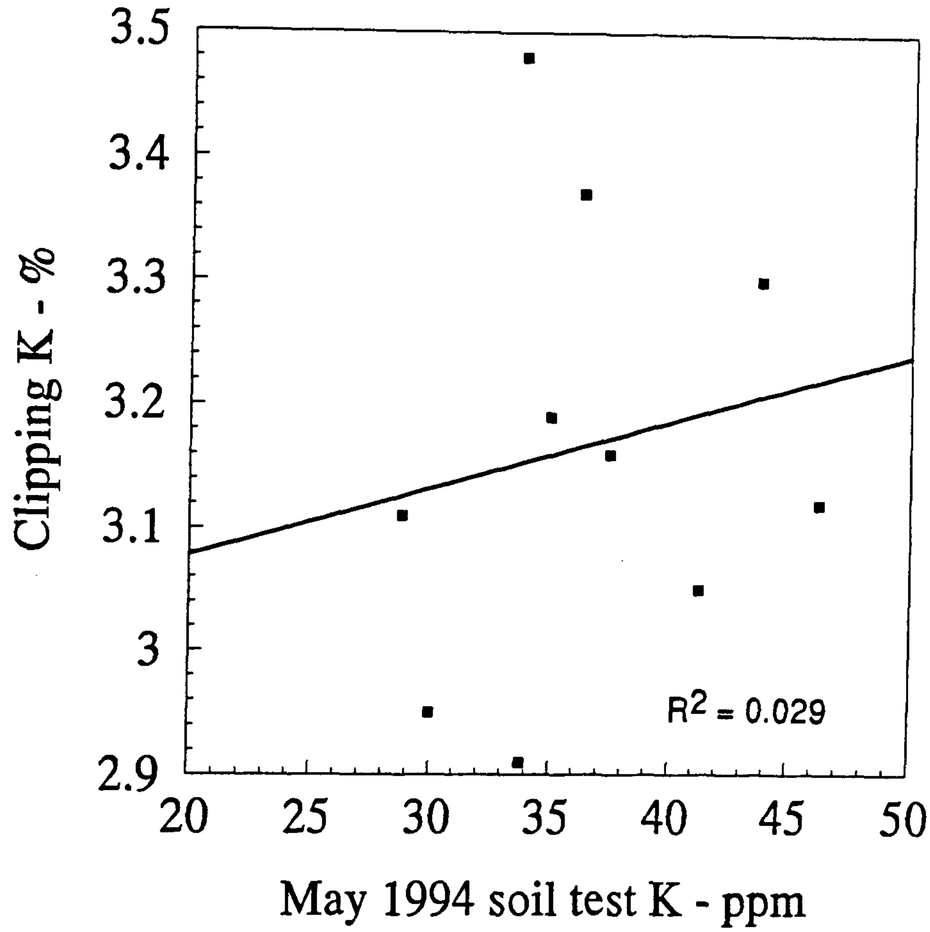

Figure 19. Root zone mix composition effects on the relationship between soil test K and bentgrass clipping K concentration.

treatments became apparent (Fig. 20). The three root zone mixes whose amendments contained high amounts of organic matter (>85%) had uniquely high equilibrium solution K levels. This can be explained on the basis that these amendments have predominantly organic-origin exchange sites, which are known to bond more strongly with Ca and Mg than with K. This results in higher concentrations of K in solution. Amendments with < 85% organic matter maintained much lower K concentrations in solution. These relationships seem to show that highly organic amendments are about three times more prone to K leaching than are the lower organic amendments with >15% mineral content. The relationship of May 1994 soil test K to root zone mix CEC (Fig. 18) provides some credibility to this statement.

The measured CEC of the ten root zone mixes appear in Table A-11. These values typify the very low CECs of root zone mixes and help explain why K leaches readily in sand-matrix putting greens. The root zone mix containing pure sand, understandably, had the lowest measured level of CEC, while the treatment containing the WPL sand with 11.4% clay + silt-sized fractions recorded the highest CEC at 6.25 cmol(+)/100 g soil. The five peat amendments were much more effective at increasing the CEC of the root zone mix than the fermented rice hulls and Isolite. The Lycon and Greensmix sands, when combined with the Canadian sphagnum peat amendment, resulted in very similar CEC levels, 1.56 and 1.64 cmol(+)/100 g soil. This illustrates the fact that root zone mix CEC, at least initially, is almost entirely dependent on the amendment added.

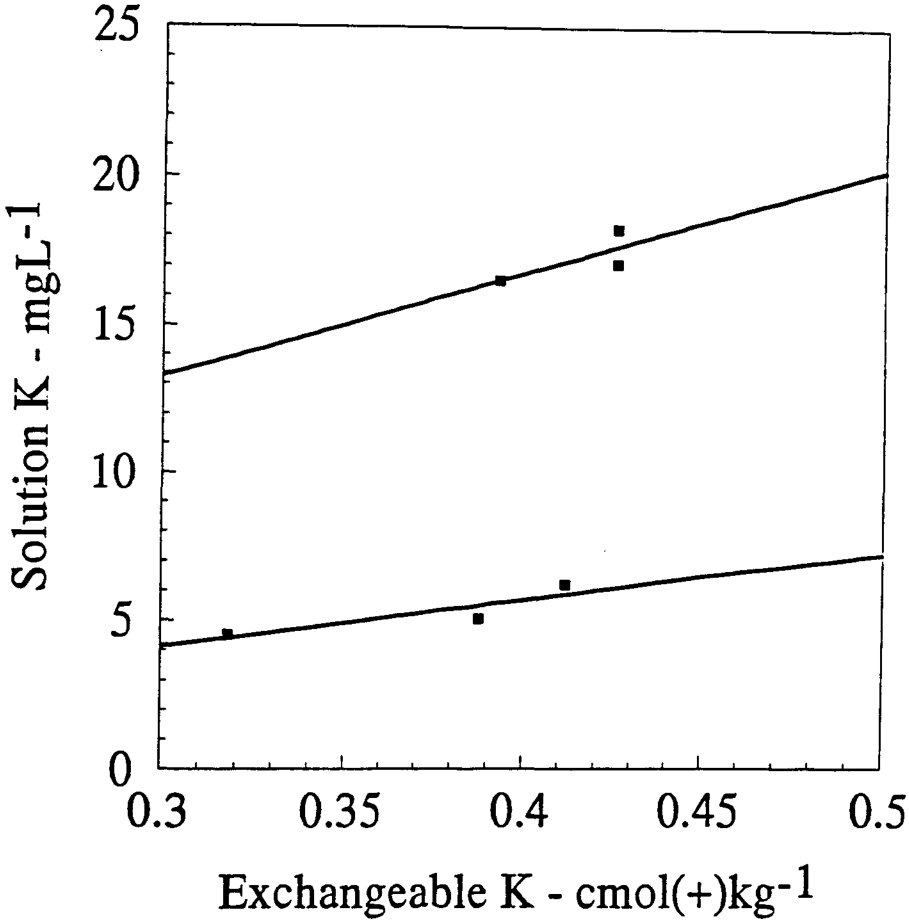

Figure 20. Root zone amendment effects on the relationship between solution and exchangeable K levels.

Secondary and Micronutrients

Table 27 shows where there were significant differences in clipping micronutrient concentrations during five sampling dates in 1995. Although there were many statistical differences, all nutrient concentrations were adequate except boron, which, according to Jones (1980), was low. Despite B levels continually less than the proposed sufficiency level of 10 ppm, boron deficiency symptoms were not observed. Laison and Love (1967) reported that boron deficiency symptoms seldom appear on creeping bentgrass. Thus, the critical level for B may be lower than suggested by Jones (1980).

Results of soil analyses for DTPA-extractable Zn, Mn, Fe, and Cu in the root zone mixes appear in Table 28. There were significant root zone treatment effects on the amounts of Zn, Mn, Fe, and Cu detected. No correlation could be found, however, between clipping concentrations of the nutrients and their DTPA-extractable levels in the root zone mixes. This may be due in part to the fact that clipping concentrations of Zn, Mn, Fe, and Cu were all adequate, but may also be an indication that the DTPA test does not reliably estimate plant available nutrient supplies.

CONCLUSIONS

The observations made during the 3 years of this study may not hold up over the long-term (10 years or more). However, all indications up to this point are that the USGA recommendation of >85% organic matter (OM) in root zone amendments is too

Table 27. Dates and nutrients for which there were significant treatment effects (Duncan's LSD, p=0.05) on clipping nutrient concentrations, 1995.

Date	N	P	K	Ca	Mg	S	Zn	B	Mn	Fe	Cu
June 12	X	X			X	X		XL†		X	
June 26	X	X		X	X	X		XL	X	X	
July 10	X	X					X	XL	X		X
July 24	X	X		X	X	X	X	XL	X	X	
August 28	X	X	X			X	X	L	X	X	X

† "L" signifies low concentrations according to Jones (1980).

Table 28. Root zone mix DTPA-extractable Zn, Mn, Fe, and Cu.

Root zone mix	Zn	Mn	Fe	Cu
	ppm			
Canadian peat	0.97	2.20	4.36	0.97
Michigan peat	0.94	2.83	4.65	0.99
Reed sedge peat	0.81	0.92	5.61	0.54
Wisconsin peat	1.01	1.65	5.23	0.76
Iowa peat	0.99	1.49	8.06	0.60
Rice hulls	1.09	2.65	3.35	0.91
Isolite	0.78	0.81	3.07	0.73
WPL sand	0.70	0.78	12.03	1.66
Lycon sand	0.83	1.33	3.20	0.66
Pure sand	0.62	0.70	1.93	0.60
Duncan's LSD ($p = 0.05$)	0.09	0.13	0.54	0.17

stringent, based on the strong performances of the Iowa peat (64% OM) and Wisconsin peat (83% OM) treatments. The added moisture and nutrient retention gained by using an amendment with >15% mineral matter appears to significantly improve putting green quality without adversely affecting infiltration or drainage.

Early in this study, it was observed that fiber content seemed to be an important consideration in the selection of a root zone amendment. Moisture retention was found to increase with decreasing fiber content, while the reverse was true for infiltration rate. Re-examination of the amendment fiber content-moisture retention relationship revealed that this may well be the result of the fact that root zone mix organic matter content is inversely related to amendment fiber content and, in turn, moisture retention is a direct function of the amount of organic matter in the root zone mix. The higher the fiber content of peat, the lower its bulk density. Thus, blending with sand on a volume basis tends to result in a lower organic matter content when the amendment has a high fiber content. There is far more logic in attributing increased water retention by root zone mixes to organic matter content per se than to the fiber content of the amendment.

The ability of a root zone mix to retain an average of 12% or more by volume helps prevent localized dry spot and greatly enhances creeping bentgrass quality. Two of the amendments studied (Isolite, and fermented rice hulls) resulted in root zones that actually retained less water than the pure sand treatment containing no root zone amendment.

The reasons for this are thought to be different for the two materials. Much of the water held by Isolite is retained at tensions > -4 MPa. When dry Isolite is added to moist sand, it actually dries down the sand. Hence, while Isolite may increase the total amount of water retained by the root zone mix, much of the water cannot be accessed by plants.

Relative to peats, the percent by weight of water retained by rice hulls is relatively low (Table 6). When blended with sand at the volume percentages used in this study (87/13), the capillary porosity of the mix (Table 5) is one-half or less that of some of the sand-peat mixes. Thus, the rice hull amended putting green was droughty and plagued with localized dry spot.

The type of root zone amendment does not consistently affect the N status of the creeping bentgrass clippings. Tracking the fate of 0.5 lb N/M of ^{15}N depleted ammonium sulfate revealed that the amounts of fertilizer N recovered in the creeping bentgrass clippings over a 28-day period ranged from 17 to 20%, and differed significantly among amendment type.

However, the reasons for the different fertilizer N recoveries appeared to result primarily from variation in irrigation rates. Some of this variation is inherent in the irrigation system and some resulted from day-to-day changed in wind direction and velocity at the time of irrigation. Over 28 days, the mean total precipitation (rainfall + irrigation) varied among the six treatment by as much as 0.88 inch. At its worst, some plots received only 32% of the daily intended irrigation water. This was sufficient variation to result in significant treatment-related effects on the amounts of soluble N leached to the 8-inch depth in the putting greens. The amounts of N leached to this depth accounted for 77% of the observed variation in fertilizer N recovery. What accounted for the remaining 23% of variation in fertilizer N recovery could not be discerned from the data collected.

Based on the foregoing observations and lack of consistent treatment effects on clipping N concentrations at various times during the growing season, the conclusion is that for the six root zone amendments studied, choice of amendment does not significantly impact on the N nutrition of creeping bentgrass. The standard practice of light, frequent fertilizer N applications on golf putting greens further mitigates against the root zone amendment having a significant role to play in the N management of putting greens.

There were implications regarding root zone amendment effects on P and K nutrition management. Perhaps for the first time, information was assembled regarding the amount of fertilizer P_2O_5 required to increase soil test P by one unit. This ratio of fertilizer P_2O_5/ppm (mg kg^{-1}) soil test P was found not to be significantly influenced by root zone amendment on soil test method (Bray-1 or Bray-2). Thus, the value of 2.6 mg P_2O_5 kg^{-1}/ppm soil test P appears to have widespread value as a management tool. The 2.6 mg P_2O_5 kg^{-1} root zone mix per 1 ppm soil test P, when applied to a root zone mix with a bulk density of 1.5 g cm^{-3}, equates to 0.029 lb P_2O_5/yd^3 of root zone mix/1 ppm soil test P. Raising the soil test P by 10 ppm therefore requires about 0.29 lb P_2O_5/yd^3 of root zone mix, or, in the top 4 inches of a putting green, 3.6 lb P_2O_5/M [(4/12 ft)(1,000 ft^2)/27 ft^3/yd^3 x 0.029 lb P_2O_5/yd^3 x 10 ppm soil test P].

While root zone amendment did not affect the amount of fertilizer P_2O_5 needed to increase soil test P, there were significant differences among the amendments with regard to what appeared to constitute an adequate level of soil test P. Application of the criteria that adequate soil test P at 0.05 ppm solution P level, leads to the conclusion that, depending on the amendment used in the root zone mix, the optimum soil test P level can range from 5 ppm (no amendment) to as much as 32 ppm for a mix containing an amendment such as Iowa peat with its 36% mineral content.

Establishment of the relationship between exchangeable K and equilibrium solution K levels in the root zone mixes clearly illustrated the problem of maintaining adequate K levels in sand-matrix putting greens. For mixes prepared with highly organic (>85% weight loss on ignition) amendments, equilibrium solution K levels were nearly three times as high as mixes prepared with amendments having mineral contents in excess of 17%. This readily explains the high mobility of K in root zone mixes composed with highly organic amendments and is a clear indication that what constitutes a sound K management system for one root zone mix is not universally applicable.

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APPENDIX A

Table A-1. Putting green quality ratings † in 1994.

Root zone mix	5/3 123	5/26 146	6/3 154	6/6 157	6/13 164	6/20 171	6/27 178	7/5 186	7/11 192
Canadian peat	5.15	7.95	7.75	8.05	8.10	8.28	8.05	7.98	7.88
Michigan peat	4.70	7.25	7.88	8.15	8.10	7.82	7.95	8.10	7.80
Reed sedge peat	5.28	7.58	7.90	8.12	8.08	8.22	8.00	8.18	7.95
Wisconsin peat	5.35	7.92	7.60	8.20	7.85	8.15	7.78	8.08	7.88
Iowa peat	5.52	7.90	7.88	8.10	8.25	8.38	8.18	8.28	7.98
Rice hulls	2.68	4.95	5.48	4.70	4.70	4.82	5.82	6.22	6.15
Isolite	3.05	5.52	6.80	5.58	5.58	5.80	6.50	7.00	6.95
WPL sand	5.52	7.85	7.80	7.90	7.90	8.08	7.78	8.18	7.58
Lycon sand	5.55	8.00	7.60	8.08	8.08	8.15	7.98	8.18	7.90
Pure sand	2.32	5.48	4.60	5.25	5.95	6.15	6.92	7.18	7.15
Duncan's LSD (p=0.05)	0.55	1.03	0.73	0.77	0.74	0.58	0.33	0.57	0.43

Root zone mix	7/14 195	7/18 199	7/25 206	8/1 213	8/8 220	8/15 227	8/22 234	8/29 241	9/7 250
Canadian peat	8.08	8.38	8.22	8.42	8.18	8.20	8.35	8.22	7.95
Michigan peat	8.08	8.20	8.28	8.32	7.95	8.38	8.22	8.18	8.15
Reed sedge peat	8.15	8.32	8.35	8.35	8.22	8.28	8.38	8.22	8.10
Wisconsin peat	7.95	8.25	8.30	8.25	8.22	8.22	8.28	8.25	8.30
Iowa peat	8.30	8.50	8.40	8.45	8.32	8.40	8.38	8.32	8.22
Rice hulls	6.28	6.80	6.78	7.02	6.85	7.42	7.38	7.05	7.40
Isolite	6.98	7.28	7.15	7.35	7.40	7.80	7.62	7.68	7.90
WPL sand	7.88	8.32	8.28	8.30	8.18	8.15	8.12	8.15	7.68
Lycon sand	8.18	8.40	8.35	8.38	8.22	8.25	8.25	8.22	8.05
Pure sand	7.60	7.98	7.90	7.98	7.68	7.80	8.12	7.85	7.75
Duncan's LSD (p=0.05)	0.38	0.28	0.35	0.27	0.33	0.51	0.47	0.46	0.21

- continued -

Table A-1. (continued).

Root zone mix	9/12 255	9/19 262	9/25 268
Canadian peat	8.22	8.10	8.08
Michigan peat	8.15	8.05	7.90
Reed sedge peat	8.28	8.05	8.10
Wisconsin peat	8.05	7.92	7.98
Iowa peat	8.15	8.02	8.10
Rice hulls	7.38	7.42	7.25
Isolite	7.75	7.60	7.32
WPL sand	8.00	7.88	7.80
Lycon sand	8.25	8.02	8.02
Pure sand	7.75	7.80	7.80
Duncan's LSD (p=0.05)	0.26	0.25	0.23

† On a scale of 1 to 9 (superior).

Table A-2. Putting green quality ratings † in 1995.

Root zone mix	5/22 142	5/30 150	6/5 156	6/12 163	6/19 170	6/26 177	7/3 184	7/11 192	7/17 198
Canadian peat	7.63	8.08	8.08	8.18	8.05	8.18	8.18	8.05	8.08
Michigan peat	7.63	7.93	7.85	7.93	7.95	8.20	8.23	8.33	8.28
Reed sedge peat	7.85	8.03	7.905	8.18	8.10	8.30	8.20	8.30	8.30
Wisconsin peat	7.80	8.05	8.08	8.25	8.15	8.33	8.25	8.35	8.30
Iowa peat	7.65	8.18	8.10	8.18	8.20	8.40	8.35	8.35	8.40
Rice hulls	7.18	7.73	7.25	7.28	7.13	7.28	7.65	7.70	7.75
Isolite	7.05	7.68	7.15	7.28	7.30	7.45	7.65	8.08	8.10
WPL sand	7.68	8.03	8.13	8.20	8.15	8.25	8.23	8.15	8.18
Lycon sand	7.60	7.95	8.00	8.05	8.08	8.20	8.15	8.30	8.28
Pure sand	7.60	7.88	7.48	7.98	7.85	7.80	7.90	7.95	7.98
Duncan's LSD (p=0.05)	0.39	0.25	0.41	0.50	0.46	0.51	0.42	0.33	0.28

Root zone mix	7/24 205	7/31 212	8/13 225	8/21 233	8/29 241	9/3 246	9/11 254
Canadian peat	8.03	8.15	8.08	7.88	8.00	7.95	7.85
Michigan peat	8.23	8.23	8.23	8.30	8.20	8.25	8.20
Reed sedge peat	8.25	8.25	8.25	8.28	8.33	8.25	8.25
Wisconsin peat	8.23	8.38	8.28	8.28	8.28	8.38	8.30
Iowa peat	8.35	8.30	8.38	8.35	8.40	8.25	8.35
Rice hulls	7.85	7.93	7.98	7.95	7.90	7.78	7.85
Isolite	8.13	7.95	7.98	8.03	8.03	7.88	7.90
WPL sand	8.20	8.20	8.08	8.15	8.10	8.08	8.03
Lycon sand	8.25	8.20	8.18	8.25	8.23	8.28	8.23
Pure sand	7.88	8.00	7.90	8.13	7.60	7.63	7.68
Duncan's LSD (p=0.05)	0.29	0.22	0.28	0.36	0.28	0.24	0.28

† On a scale of 1 to 9 (superior).

Table A-3. Quality ratings† during 1995 for putting greens with simulated golf course traffic.

Root zone mix	July 11 192	July 17 198	July 24 205	July 31 212	Aug. 13 225	Aug. 21 233	1995 mean
Canadian peat	7.75	7.83	7.83	7.83	7.48	7.70	7.73
Michigan peat	7.93	7.80	7.88	7.75	7.55	7.75	7.78
Reed sedge peat	7.85	7.93	7.95	7.88	7.50	7.68	7.80
Wisconsin peat	8.05	7.98	7.98	8.05	7.82	7.83	7.95
Iowa peat	8.05	7.98	8.03	8.03	7.78	7.93	7.96
Rice hulls	7.30	7.53	7.60	7.53	7.35	7.58	7.48
Isolite	7.53	7.73	7.75	7.23	7.10	7.25	7.43
WPL sand	7.80	7.85	7.98	7.85	7.65	7.85	7.83
Lycon sand	7.88	7.90	7.88	7.80	7.40	7.70	7.76
Pure sand	7.70	7.68	7.60	7.58	7.38	7.73	7.61
Duncan's LSD (p = 0.05)	0.40	0.33	0.34	0.45	0.53	0.45	0.35

† On a scale of 1 to 9 (superior).

Table A-4. Date and number of simulated rounds of golf imposed on putting greens in 1995.

Date	Rounds simulated	Cumulative rounds	Date	Rounds simulated	Cumulative rounds
5/24	80	80	7/7	160	2320
5/25	80	160	7/11	160	2480
5/30	80	240	7/12	160	2640
6/5	80	320	7/17	320	2960
6/6	160	480	7/18	200	3160
6/9	160	640	7/19	200	3360
6/12	160	800	7/20	80	3440
6/13	80	880	7/21	200	3640
6/14	80	960	7/24	320	3960
6/15	80	1040	7/26	200	4160
6/16	80	1120	7/27	200	4360
6/19	80	1200	7/28	200	4560
6/21	80	1280	7/31	240	4800
6/22	80	1360	8/1	200	5000
6/23	80	1440	8/10	200	5200
6/26	80	1520	8/11	240	5440
6/27	80	1600	8/14	240	5680
6/29	80	1680	8/18	240	5920
7/3	160	1840	8/21	200	6120
7/5	160	2000	8/22	200	6320
7/6	160	2160	8/23	200	6520

Table A-5. Root zone mix pH changes over a 2-year period.

Root zone mix	May 1994 0 to 6 inches	Aug. 1995 0 to 4 inches	April 1996 0 to 4 inches
Canadian peat	7.80	7.38	7.43
Michigan peat	7.65	7.48	7.38
Reed sedge peat	8.03	7.55	7.50
Wisconsin peat	7.78	7.50	7.45
Iowa peat	7.98	7.50	7.38
Rice hulls	7.68	7.30	7.50
Isolite	7.80	ND †	7.63
WPL sand	8.68	ND	8.35
Lycon sand	8.03	ND	7.70
Pure sand	7.80	ND	7.68
Duncan's LSD ($p = 0.05$)	0.21	0.14	0.13

† ND = not determined.

Table A-6. Root zone mix volumetric moisture contents in 1994.

Root zone mix	TDR probe depth (inches)	Volumetric moisture (%)		
		6/10/94	6/20/94	7/15/94
Canadian peat	2	18.1	15.1	14.0
	4	15.8	14.0	12.5
	6	16.2	14.4	14.0
	8	20.0	18.1	15.8
	10	29.2	29.4	24.2
Michigan peat	2	17.0	14.0	12.5
	4	15.5	12.9	11.5
	6	16.6	14.7	12.5
	8	18.8	18.5	15.5
	10	26.8	24.6	20.4
Reed sedge peat	2	19.2	16.2	15.1
	4	17.3	15.5	13.3
	6	18.5	17.7	14.4
	8	20.7	21.5	17.7
	10	26.8	28.3	25.3
Wisconsin peat	2	17.0	13.3	12.9
	4	14.4	12.9	11.5
	6	15.5	13.6	12.5
	8	17.7	17.3	13.8
	10	26.4	27.2	23.0
Iowa peat	2	19.2	17.3	15.8
	4	17.3	15.8	14.7
	6	19.6	17.3	15.8
	8	21.9	20.0	18.1
	10	25.7	26.8	23.4
Rice hulls	2	10.5	8.1	8.7
	4	9.5	8.1	8.4
	6	11.8	9.4	8.7
	8	13.6	12.5	10.4
	10	22.7	22.7	16.7

- continued -

Table A-6. (continued).

Root zone mix	TDR probe depth (inches)	Volumetric moisture (%)		
		6/10/94	6/20/94	7/15/94
Isolite	2	11.8	11.1	9.4
	4	12.2	10.8	9.7
	6	12.9	11.8	10.8
	8	19.3	17.8	16.0
	10	30.3	27.8	24.5
WPL sand	2	39.5	37.0	29.4
	4	39.8	39.0	34.7
	6	42.8	40.5	38.9
	8	43.4	44.1	43.5
	10	31.1	32.4	24.4
Lycon sand	2	20.0	17.3	16.2
	4	19.6	18.5	15.8
	6	21.1	20.0	17.7
	8	25.7	24.2	20.4
	10	37.9	37.0	36.7
Pure sand	2	10.1	8.4	7.4
	4	11.5	9.4	8.4
	6	12.9	11.5	10.1
	8	20.0	18.5	14.0
	10	35.9	34.0	30.3
Duncan's LSD (p=0.05)		5.1	4.5	5.3

Table A-7. Root zone mix volumetric moisture contents in 1995.

Root zone mix	TDR probe depth (inches)	Volumetric moisture (%)		
		6/1/95	7/10/95	8/28/95
Canadian peat	2	12.2	11.7	13.3
	4	10.4	11.7	12.2
	6	10.8	12.9	13.3
	8	11.8	14.4	14.0
	10	13.6	20.8	22.9
Michigan peat	2	11.2	15.1	9.9
	4	10.6	12.9	10.4
	6	11.3	13.6	10.8
	8	11.8	15.1	11.8
	10	13.8	18.5	14.4
Reed sedge peat	2	13.6	16.6	15.8
	4	12.2	14.0	13.3
	6	13.1	15.8	14.4
	8	14.9	19.2	17.7
	10	16.4	23.4	23.3
Wisconsin peat	2	10.1	15.1	12.5
	4	9.4	12.2	10.4
	6	10.1	12.5	10.7
	8	10.8	14.0	12.6
	10	13.8	21.5	18.2
Iowa peat	2	14.9	18.1	15.5
	4	12.5	15.8	14.4
	6	13.6	16.6	15.1
	8	14.2	18.1	17.0
	10	16.4	22.7	21.1
Rice hulls	2	5.1	9.1	7.5
	4	6.3	7.5	7.8
	6	8.2	8.4	9.1
	8	8.5	9.6	10.1
	10	13.5	14.4	10.2

- continued -

Table A-7. (continued).

Root zone mix	TDR probe depth (inches)	Volumetric moisture (%)		
		6/1/95	7/10/95	8/28/95
Isolite	2	6.8	11.6	9.0
	4	7.6	10.5	8.8
	6	9.7	11.1	9.1
	8	12.1	14.0	10.8
	10	19.8	17.4	12.2
WPL sand	2	28.7	29.4	28.2
	4	33.7	36.7	38.3
	6	35.4	41.0	42.5
	8	41.2	43.9	44.4
	10	24.8	27.4	19.9
Lycon sand	2	13.6	17.4	15.8
	4	13.6	15.5	13.6
	6	14.0	17.7	15.5
	8	15.5	20.0	17.0
	10	29.1	32.7	29.2
Pure sand	2	4.3	7.8	6.9
	4	6.6	7.8	6.5
	6	7.7	9.1	8.4
	8	10.6	13.7	12.4
	10	24.8	27.4	21.0
Duncan's LSD (p=0.05)		4.5	5.5	6.1

Table A-8. Daily precipitation (irrigation + rainfall) received by the research plots during the 21 days after application of ^{15}N depleted ammonium sulfate.

Root zone amendment	Rep	7/11	7/12	7/13	7/14	7/15	7/16	7/17	7/18
Canadian peat	A	0.18	0.21	0.18	0.19	0.23	1.13	0.16	0.13
Michigan peat		0.09	0.19	0.06	0.13	0.21	1.10	0.19	0.14
Reed sedge peat		0.25	0.18	0.19	0.39	0.42	1.30	0.36	0.29
Wisconsin peat		0.24	0.24	0.11	0.41	0.31	1.25	0.32	0.26
Iowa peat		0.20	0.19	0.25	0.21	0.25	1.29	0.25	0.21
Rice hulls		0.23	0.16	0.27	0.29	0.26	1.25	0.31	0.24
Canadian peat	B	0.19	0.15	0.56	0.19	0.24	1.14	0.32	0.23
Michigan peat		0.24	0.19	0.07	0.17	0.26	1.14	0.34	0.27
Reed sedge peat		0.14	0.13	0.06	0.23	0.22	1.13	0.26	0.18
Wisconsin peat		0.11	0.08	0.05	0.11	0.21	1.09	0.23	0.16
Iowa peat		0.14	0.13	0.04	0.12	0.21	1.07	0.17	0.13
Rice hulls		0.12	0.14	0.11	0.20	0.19	1.14	0.14	0.13
Canadian peat	C	0.11	0.11	0.01	0.13	0.24	1.07	0.24	0.12
Michigan peat		0.09	0.04	0.04	0.12	0.21	0.94	0.22	0.10
Reed sedge peat		0.10	0.06	0.04	0.14	0.18	1.00	0.19	0.15
Wisconsin peat		0.11	0.12	0.04	0.16	0.19	1.43	0.16	0.08
Iowa peat		0.14	0.18	0.00	0.11	0.21	1.11	0.29	0.14
Rice hulls		0.14	0.11	0.06	0.14	0.16	1.09	0.21	0.18
Canadian peat	D	0.24	0.25	0.16	0.41	0.37	1.43	0.37	0.29
Michigan peat		0.11	0.14	0.00	0.19	0.21	1.14	0.27	0.15
Reed sedge peat		0.15	0.16	0.07	0.19	0.23	1.17	0.15	0.15
Wisconsin peat		0.11	0.12	0.10	0.14	0.19	1.07	0.14	0.14
Iowa peat		0.20	0.26	0.11	0.23	0.24	1.21	0.27	0.18
Rice hulls		0.16	0.21	0.18	0.25	0.26	1.21	0.24	0.14

- continued -

Table A-8. (continued).

Root zone amendment	Rep	7/19	7/20	7/21	7/23	7/24	7/25	7/26	7/27
Canadian peat	A	0.15	1.05	0.16	1.14	0.16	0.11	0.19	0.19
Michigan peat		0.17	1.08	0.26	1.07	0.13	0.14	0.18	0.23
Reed sedge peat		0.32	1.26	0.29	1.24	0.22	0.35	0.05	0.26
Wisconsin peat		0.31	1.24	0.33	1.30	0.24	0.31	0.24	0.21
Iowa peat		0.22	1.13	0.25	1.18	0.23	0.28	0.21	0.28
Rice hulls		0.29	1.13	0.25	1.21	0.26	0.29	0.21	0.28
Canadian peat	B	0.27	1.13	0.28	1.01	0.19	0.29	0.21	0.28
Michigan peat		0.36	1.16	0.25	1.06	0.22	0.32	0.11	0.26
Reed sedge peat		0.21	1.10	0.21	1.01	0.23	0.26	0.14	0.18
Wisconsin peat		0.24	1.00	0.14	0.84	0.07	0.22	0.12	0.06
Iowa peat		0.14	0.93	0.19	0.90	0.19	0.17	0.06	0.24
Rice hulls		0.14	1.04	0.15	1.09	0.18	0.13	0.04	0.14
Canadian peat	C	0.21	0.98	0.16	0.88	0.12	0.24	0.11	0.14
Michigan peat		0.17	1.06	0.12	0.82	0.13	0.20	0.11	0.13
Reed sedge peat		0.19	0.96	0.10	0.80	0.10	0.14	0.32	0.08
Wisconsin peat		0.20	1.01	0.19	0.93	0.21	0.16	0.21	0.16
Iowa peat		0.27	0.93	0.19	0.91	0.26	0.23	0.10	0.23
Rice hulls		0.22	0.93	0.21	0.82	0.21	0.18	0.16	0.08
Canadian peat	D	0.41	1.06	0.30	1.33	0.44	0.34	0.16	0.36
Michigan peat		0.24	1.09	0.20	1.06	0.18	0.16	0.26	0.23
Reed sedge peat		0.25	1.04	0.29	1.09	0.21	0.18	0.33	0.19
Wisconsin peat		0.17	1.07	0.16	1.00	0.11	0.11	0.21	0.14
Iowa peat		0.31	0.99	0.34	1.04	0.37	0.21	0.34	0.24
Rice hulls		0.23	1.15	0.25	1.29	0.16	0.18	0.16	0.16

- continued -

Table A-8. (continued).

Root zone amendment	Rep	7/28	7/29	7/30	7/31	8/1
Canadian peat	A	1.04	0.09	0.14	0.25	0.34
Michigan peat		1.04	0.16	0.19	0.23	0.43
Reed sedge peat		1.12	0.29	0.23	0.33	0.26
Wisconsin peat		1.01	0.31	0.25	0.32	0.50
Iowa peat		1.12	0.24	0.21	0.24	0.45
Rice hulls		1.07	0.30	0.21	0.31	0.47
Canadian peat	B	1.09	0.28	0.16	0.24	0.29
Michigan peat		1.04	0.31	0.18	0.27	0.21
Reed sedge peat		0.96	0.24	0.14	0.23	0.32
Wisconsin peat		0.96	0.20	0.04	0.22	0.21
Iowa peat		0.96	0.14	0.18	0.14	0.19
Rice hulls		0.99	0.10	0.15	0.21	0.21
Canadian peat	C	0.86	0.21	0.15	0.16	0.29
Michigan peat		0.95	0.18	0.09	0.20	0.24
Reed sedge peat		0.92	0.14	0.11	0.18	0.24
Wisconsin peat		0.95	0.15	0.20	0.14	0.22
Iowa peat		0.86	0.26	0.29	0.09	0.33
Rice hulls		0.89	0.22	0.16	0.12	0.29
Canadian peat	D	1.00	0.42	0.35	0.36	0.40
Michigan peat		0.99	0.16	0.17	0.14	0.38
Reed sedge peat		1.01	0.16	0.16	0.16	0.39
Wisconsin peat		0.96	0.11	0.08	0.21	0.38
Iowa peat		1.06	0.29	0.33	0.129	0.37
Rice hulls		0.99	0.20	0.17	0.24	0.40

- continued -

Table A-8. (continued).

Root zone amendment	Mean	±	Standard deviation
Canadian peat	8.50	±	1.74
Michigan peat	7.62	±	0.92
Reed sedge peat	8.04	±	1.51
Wisconsin peat	7.62	±	1.39
Iowa peat	8.06	±	1.22
Rice hulls	7.90	±	1.37
Dunsans LSD (p=0.05)	NS †		

† NS = not significant.

Table A-9 Putting green soil analyses by depth in October 1994.

Root zone mix	Depth	pH	Bray-1 P	Bray-2 P	K
	inches		---------------	ppm	------------
Canadian peat	0 to 2	7.4	13	20	51
	2 to 4	7.8	5	11	20
	4 to 6	7.9	4	10	16
	6 to 8	7.8	4	9	15
Michigan peat	0 to 2	7.6	9	19	50
	2 to 4	7.8	3	12	19
	4 to 6	7.9	3	10	20
	6 to 8	8.0	2	11	16
Reed sedge peat	0 to 2	7.7	14	22	44
	2 to 4	7.9	9	15	18
	4 to 6	8.0	6	13	18
	6 to 8	8.1	6	13	20
Wisconsin peat	0 to 2	7.5	10	20	45
	2 to 4	7.6	5	11	29
	4 to 6	7.5	3	10	26
	6 to 8	7.6	4	10	24
Iowa peat	0 to 2	7.4	16	21	36
	2 to 4	7.6	14	24	23
	4 to 6	7.6	9	18	20
	6 to 8	7.6	7	17	24
Rice hulls	0 to 2	7.3	11	20	43
	2 to 4	7.4	5	14	33
	4 to 6	7.5	2	10	25
	6 to 8	7.6	3	11	29
Isolite	0 to 2	7.5	19	32	48
	2 to 4	7.8	9	19	40
	4 to 6	7.9	5	14	33
	6 to 8	8.3	4	12	21

- continued -

Table A-9. (continued).

Root zone mix	Depth	pH	Bray-1 P	Bray-2 P	K
	inches		----------------	ppm	-------------
WPL sand	0 to 2	8.3	17	78	76
	2 to 4	8.5	3	6	23
	4 to 6	8.7	2	4	19
	6 to 8	8.6	2	3	16
Lycon sand	0 to 2	7.7	12	19	41
	2 to 4	7.9	6	15	21
	4 to 6	8.0	4	13	18
	6 to 8	8.0	4	15	20
Pure sand	0 to 2	7.7	10	18	49
	2 to 4	8.1	4	12	23
	4 to 6	8.2	3	9	18
	6 to 8	8.4	3	10	21
Duncan's LSD (p=0.05)		0.2	4	8	14

Table A-10. Root zone mix P status after addition of P as KH_2PO_4.

Root zone mix	P added	Soil Bray-1 P	Soil Bray-2 P	Labile P	Solution P
	mg kg^{-1}	-------- ppm	---------	------- mg kg^{-1}	------
Canadian peat	0	18.86	39.85	0.07	0.744
	10	27.27	60.84	0.118	1.57
	20	31.03	61.95	0.303	4.86
	40	54.91	80.07	0.836	6.09
	80	88.53	121.84	1.206	10.47
Michigan peat	0	22.84	34.32	0.076	1.09
	10	25.5	43.16	0.108	1.77
	20	32.13	52.0	0.361	2.98
	40	50.93	80.07	0.657	6.4
	80	90.74	111.01	1.1	10.47
Reed sedge peat	0	21.07	42.72	0.176	0.88
	10	29.48	46.7	0.604	1.54
	20	35.44	45.37	1.037	2.25
	40	48.28	68.58	1.628	4.99
	80	74.15	106.81	1.734	9.79
Wisconsin peat	0	28.37	48.46	0.203	0.88
	10	30.36	54.21	0.498	1.95
	20	38.1	60.4	0.783	2.8
	40	60.88	74.54	1.523	5.4
	80	92.95	111.23	1.628	9.93
Iowa peat	0	31.03	46.48	0.105	0.98
	10	33.46	50.23	0.105	1.22
	20	37.22	46.25	0.123	1.68
	40	72.6	82.72	0.213	5.68
	80	84.1	133.77	0.451	9.93

- continued -

Table A-10. (continued).

Root zone mix	P added	Soil Bray-1 P	Soil Bray-2 P	Labile P	Solution P
	mg kg^{-1}	-------- ppm	---------	------- mg kg^{-1}	------
Rice hulls	0	18.2	38.3	0.092	1.16
	10	22.18	41.17	0.155	2.9
	20	36.55	52.66	0.169	6.09
	40	52.7	72.55	0.216	9.79
	80	92.95	113.88	1.607	18.7
Isolite	0	27.93	64.16	0.15	0.68
	10	30.58	63.05	0.123	1.81
	20	43.63	76.31	0.184	3.9
	40	58.23	86.26	0.234	6.23
	80	112.85	121.62	0.562	9.38
WPL sand	0	26.16	180.18	0.498	1.77
	10	21.74	202.28	0.731	1.87
	20	24.39	213.33	0.614	1.91
	40	26.6	235.43	0.815	3.99
	80	40.98	235.43	1.21	4.17
Lycon sand	0	22.18	43.16	0.111	0.85
	10	24.83	46.48	0.134	1.57
	20	37.22	56.86	0.245	2.73
	40	52.26	73.66	0.34	5.58
	80	84.77	99.52	0.625	8.83
Pure sand	0	17.31	36.53	0.092	0.63
	10	23.95	43.16	0.123	2.16
	20	36.55	50.9	0.195	5.13
	40	50.93	72.55	0.285	7.16
	80	90.07	122.72	0.614	13.21

Table A-11. Cation exchange capacities (CEC) for all ten root zone mixes used in the present study.

Root zone mix	CEC
	cmol(+)/100 g
Canadian sphagnum peat	1.64
Michigan sphagnum peat	1.85
Reed sedge peat	2.19
Wisconsin peat	1.54
Iowa peat	2.87
Fermented rice hulls	0.75
Isolite	0.66
WPL sand	6.25
Lycon sand	1.56
Pure sand	0.47

APPROVED: Wayne R. Kussow

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