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Research at the University of Nebraska investigated the physical and chemical changes that occur as newly built putting greens age. Shown above is the visual accumulation of organic matter as the putting green ages from years five through eight.

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PURPOSE

The purpose of *USGA Turfgrass and Environmental Research Online* is to effectively communicate the results of research projects funded under USGA's Turfgrass and Environmental Research Program to all who can benefit from such knowledge. Since 1983, the USGA has funded more than 290 projects at a cost of $25 million. The private, non-profit research program provides funding opportunities to university faculty interested in working on environmental and turf management problems affecting golf courses. The outstanding playing conditions of today's golf courses are a direct result of ***using science to benefit golf***.

Editor

Jeff Nus, Ph.D.
1032 Rogers Place
Lawrence, KS 66049
jnus@usga.org
(785) 832-2300
(785) 832-9265 (fax)

Research Director

Michael P. Kenna, Ph.D.
P.O. Box 2227
Stillwater, OK 74076
mkenna@usga.org
(405) 743-3900
(405) 743-3910 (fax)

Soil Physical and Chemical Characteristics of Aging Golf Greens

Roch Gaussoin, Robert Shearman, Leonard Wit, Ty McClellan, and Jason Lewis

SUMMARY

Since 1997, research at the University of Nebraska has evaluated the physical and chemical effects of accelerated establishment on the long-term performance of putting greens. The study's findings include:

- Water infiltration decreases as a sand-based rootzone matures. The decrease is associated with a decrease in air-filled porosity and an increase in capillary porosity over time. Total porosity, however, remains relatively constant.
- The addition of soil to the rootzone does not affect the rate of decrease in infiltration with maturity.
- The decrease in infiltration may be attributable to placement and movement of fine sand particles from topdressing sand or accumulated organic matter.
- Beyond the establishment, or grow-in year, phosphorous was the only element that accumulated in the rootzone from initial applications during establishment.
- Nitrogen and phosphorous begin to accumulate in the later years of a greens maturity indicating the potential for decreasing inputs as greens matures.

Since 1997 research at the University of Nebraska has been focused on a USGA-funded project focused on developing a better understanding of the agronomic characteristics of a sand-based rootzones as they mature. While many research endeavors may be conducted for two or three years, it is rare when a research site is evaluated for more than five years. Thanks to long-term funding commitment of the USGA and in the initial five years, the Environmental Institute for Golf and the USGA, we have been able to evaluate the long-term microbial, chemical, and physical characteristics of structured research greens ranging in age from one to eight years. The research on golf green microbial ecology has been reported in numerous publications (19, 24, 25). This article will focus on a summary of the physical and chemical characteristics of aging golf greens.

ROCH GAUSSOIN, Ph.D., Professor and Extension Turfgrass Specialist; ROBERT SHEARMAN, Ph.D., Professor and Extension Turfgrass Specialist; LEONARD WIT, Research Station Manager; TY MCCLELLAN, Graduate Student; and JASON LEWIS, Graduate Student; Department of Agronomy and Horticulture, University of Nebraska, Lincoln, NE

Experimental Set-up & Design

Research was conducted at the University of Nebraska John Seaton Anderson Turfgrass Research Facility near Mead, NE. Four experimental greens were constructed following USGA recommendations in sequential years from 1997 to 2000 (53). Treatments included two rootzones, 80:20 (v:v) sand and sphagnum peat and an 80:15:5 (v:v:v) sand, sphagnum peat, and soil (silty clay loam), and two establishment or grow-in programs, accelerated and controlled.

Establishment treatments were based on recommendations gathered by surveying golf course superintendents and a USGA agronomist with experience in establishing putting greens. A consensus of their recommendations for establishment treatments can be found in Table 1. The accelerated establishment treatment included high

An important part of managing successful putting greens is managing the organic matter build-up that occurs above the original rootzone.

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Applications	Establishment Treatment							
	Accelerated				Controlled			
	N†	P	K	STEP‡	N	P	K	STEP
	(lbs 1000 ft^2)							
Pre-plant§	6	1.5	3.2	16	3	0.75	1.6	8
Post plant	5	1.5	3	2.3	1.2	4.2	0.75	2.3
Total	11	3	6.2	18.3	4.2	7.5	1.2	10.3

†Amounts are actual N, P and K.

‡Micronutrient fertilizer with analysis 12Mg-9S-0.5Cu-8Fe-3Mn-1Zn.

§Pre-plant was incorporated into upper 8 cm of the rootzone prior to seeding. Analyses for fertilizer sources applied were 0N-0P-0K (STEP), 16N-11P-10K, 15N-0P-24K, and 38N-0P-0K.

Post plant fertilizers applied during the growing season.

Total application amounts during the establishment year.

Table 1. Establishment year treatments on USGA putting greens at John Seaton Anderson Turfgrass Research Facility near Mead, NE from 1997 to 2000.

nutrient inputs and was intended to speed turfgrass cover development and readiness for play. The controlled establishment treatment was based on agronomically sound turfgrass nutrition requirements.

Pre-plant fertilizer was incorporated into the top three inches of the rootzone prior to seeding. Analyses for pre-plant fertilizers applied were16N-11P-10K, 15N-0P-24K, 38N-0P-0K, and 0N-0P-0K (STEP). STEP is a micronutrient fertilizer with an analysis of 12Mg-9S-0.5Cu-8Fe-3Mn-1Zn. Plots were seeded with 'Providence' creeping bentgrass (*Agrostis stolonifera* Huds.) at 1.5 lbs per 1000 ft^2. Post-plant fertilizers were applied during the growing season and had analyses of 0N-0P-0K (STEP) and 16N-11P-10K. During the establishment year, the total amount of N, P, and K of the accelerated establishment treatment was two and four times the amount of the controlled establishment treatment for pre-plant and post-plant, respectively (Table 1).

All construction materials were tested by Hummel & Co, Inc. (Trumansburg, NY) and met USGA recommendations for putting green construction (53). The first putting green was constructed in late summer of 1996. The rootzones were allowed to settle over the winter and seeded May 30, 1997. The same procedures were used for construction and seeding of subsequent greens in 1998, 1999, and 2000.

Following the establishment year, management practices applied to the putting greens did not differ and were maintained according to regional recommendations for golf course putting greens. Plots were mowed at 0.125 inch with annual fertility applications of N, P, and K at 3.5, 2 and 3.5 lbs/1000 ft^2, respectively. Management practices included sand topdressing as: (1) light, frequent during the growing season every 10 to 14 days at a rate relative to turfgrass growth, combined with vertical mowing and (2) heavy sand topdressing twice annually (spring and fall) at a rate sufficient to fill coring holes (0.5-inch diameter spaced 2x2 inches). Traffic stress was applied three times weekly using modified greens mower rollers with golf spikes attached to the rollers.

Soil Physical Characterization Data Collection

Rootzone infiltration was determined *in situ* yearly in October with a thin-walled single-ring infiltrometer at three locations per plot.

Measurements were taken as described in Bouwer (7). Undisturbed soil cores were obtained and analyzed for infiltration using physical property testing procedures (6, 17, 27). Grass and thatch were removed. Bulk density and capillary porosity data was collected as described in Danielson and Sutherland (17).

Chemical Characterization Data Collection

Soil samples were obtained annually from 1997 to 2003 from putting greens. Soil samples were collected to a 3-inch depth in the fall of each year with a 1-inch diameter soil probe. Thatch was removed from all samples.

Soil samples were air-dried prior to chemical analysis. Chemical analyses were performed and analyzed for pH (38), electrical conductivity for total soluble salts (41), organic matter (OM) (44), nitrate-nitrogen (NO_3-N) (28, 42), phosphorus (10), potassium, calcium, magnesium, and sodium (12), sulfur (22), zinc, iron, manganese, and copper (33), and boron (4). The cation exchange capacity (CEC) of each sample was obtained by summing the exchangeable cations (49).

Results

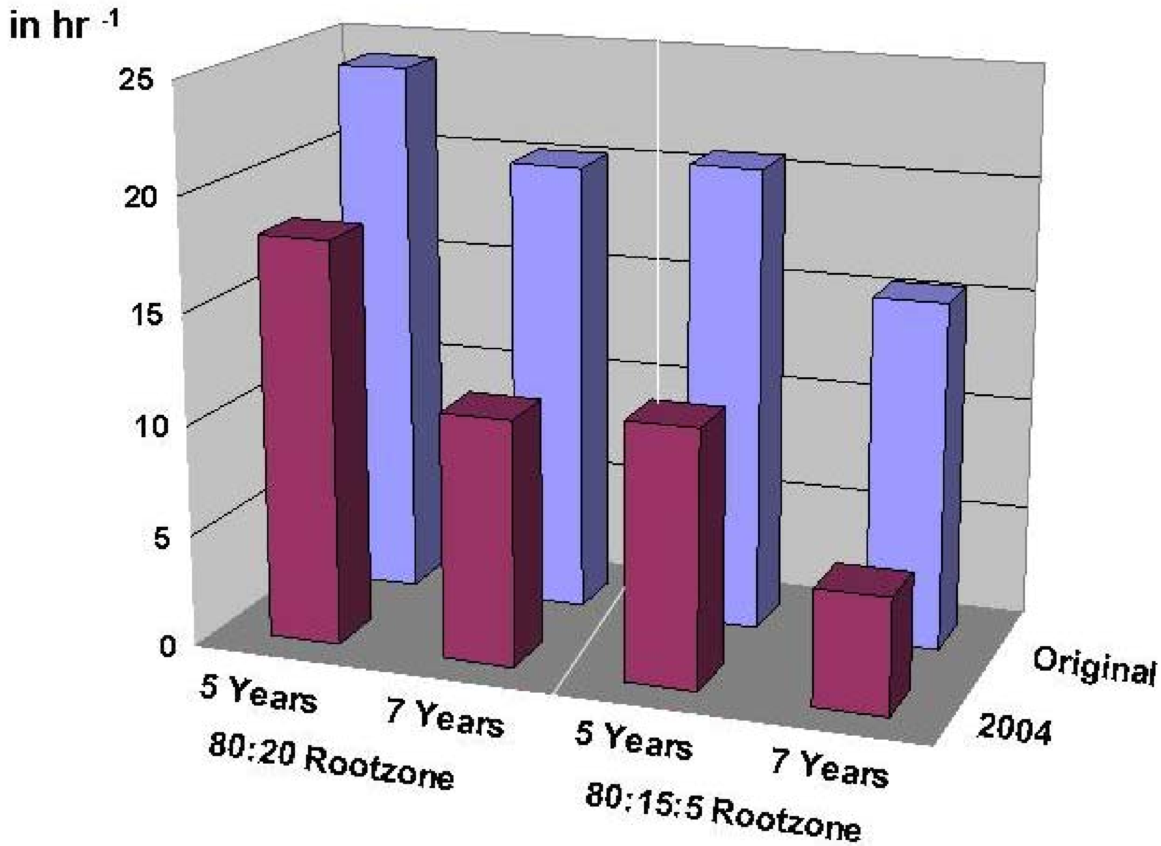
Soil Physical Characterization

After the grow-in year, rootzone treatment influenced soil physical properties while establishment treatments did not. Air-filled porosity (i.e. large pores), capillary porosity (i.e. small pores), total porosity (i.e all pores), bulk density, and infiltration were significantly correlated with rootzone age for both rootzones. All soil physical properties demonstrated the same rate of change (slope) with age between the two rootzone treatments. Capillary porosity was correlated with rootzone age (increased as green aged), and increased 53% and 60% for the 80:20 and 80:15:5 rootzones, respectively. Air-filled porosity was negatively correlated (decreased as green aged) with rootzone age and decreased 28% for the 80:20 rootzone and 34% for the 80:15:5 rootzone.

Others have reported similar increases in capillary porosity and decreases in air-filled porosity in aging putting green rootzones. Habeck and Christians (21) reported an increase in capillary porosity and a decrease in air-filled porosity from clay contamination. Ok et al. (40) reported a 220% increase in capillary porosity and a 60% decrease in air-filled porosity three and one-half years after establishment due to changes in the pore size distribution and thatch accumulation. Murphy et al. (39) reported that air-filled porosity decreased as organic matter increased. McCoy (36) reported that decreases in air-filled porosity often resulted in decreased infiltration.

Infiltration was decreased as the greens matured. Infiltration declined 70% for the 80:20 rootzone, while the 80:15:5 rootzone declined 74%. The soil amended rootzone, 80:15:5, initially had a lower infiltration than the 80:20 rootzone, however both declined at similar rates. Our findings support Waddington et al. (56), who reported lower infiltration for rootzones amended with soil. Also, several researchers have documented decreases in infiltration concurrent with changes with rootzone soil physical properties over time (16, 20, 21, 39).

Reductions in rootzone infiltration have been attributed to contamination from silt (0.002-0.05 mm) and clay (< 0.002 mm) particles, (13, 21) fine particle migration, (13) and organic matter layering (16). Our data indicates no increase in clay accumulation or clay migration. In addition, the soil-amended rootzone infiltration, while initially lower, did not decline at a faster rate than the rootzone without soil. Curtis and Pulis (16) reported that infiltration declined from 95 cm hr^{-1} to 3.1 cm hr^{-1} three years after establishment because of organic matter layering in the rootzone. In our study, the light frequent sand topdressing applications may explain the relatively slow decline in infiltration as no layering was present in the rootzones. Surface organic matter accumulation has been reported to cause reduction in infiltration of putting green rootzones (16, 21, 39, 41). In our study, a mat layer did develop, but



Infiltration of two rootzones five and seven years after construction. Samples for infiltration analysis were obtained below the mat layer in the original rootzone for all data.

data were not collected on the amount or rate of accumulation.

Rootzone samples taken in 2004 from below the visible mat layer had lower infiltration than the preconstruction infiltration values. The infiltration decline with age may have resulted from increased fine sand amounts and decreased coarse sand in the rootzone. The rootzone samples taken in 2004 had increased fine sand amounts in six of the eight rootzones, and decreased coarse sand amounts in five of the eight rootzone sampled, compared to the preconstruction rootzones.

These changes likely originated from the sand topdressing applications. The USGA recommends that topdressing sand meet rootzone particle size distribution (54). The topdressing sand used in our study met USGA specifications, however, it had had a higher amount of fine sand (0.25 - 0.15 mm) particles, and less coarse sand (0.5 - 1.0 mm) than the sand used in the original rootzones. The fine sand particles may have been placed into the rootzone during core cultivation, especially during the first two years.

Zontek (58) and Vavrek (55) reported that the long-term effects of sand topdressing on putting green soil physical properties are not well-defined. The decline in rootzone infiltration may be attributed to the increased fine sand content of the rootzone. However, the decline in infiltration due to increased fine sand content does not completely explain the reduction of infiltration. Organic matter accumulation may account for the decrease, but was not measured in this study.

Bulk density was correlated with rootzone age (increased as green matured), and increased 4% for the 80:15:5 and 6% for the 80:20 rootzone after the establishment year. Total porosity was negatively correlated with rootzone age and decreased 5% for the 80:20 rootzone and 7% for the 80:15:5 rootzone. An increase in bulk density is expected to be related to a decrease in total porosity. Compaction may account for the observed increased bulk density and decreased total porosity.

Few studies have reported changes in bulk density and total porosity with rootzone age. Ok et al. (40) reported minimal change in bulk density and total porosity over three years. Habeck and Christians (21) reported a decrease in bulk density with age, but concluded that this data was not as expected because their samples were contaminated with thatch. Murphy et al. (39) reported an increased total porosity with age, which may have been the result of sampling different locations. Bulk density was not reported in that study.

Chemical Characterization

USGA rootzone mixes comprised of 80:20 (sand:peat) generally were not significantly different from 80:15:5 (sand:peat:soil) during the establishment year or beyond for chemical properties investigated. For the purpose of clarity, establishment year and grow-in year will be used synonymously throughout this discussion.

During the grow-in year, all but four of the chemical properties investigated were significantly greater for the accelerated grow-in treatment when compared to the controlled grow-in treatment. Boron, organic matter, and sodium were also higher in the accelerated grow-in treatment, but these differences were not significant. Only pH was lower in the accelerated grow-in treatment during the grow-in year. This was likely caused by an acidification effect from increased fertilizer inputs containing ammonium-nitrogen and sulfur, both known to lower soil pH (3, 18, 29, 35, 51, 56, 57).

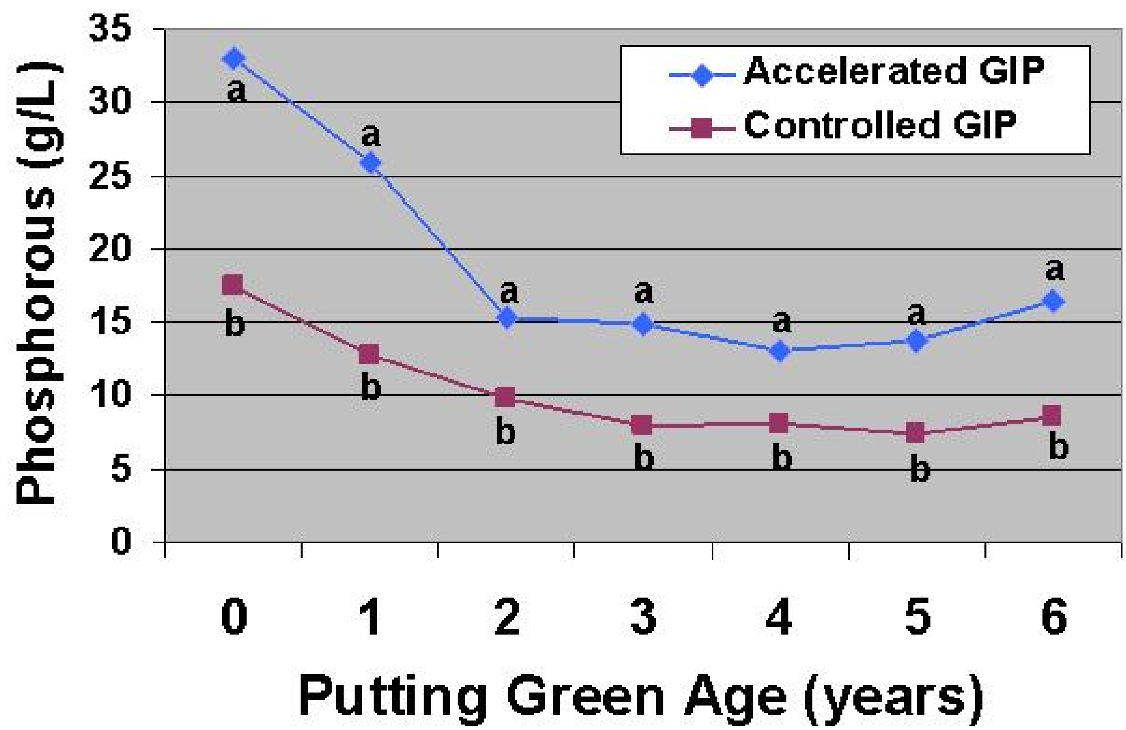
All USGA-recommendation putting greens receiving increased amounts of phosphorus during the first year of establishment retain significantly more phosphorus beyond establishment. This relationship was not evident for any other nutrients investigated. Phosphorus retention likely occurred because it is relatively non-mobile even in high-sand soils and thus does not readily leach (31, 35, 43, 51, 52). Furthermore, sands used in construction of these greens were calcareous sands with an alkaline pH. Alkaline conditions have been found to further contribute to limited mobility of phosphorus because alkalinity increases the tendency of phosphorus to form complexes with other elements in the soil and is less soluble for plant uptake or leaching (2, 35, 37, 50).

Calcium carbonate in calcareous soils may also limit the mobility of phosphorus because calcium, in the presence of $CaCO_3$, bonds with phosphorus and forms insoluble calcium phosphates (2, 30). In a two-year study on a sand-based putting green with a soil pH of 8.0, phosphorus was found to increase rapidly in the soil after only one to two years of annual fertilizer applications (8). For this reason, slightly alkaline soil conditions and calcareous sands may have contributed to phosphorus retention in the putting green rootzone compared to other nutrients investigated.

Conversely, several studies have observed considerable phosphorus leaching through sand-based systems (1, 26, 45, 46). However, researchers in their respective studies attributed phosphorus leaching primarily to the turfgrass being immature during the establishment year when roots were unable to adequately absorb phosphorus from the soil, excessive rates of phosphorus fertilization, or increased irrigation, high rainfall events, or both (1, 26, 45).

High soil pH can also limit the solubility of other nutrients in addition to phosphorus, including iron, manganese, copper, boron, and zinc (2, 15, 35, 50). Iron, copper, and zinc, all of which exhibit varying degrees of solubility and mobility in soils, were also observed to be consistently higher beyond the establishment year for greens receiving the accelerated grow-in treatment, although these differences were not always significant for iron, copper, or zinc.

Nitrate-nitrogen (NO_3-N) is highly soluble and very mobile in soils (47). Numerous studies have documented NO_3-N detection in leachates from sand-based turfgrass rootzones (9, 11, 34,



Grow-in treatment generally had no effect beyond the grow-in year. Only phosphorus remained higher for greens receiving increased inputs via the accelerated fertility program.

45, 46, 48). As expected, NO_3-N in our study was not retained beyond the grow-in year for rootzones receiving the accelerated grow-in treatment when compared to rootzones receiving the controlled grow-in treatment .

Other relatively mobile nutrients that are readily lost by leaching include potassium and sulfur, particularly in sulfate form (2). Both are highly soluble in the soil solution, and in the case of potassium, highly exchangeable on exchange sites of colloidal surfaces, causing them to less likely be adsorbed by soil particles or taken up by roots (23, 35). It is speculated that greens receiving the accelerated grow-in treatment in this study may not have retained potassium, sulfur, or other mobile nutrients because the amount supplied exceeded turfgrass demand.

Putting green establishment year comparisons, when compared among the four experimental putting greens (i.e., green constructed in 1997 vs. 1998, etc.), were significant for all but three chemical properties investigated. While all four experimental putting greens were constructed in the same way from 1997 to 2000 and all met USGA rootzone recommendations, they were not constructed with exactly the same rootzone material each year and therefore were not identical (32). Results from this study suggest that USGA recommendation putting greens are also not the same in regard to nutritional status as evident by the variability between these four USGA experimental putting greens and the significant differences for nearly all chemical properties investigated.

All nutrients and chemical properties investigated, excluding pH and potassium, generally decreased following the grow-in year, but began to increase several years later. Increased chemical properties and nutrient retention may be explained, at least in part, by the development of a mat layer. Mat development was observed, although not measured, in the upper region of putting green rootzones in this study, particularly as putting greens increased in age.

Beard (2) and Carrow (14) define mat as an organic zone, or layer, that is buried below the soil surface and comprised of partially decomposed thatch. Organic matter in the mat is intermixed with soil from sand topdressing. Organic matter enhances nutrient retention and cation exchange capacity in high-sand rootzones (5). As such, mat development and organic matter accumulation in our study likely contributed to increased chemical properties, such as CEC, and nutrient retention in older putting greens.

In summary, the 80:20 (sand:peat) rootzone mix was generally not chemically different from the 80:15:5 (sand:peat:soil) during or beyond the establishment year. Additionally, Lewis (32) found that rootzone generally had no effect on turfgrass establishment or quality ratings for putting greens used in this study. Since rootzone mix generally had no effect, incorporating soil into the rootzone may be a more economical alternative than peat when used as an amendment in USGA greens.

Conclusions

Soil Physical Characterization

After eight years, rootzone infiltration remained acceptable. There was no apparent negative response from the addition of soil to the rootzone. The change in soil physical properties was, in part, the result of fine sand accumulation from topdressing sand. Fine sand accumulation from topdressing applications resulted in increased capillary porosity, decreased air-filled porosity and infiltration. Future studies of organic matter dynamics are needed as their influence on soil physical properties are not well defined or, in some cases, contradictory in the turfgrass literature. While this research investigated physical dynamics of sand rootzone as they age, minimal organic matter data was obtained.

Soil Chemical Characterization

During the grow-in year, all but four of the chemical properties investigated were significantly higher for the accelerated grow-in treatment compared to the controlled grow-in treatment. Only soil pH was lower in the accelerated grow-in treatment compared to the controlled grow-in treatment. Excluding phosphorus, establishment treatment generally had no effect beyond the grow-in year. Only phosphorus remained higher for greens receiving increased inputs via the accelerated fertility program. Furthermore, Lewis (32) reported that the accelerated establishment treatment did not speed turfgrass establishment for putting greens investigated in this study. In fact, rootzones receiving the accelerated establishment resulted in reduced creeping bentgrass quality ratings due to increased incidence of Pythium foliar blight (*Pythium sp.*) injury.

Increased fertilizer inputs during the establishment year may not be feasible or environmentally responsible since they had negative effects on turfgrass establishment and these rootzones did not retain these inputs over time compared to the controlled grow-in treatment. Additionally, since the rootzone containing soil was essentially equal to the rootzone without soil, incorporating an appropriate, locally available soil into the rootzone may be a more economical alternative than peat when used as an amendment in USGA greens.

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