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Researchers at North Carolina State University tested various inorganic amendments and sphagnum peat for their ability to inhibit nitrogen leaching of sand-based mixtures when soluble fertilizers were applied.

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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***.

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Inorganic Soil Amendments Limit Nitrogen Leaching in Newly Constructed Sand-based Putting Green Rooting Mixtures

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SUMMARY

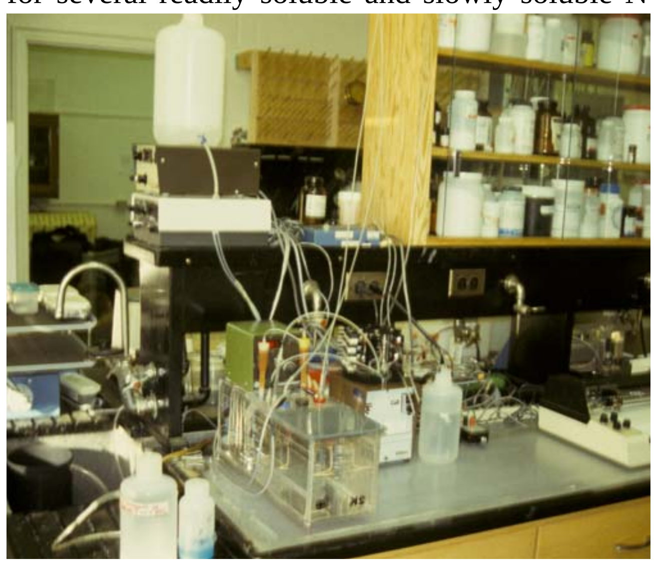
Sand-based rootzones (> 80% by volume) are most often specified for modern golf course putting greens because they resist compaction and maintain drainage and air-filled porosity even under heavy traffic. Although sands provide favorable physical properties, nutrient retention is generally poor and soluble nutrients like nitrogen (N) are prone to leaching which can pollute the environment. Laboratory experiments were conducted at the North Carolina State University to evaluate several commercially available inorganic soil amendments: clinoptilolite zeolite, diatomaceous earth, two porous ceramics varying in cation exchange capacity (CEC), and sphagnum peat moss for their ability to limit N leaching in newly constructed sand rootzone mixtures. Findings include:

- All amendments significantly decreased ammonium (NH_4^+) leaching when incorporated at the 20% by volume rate. Ammonium losses could be decreased 27% to 88%, compared to unamended quartz sand and effects were directly proportional to the CEC of the amendments.
- Nitrate (NO_3^-) losses were consistently high, and no amendment effectively decreased loss compared to unamended sand.
- Clinoptilolite zeolite and a calcined porous ceramic, which had the highest CECs, were selected to further study the effects of amendment incorporation rate and depth on N leaching. At the 10% amendment rate, only 17% to 33 % of applied NH_4^+ leached from the amended sands and uniform distribution through the entire 12-inch rootzone depth was more effective than placement within the upper 1 or 6 inches.

Most modern golf course putting green root zones are constructed using high sand contents, sometimes 90% or more by volume. Sand is used because it resists compaction, maintains drainage and air-filled porosity, even under heavy traffic. Additionally, it is a relatively inexpensive material and readily available most anywhere.

Although sands provide favorable physical properties, nutrient retention is generally poor and water soluble nutrients like nitrogen (N) are prone to leaching. Putting greens often receive as much N as 6 to 8 lbs. of actual N per 1000 ft^2 annually using highly soluble sources like ammonium nitrate, ammonium sulfate, or urea. During turfgrass establishment, N applications of 10 - 12 lbs. of actual N per 1000 ft^2 are not uncommon (1). Thus, the combination of soluble N applications, porous media, and the necessity for regular irrigation during seedling establishment creates the potential for significant N leaching losses (5).

It is well documented that a dense mature turfgrass system is very effective in capturing N. Mancino and Troll (14) monitored leaching losses of nitrate (NO_3^-) and ammonium (NH_4^+) nitrogen for several readily soluble and slowly soluble N



In laboratory column tests, ammonium nitrogen appeared rapidly in the effluent from all rootzone media with peak concentrations occurring at approximately 0.5 pore volumes.

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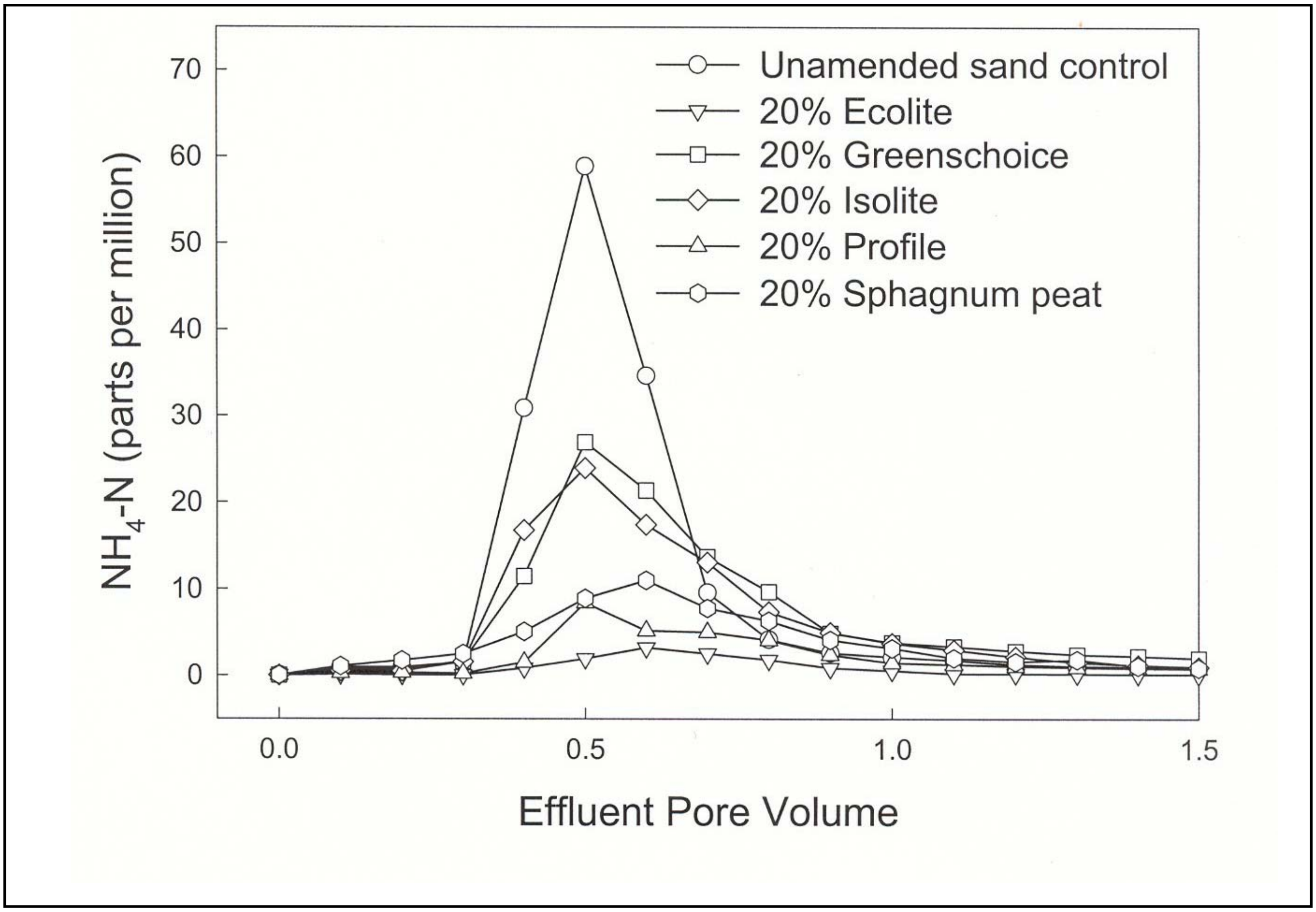

Figure 1. Concentration of ammonium in the leachate of unamended quartz sand and sand amended with inorganic soil amendments and sphagnum peat at 20% (by volume)

fertilizers on 10-month-old creeping bentgrass (*Agrostis palustris* Huds.) grown in a sand medium amended with 20% sphagnum peat. They reported that less than 0.5% of applied N leached, even when irrigated at moderately heavy rates. Nitrate-N was the major form leached while NH_4^+-N losses were negligible. Miltner et al. (16) found that an established turf was very effective for retaining N in the rootzone. They grew Kentucky bluegrass (*Poa pratensis* L.) on a fine sandy loam and reported that only 0.23% of applied labeled fertilizer N leached over a two-year period.

While there may be low potential for NO_3^--N leaching from mature turfgrass systems, the same is not true for immature turfgrasses common to new establishment or renovation situations. Frequent light irrigation is required to ensure seedling survival in well-drained sands. Further, the shallow root system of an immature turf is less efficient at N absorption which increases leaching potential.

Brauen and Stahnke (4) reported that N leaching was greater during year one than in year two of a newly established creeping bentgrass putting green. They suggested this was due to more extensive rooting, increased thatch, and increased rootzone organic matter in year two. Bowman et al. (3) reported similar effects of root development on nitrate leaching and found that NO_3^--N losses were greater in shallow versus deeply rooted creeping bentgrass clones.

Historically, most sand-based golf greens have been amended with stabilized organic matter, such as peat moss, to improve nutrient and water retention. In the past decade, many inorganic soil amendments (i.e. porous ceramics, diatomaceous earth, and clinoptilolitic zeolites) have been sug-

Soil amendment	NH_4^+-N Peak conc. (ppm)	NH_4^+-N Total loss (%)
Nonamended	59.3 a[x]	96.2 a
Ecolite	3.3 c	7.8 e
Isolite	23.9 b	63.9 b
Profile	8.4 c	21.3 d
Greenschoice	26.9 b	69.4 b
Sphagnum peat	11.0 c	37.7 c

[x]Mean separation within columns by Fisher's protected LSD, P=0.05.

Table 1. Peak concentration and percentage loss of ammonium in the effluent of sand amended at 20% (by volume) with four inorganic soil amendments and sphagnum peat.

gested as alternatives to peat moss. The inorganic products may be better suited to rootzones because they are not susceptible to biological degradation and may sustain the physical properties of the originally constructed rootzone longer than peat moss.

Several researchers have reported that zeolite incorporation dramatically decreased N leaching from sand media (11, 19). Ferguson and Pepper (9) attributed the lower leaching losses to the high NH_4^+ ion retention of zeolite. MacKown and Tucker (13) also reported lower NH_4^+ losses with zeolites and found that as incorporation rate increased, N loss decreased significantly. This is not surprising since some zeolites have a theoretical cation exchange capacity of 220 meq 100 g^{-1} (17). Increasing the zeolite incorporation rate could significantly increase CEC in the resultant mix. While much information exists for zeolite, comparable data for other commercial inorganic amendments are lacking.

The objective of this laboratory study was to determine if enhancing the CEC of sand-based rootzones with soil amendments of varying CECs could limit N leaching compared to peat moss in newly constructed sand-based golf green rootzones. The effects of amendment type, incorporation rate, and depth were examined.

Materials and Methods

Experimental rootzone media were prepared by amending an air-dried locally available washed quartz sand conforming to USGA size guidelines (28) with the following amendments: sphagnum peat (Irish Spagnum Peat Moss, Bordnamona Co., Dublin, Ireland); clinoptilolite zeolite (Ecolite, Western Organics, Inc., Tempe, Ariz.); diatomaceous earth containing 5% of a clay binder (Isolite, Sundire Enterprises, Arvada, Colo.); and two porous ceramic products, (Profile, Applied Industrial Materials Corp., Buffalo Grove, Ill.) and Greenschoice (Premier Environmental Products, Inc., Houston, Texas). According to literature from their manufacturers, the cation exchange capacity (CEC) of the inorganic amendments Ecolite, Greenschioce, Isolite, Profile, and sphagnum peat were 185-220, 1.0, 0.8, 33.6, 75-100 meq 100 g^{-1}, respectively. Cation exchange capacities of selected rootzone mixtures were determined using 1M ammonium acetate extraction at pH=7.

Experimental rootzones were constructed by installing sand or amended sand mixtures into 3-inch diameter by 12-inch tall acrylic columns, placed over a 4-inch thick gravel sub-layer. After 24 hours at saturation, each column was placed on a screen and allowed to drain for 24 hours to reach field capacity. After drainage, a liquid ammonium nitrate solution containing N equivalent of 1 lb. of N per 1000 ft^2 was applied to the surface of each rootzone and leached with twice-distilled water. The leachate was collected in small aliquots and analyzed for the presence of ammonium (NH_4^+-N) and nitrate (NO_3^--N).

Soil amendment	Rate (%,v/v)	NH_4^+-N Peak conc. (ppm)	Total loss (%)
Nonamended	0	58.4	95.7
Ecolite	1	49.6 a[z]	75.0 a*[y]
	5	39.1 a ***	52.3 b *
	10	10.3 b ***	17.0 c *
	20	4.3 b ***	7.7 d *
Profile	1	52.3 a	78.7 a *
	5	25.4 b ***	51.6 b *
	10	11.4 c ***	32.6 c *
	20	6.7 c ***	22.4 d *
Orthogonal contrasts[x]			
Ecolite vs Profile 1%		NS	NS
Ecolite vs Profile 5%		NS	NS
Ecolite vs Profile 10%		NS	NS
Ecolite vs Profile 20%		*	***

[x]Orthogonal contrasts nonsignificant (NS) or significant at 0.05(*) or 0.001 (***), respectively.

[y]Means within the same column followed by *, or *** are significantly different from nonamended sand at P=0.05, or 0.001, respectively.

[z]Means within columns for the same soil amendment followed by the same letter are not significantly different at P=0.05 by Fisher's protected LSD.

Table 2. Peak concentration and percentage loss of ammonium in the effluent of sand amended with Ecolite and Profile at 1%, 5%, 10% and 20% (by volume).

What We Discovered

Amendment Effects

A wide range in NH_4^+-N leaching was observed from the various amendment mixtures (Table 1). Ammonium nitrogen appeared rapidly in the effluent from all rootzone media with peak concentrations occurring at approximately 0.5 pore volumes (Figure 1). This pattern was consistent in all experiments (data not presented). Significantly higher peak NH_4^+-N concentrations and more cumulative NH_4^+-N leached from nonamended sand than from the 20% amended mixtures (Table 1).

By contrast, more than 90% of applied NO_3^--N, was recovered in the leachate of all rootzone mixtures in all experiments (data not presented). In general, nonamended sand and most amended sand mixtures in all experiments were similar regarding NO_3^--N leaching with only a few exceptions. Peak NO_3^--N concentrations were greatest for nonamended sand (78 ppm) and slightly less (50 ppm) for amended media, probably due to the slower percolation rates of amended mixtures.

Amendment Volume Effect

As incorporation rates for the two most effective amendments, Profile and Ecolite, increased from 1% to 20%, NH_4^+-N loss and the peak effluent concentrations decreased in a stepwise manner, with the 20% rate resulting in the least NH_4^+-N loss for both amendments (Table 2). No differences in N retention between the two products were observed except at the 20% rate where significantly less $NH4^+$-N leached from the Ecolite-amended sand which had a higher CEC (9.6 vs. 4.6 meq/100 g soil for Ecolite- and Profile-amended sand, respectively). Incorporating any amendment at 20% by volume could be extremely expensive, thus it was determined that the 10 % volume rate may be more cost effective for most situations.

Incorporation Depth

Based on the results obtained in the optimum amendment volume experiment, the influence of incorporation depth with Ecolite and Profile at 10% by volume were examined. It was found that, as expected, incorporation depth significantly affected NH_4^+-N leaching. Increasing amendment incorporation depth resulted in a stepwise reductions in NH_4^+-N leaching (Table 3). Even incorporating either of these amendments to

Soil amendment	Depth (inches)	NH_4^+-N Peak conc.[z] (ppm)	Total loss (%)
Nonamended	0	61.9	97.6
Ecolite	1	30.7 a ***[y]	68.2 a *
	6	20.1 ab ***	38.2 b *
	12	10.4 b ***	17.6 c *
Profile	1	38.1 a ***	76.6 a *
	6	19.9 b ***	49.4 b *
	12	11.4 c ***	32.2 c *
Orthogonal contrasts[x]			
Ecolite vs Profile	1 inch	***	NS
Ecolite vs Profile	6 inches	NS	NS
Ecolite vs Profile	12 inches	NS	*

[x]Orthogonal contrasts nonsignificant (NS) or significant at 0.05(*) or 0.001 (***), respectively.

[y]Means within the same column followed by *, or *** are significantly different from nonamended sand at P=0.05, or 0.001, respectively.

[z]Means within columns for the same soil amendment followed by the same letter are not significantly different at P=0.05 by Fisher's protected LSD.

Table 3. Peak concentration and percentage loss of ammonium in the effluent for sand amended with Ecolite and Profile at 10% (v/v) incorporated to 2.5, 15 and 30 cm depths

a rather shallow depth of one inch decreased cumulative NH_4^+-N losses by almost 25%, compared to nonamended sand.

How This Study Relates to Others

The higher affinity of the porous ceramic, Profile amendment, for NH4+-N compared to the diatomaceous earth product is consistent with previous research regarding similar inorganic amendments (15). Additionally, our results regarding decreased NH_4^+-N leaching with increasing zeolite incorporation rates is consistent with similar studies by MacKown and Tucker (13).

Although NH_4^+-N may be protected from leaching, previous research found that significant NO_3^--N leached from a sandy medium amended with zeolite and fertilized with ammonium sulfate (11, 20). Therefore, caution regarding timing of N applications to coincide with plant uptake may be necessary. Huang and Petrovic (11) reported that substantial NO_3^--N losses occurred after a large N application to a nonamended sand, but that addition of zeolite to sand significantly decreased NO_3^--N concentrations with leachate levels consistently less than 10 ppm. However, their experimental system included relatively mature creeping bentgrass turf and it is possible that zeolite affected NO_3^--N leaching by improving the rootzone physical properties and consequently promoting deeper and more extensive rooting.

The poor retention of NO_3^--N in these experiments was most likely due to anion exclusion. Under normal conditions where electroneutrality is maintained between the soil surface and cations in the soil solution, electrostatic repulsion of anions occurs. Further, in coarse-textured soils like those commonly used for putting greens over half of the water movement in the rootzone is through the macropore system (21, 27). Since turfgrass roots were absent, this may have contributed to the rapid NO_3^- leaching in the percolating water and little if any opportunity for NO_3^- to be retained or removed.

Conclusion

These experiments support previously published reports regarding NH_4^+-N and NO_3^--N movement in sand-based rootzones. As has been documented, N leaching in nonamended quartz sands is very high, exceeding 95% of applied N. However, NH_4^+-N leaching losses can be decreased substantially by incorporating certain inorganic amendments and to a lesser extent, sphagnum peat, provided these amendments have sufficient CEC.

Nitrate leaching continues to be a concern in sand-based putting green media, particularly during turfgrass establishment when root systems are shallow and water soluble fertilizers are used. One potential solution to the N leaching problem is to design a system and management program that minimizes NO_3^--N leaching. This system would include a properly sized sand amended with one or more of the following amendments: peat moss, zeolite, or a relatively high CEC porous ceramic. During grow-in, the seedling turf should be fertilized with a predominantly ammonium (NH_4^+-N) based fertilizer. Collectively, these rootzone characteristics and fertilizer management strategies will provide a rooting medium which consists of adequate, but not excessive, percolation and the added benefit of ample nutrient exchange sites which would retain N in the rooting medium where it could be utilized by turfgrass roots.

Although Ecolite and Profile were effective for decreasing N leaching in sand-based rootzones, they cost considerably more (five times greater or more) than peat moss when used at equal incorporation amounts (18), which may limit their widespread adoption as a peat moss replacements. Future research regarding anion exchange materials for limiting NO_3^- leaching would be valuable.

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