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The Effect of Rootzone Mix and Compaction on Nitrogen Leaching in Kentucky bluegrass

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ABSTRACT. Research on nitrate-nitrogen (NO_3-N) leaching in turfgrass indicates that in most cases leaching poses minimal risk to the environment. Although there have been many studies investigating NO_3-N leaching, there has been little research to investigate the effect of compaction level and rootzone mix on nitrogen (N) leaching. The research objective is to determine the effect of compaction level and rootzone mix on nitrogen leaching. The four rootzone mixes are 76.0:24.0, 80.8:19.2, 87.0:13.0 and 93.7:6.3 % (sand: soil). The four levels of compaction energies are 1.6, 3.0, 6.1, and 9.1 J cm^{-2}. Nitrogen was applied using urea at a rate of 147 kg ha^{-1} split among three applications. Rootzone was packed into a polyvinylchloride pipe with a perforated bottom to facilitate drainage. Rootzone depth was 30 cm over a 5 cm gravel layer. Each column was sodded with *Poa pratensis* L. Hoagland solution designed for cool-season grasses, minus N, was used to ensure adequate nutrition in the rootzone. Turf grass quality and clipping yield were recorded from each tube at two-week intervals. The clippings were oven-dried at a temperature of 67ºC for 24 h and weighed. At the end of the study, root dry weight was determined by washing and oven-drying samples at 67ºC for 24 h. Leachate solution was collected weekly for analysis. More than 6.1 J cm-2 of compaction energy increased possibilities of surface runoff. The compaction energy between 3.0 and 6.1 J cm^{-2} produced more clipping dry weight and less N leaching than 9.1 J cm^{-2}.

Key words: nitrate-nitrogen, leaching, rootzone, Poa pratensis, compaction energy

Introduction

Research concerning nitrogen fertilization of turfgrass is plentiful, but most of this work has focused on plant response to different N application rates, response to different fertilizer sources, or impact of fertilizer N on water quality. Soil compaction is defined as the pressing together of soil particles, resulting in a more dense soil mass with less pore space (Carrow and Petrovic, 1992). Negative effects of compaction on turfgrass growth include reduced root growth, shoot growth and overall quality. However, a little compaction may improve growing condition for turfgrass and decrease NO_3-N leaching by increasing the moisture-holding potential of the soil (Vavrek, 2002). Very little information is available on compaction and NO_3-N leaching for turfgrass growth at the present time. The study was conducted to determine the effect of compaction level and rootzone mix on nitrogen leaching.

Materials and Methods

This study was conducted for 12-weeks, repeatedly, in a greenhouse at Michigan State University, East Lansing, Michigan. The well-graded sand and sandy loam textured soils were selected from Great Lakes Gravel located in Grand Ledge, MI. Four soil mixes were used for the study (Table 1). The sand A and sandy loam were used to make soil mixes of sand B and loamy sand. The cement mixer was used to mix soils. A particle size analysis was conducted to determine their percent sand, silt and clay for four soil mixes. The Michigan State University Soil and Plant Nutrient Lab performed the particle size analysis of the soil using the hydrometer method (Day, 1965). The optimum water content was determined to maximize bulk density according to the Standard Proctor Compaction Test (Proctor, 1933). The soil mixes were remixed with 11% of water and packed into a 7.62 cm diameter polyvinyl chloride (PVC) pipe using a compactor (Fig. 1). Four levels of compaction energies that are 1.6, 3.0, 6.1, and 9.1 J cm^{-2} were used for compaction of the root zone. Urea as an N source was applied for three times with a rate of 48.9 kg ha^{-1}, totally 146.7 kg ha^{-1}. The plan of application is described in Table 2.

The PVC pipe was capped with a funnel at the bottom to facilitate drainage. The root zone depth was 30.5 cm and the holding tube was 40.6 cm long. The columns were sodded with mature sod of Kentucky bluegrass (Poa pratensis L.) that was harvested from the Hancock Turfgrass Research Center at Michigan State University, East Lansing, Michigan. Pellett and Roberts (1963) nutrient solution

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Table 1. Particle size analysis of sand-soil mixtures.

Sand-Soil[y]	Particle size distribution[z] (%)								
	FG > 2 mm	VCoS (2-1 mm)	CS (1-0.5 mm)	MS (0.5-0.25 mm)	FS (0.25-0.1 mm)	VFS (0.1-0.05 mm)	Silt (0.05-0.002 mm)	Clay (<0.002)	Silt +Clay
Sand A[x]	0.0	4.1	27.4	45.5	16.2	0.5	0.2	6.1	6.3
Sand B	4.4	7.3	24.6	33.8	14.1	2.8	3.8	9.2	13.0
Loamy sand	6.2	7.8	19.9	26.3	16.3	4.3	10.2	9.0	19.2
Sandy loam[w]	8.4	7.8	13.5	20.4	12.6	13.3	13.9	10.1	24.0

[z] indicates the percent by weight of soil particles in each size class. The size classes according to the United States Department of Agriculture (USDA) are as follows: fine gravel (FG), very coarse sand (VCoS), coarse sand (CS), medium sand (MS), fine sand (FS), very fine sand (VFS), silt and clay.
[y] Sand-Soil mixes were mixed on a weight basis.
[x] Sand used to make all mixtures
[w] Sandy loam soil used to make all mixtures

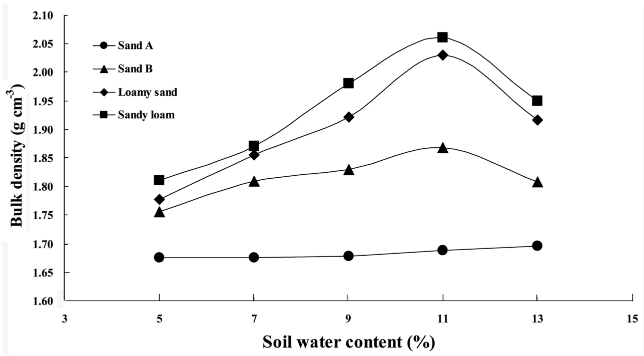

Fig. 1. Soil water content-bulk density relationship for four sand-soil mixes compacted according to the Standard Proctor method.

designed for cool-season grasses, minus N was used to provide proper levels of other essential elements in the root zone. Kentucky bluegrass on each PVC pipe was mowed weekly at 7.6 cm. Visual turfgrass quality ratings were conducted weekly on a scale of 1 to 9 (1 = poor, 6 = acceptable, and 9 = excellent). Grass clippings were collected from each tube at two-week intervals. The clippings were oven-dried at a temperature of 67ºC for 24 h and weighed to measure clipping yield. At the end of the study, root dry weight was determined by washing and oven-drying samples at 67ºC for 24 h (Steyn, 1959). All leachate solution was collected from a cup under the PVC pipe for final nutrient analysis. Nitrate nitrogen of the leachate was analyzed by using the cadmium-reduction

Table 2. Plan of urea application and a rate of each application.

Treatment Number	Ratio of sand and soil (%)	Level of compaction (J cm^{-2})	Week after treatment		
			1	5	9
1	93.7 : 6.3	1.60	48.9[z]	48.9	48.9
2	93.7 : 6.3	3.03	48.9	48.9	48.9
3	93.7 : 6.3	6.06	48.9	48.9	48.9
4	93.7 : 6.3	9.09	48.9	48.9	48.9
5	87.0 : 13.0	1.60	48.9	48.9	48.9
6	87.0 : 13.0	3.03	48.9	48.9	48.9
7	87.0 : 13.0	6.06	48.9	48.9	48.9
8	87.0 : 13.0	9.09	48.9	48.9	48.9
9	80.8 : 19.2	1.60	48.9	48.9	48.9
10	80.8 : 19.2	3.03	48.9	48.9	48.9
11	80.8 : 19.2	6.06	48.9	48.9	48.9
12	80.8 : 19.2	9.09	48.9	48.9	48.9
13	76.0 : 24.0	1.60	48.9	48.9	48.9
14	76.0 : 24.0	3.03	48.9	48.9	48.9
15	76.0 : 24.0	6.06	48.9	48.9	48.9
16	76.0 : 24.0	9.09	48.9	48.9	48.9

[z] Units of urea application are kg ha $^{-1}$.

Table 3. Analysis of variance for turfgrass quality.

Source	df	Week after treatment											
		1	2	3	4	5	6	7	8	9	10	11	12
Soil (S)	3	**	**	**	**	**	NS	NS	NS	NS	NS	NS	NS
Compaction (C)	3	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S×C	9	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

** indicates significance at P = 0.01.
NS indicates not significant at P = 0.05.

method (Bremner, 1965).

The experimental design was a randomized complete block design with four replications. The treatments were applied to grass columns with a factorial arrangement of four levels of compaction energies and four soil mixes. The data were analyzed using the t-test procedures and mean separation was performed by standard error of difference (SED) method of the Statistical Analysis System (SAS, 1987). PROC MIXED was used for multiple factor analyses of variance.

Results and Discussion

There was no significant soil type by compaction energy interaction for turfgrass quality (Table 3). No significant differences on compaction energy main effects were found on turfgrass quality throughout the study period. There was a significant soil type main effect from the first week after treatment (WAT) to 5 WAT. However, no differences among soil type main effects were found from 6 WAT. Sandy loam had the highest or equal to the highest turfgrass quality from 1 WAT to 5WAT (Table 4). Sand A had the lowest turfgrass quality from 1 WAT to 5WAT except 4 WAT. The turfgrass quality rating by all treatments of soil type was greater than the acceptable rating of six throughout the study except Sand A on 1 WAT. Based on the results, compaction energy ranged from 1.6 to 9.1 J cm^{-2} didn't have effects on turfgrass quality for 12-week period. All of soil type produced acceptable turfgrass quality of six although there were significant differences among treatments of main effects.

No significant interaction was found on clipping dry weight (Table 5). Sandy loam produced the largest or equal to the largest clipping dry weight (Table 6). Overall, sand A produced the smallest clipping dry weight. Difference between loamy sand and sandy loam was found only on 4 WAT. The soil type of sand A had acceptable turfgrass quality with the smallest clipping dry weight throughout the study. Although loamy sand and sandy loam had the highest turfgrass quality ratings from 1WAT to 5WAT, they produced

Table 4. Mean turfgrass quality for soil main effect.

Soil type[z]	Week after treatment											
	1	2	3	4	5	6	7	8	9	10	11	12
Sand A	5.9[y] c[x]	6.3 b	6.5 b	6.3 c	6.3 c	6.4	6.3	6.5	6.2	6.5	6.3	6.3
Sand B	6.8 b	7.0 a	7.1 a	6.6 bc	6.8 b	6.8	6.8	6.7	6.8	6.7	6.6	6.6
Loamy sand	7.2 a	7.3 a	7.1 a	6.8 ab	6.8 b	6.8	6.8	6.9	6.6	6.9	6.8	7.0
Sandy loam	7.1 a	7.2 a	7.3 a	7.2 a	7.3 a	7.1	6.6	6.8	6.6	6.8	6.6	6.8

[z] Source of soil
[y] Kentucky bluegrass quality was rated from 1 to 9 (1 = worst, 9 = best, and 6 = acceptable).
[x] Means in a column followed by the same letter are not significantly different according to Fisher's LSD (P=0.05).

Table 5. Analysis of variance for clipping dry weight.

Source	df	Week after treatment											
		1	2	3	4	5	6	7	8	9	10	11	12
Soil (S)	3	**	**	**	**	**	**	**	**	**	**	**	**
Compaction (C)	3	**	**	NS	NS	**	**	**	**	*	*	NS	*
S×C	9	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

* indicates significance at P = 0.05.
** indicates significance at P = 0.01.
NS indicates not significant at P = 0.05.

Table 6. Mean clipping dry weight for soil type main effect.

Soil type[z]	Week after treatment											
	1	2	3	4	5	6	7	8	9	10	11	12
Sand A	1.9[y] c[x]	1.9 c	2.3 c	1.1 c	2.9 c	7.7 c	4.1 c	4.5 c	6.8 b	8.6 b	9.0 b	15.1 c
Sand B	7.8 b	4.6 b	4.4 bc	3.0 bc	7.3 b	17.7 b	8.8 b	8.6 b	14.3 a	18.0 a	16.2 a	25.0 b
Loamy sand	12.5 a	6.7 ab	6.5 ab	4.4 b	13.0 a	23.3 a	13.2 a	13.6 a	17.2 a	17.6 a	16.9 a	30.0 ab
Sandy loam	10.7 ab	8.9 a	10.1 a	9.6 a	17.0 a	23.0 a	14.5 a	14.9 a	16.4 a	19.4 a	20.1 a	34.0 a

[z] Source of soil
[y] Clipping dry weight units are g m^{-2}
[x] Means in a column followed by the same letter are not significantly different according to Fisher's LSD (P=0.05).

Table 7. Mean clipping dry weight for compaction energy main effect.

Compaction energy[z]	Week after treatment											
	1	2	3	4	5	6	7	8	9	10	11	12
1.6	13.4[y] a[x]	8.0 a	7.8	5.6	13.8 a	25.2 a	13.8 a	13.9 a	16.7 a	18.8 a	17.8	30.2 a
3.0	8.7 b	6.7 ab	5.5	3.8	9.9 a	18.3 b	10.5 b	10.1 b	13.4 ab	14.8 a	17.2	28.1 a
6.1	5.3 b	4.5 bc	5.1	5.8	11.3 a	17.4 b	10.5 b	11.2 b	14.5 ab	18.0 a	15.2	28.9 a
9.1	5.5 b	2.8 c	4.9	2.8	5.2 b	10.8 c	5.8 c	6.4 c	10.0 b	11.9 b	12.1	21.9 b

[z] Compaction energy units are J cm^{-2}
[y] Clipping dry weight units are g m^{-2}
[x] Means in a column followed by the same letter are not significantly different according to Fisher's LSD (P=0.05).

Table 8. Analysis of variance for nitrate nitrogen (NO_3-N) leached.

Source	df	Week after treatment												Total
		1	2	3	4	5	6	7	8	9	10	11	12	
Soil (S)	3	**	NS	*	NS	**	**	NS	NS	NS	NS	NS	**	NS
Compaction (C)	3	*	NS	NS	**	**	**	**	**	**	NS	NS	NS	**
S×C	9	NS	NS	NS	NS	**	*	NS	NS	NS	NS	NS	NS	NS

** indicates significance at P = 0.01.
NS indicates not significant at P = 0.05.

the largest clipping dry weight which may induce more cost and labor for turfgrass management. The 1.6 J cm^{-2} of compaction energy produced the largest or equal to the largest clipping yield on 9 of 12 ratings (Table 7). On the contrary, the 9.1 J cm^{-2} of compaction energy produced the smallest clipping yield during the study.

There were significant soil type by compaction energy interactions on two of 12 ratings (Table 8). Soil type and compaction energy main effects were found, respectively. Significant difference was found on total NO_3-N leached only for compaction energy main effect. Generally, more NO_3-N with large pore space is expected. However, the largest amount of NO_3-N was leached from the 9.1 J cm^{-2} of compaction energy based on the results (Fig. 2). This is due to preferential water flow from a gap between soil profile and PVC tube (Fig. 3). Loamy sand had more NO_3-N leached than sand A and sand B.

In conclusion, no differences were found on turfgrass

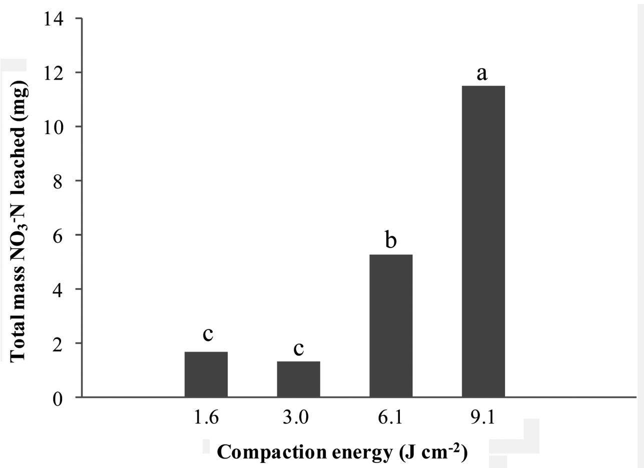

Fig. 2. Mean turfgrass total mass NO_3-N leached (mg) for the compaction energy main effect. Means with the same letter within each energy level are not significantly different according to Fisher's LSD (P=0.05).

Fig. 3. NO_3^-N leached with water through space between the wall of tube and soil on high level of compaction energy.

turfgrass quality after 5 WAT. The total NO_3-N leached leached from soil column was not affected by soil type main effect. More than 6.1 J cm^{-2} of compaction energy increased possibilities of surface runoff. The compaction energy between 3.0 and 6.1 J cm^{-2} produced more clipping dry weight and less N leaching than 9.1 J cm^{-2}.

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토양의 종류와 답압이 켄터키블루그래스 토양층에서 질소용탈에 미치는 영향

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요　약: 환경문제를 야기 시킬수 있는 질소의 용탈에 관한 문제는 수많은 연구를 통해 그 결과를 문헌에서 찾아 볼 수 있다. 그러나 대부분의 연구가 질소의 토양내 용탈에 관해서 이루어진 반면에 토양의 답압과 토양의 종류에 따라 질소의 용탈 정도에 관한 연구는 그 결과를 문헌에서 찾아 보기가 어렵다. 본 연구는 토양의 종류와 답압의 정도가 질소의 용탈에 미치는 영향 그리고 토양에 잔류된 질소가 켄터키블루그래스의 성장에 주는 영향에 대해서 알아보기 위하여 수행 되었다. 질소는 총 147 kg ha^{-1}이 12주 동안 3회에 걸쳐 나누어 시비되었다. 토양의 종류는 성분비율에 따라 76.0:24.0, 80.8:19.2, 87.0:13.0 그리고 93.7:6.3% (sand: soil)의 4가지로 구성이 되었다. 토양은 PVC 파이프에 30 cm 깊이로 조성이 되었으며 토양층 밑에 5 cm의 자갈층으로 구성되었다. PVC 파이프 밑부분의 구멍을 통해 질소용탈수의 수집을 용이하게 하였으며 질소외 영양성분을 위해 Hoagland solution에서 질소만 제외하여 사용되었다. 켄터키블루그래스의 질과 예초량이 매주 측정이 되었으며 예초물은 건물량 측정을 위해 예초후 67도에서 24시간 동안 건조되었다. 질소용탈수는 매주 PVC 파이프의 밑부분을 통해 매주 수집이 되었다. 6.1 J cm^{-2} 이상의 답압에너지는 더 많은 표면배수의 가능성을 야기 시킬 수 있다. 3.0과 6.1 J cm^{-2} 사이의 답압에너지는 다른 처리구에 비해 더 많은 건물량이 측정이 되었고 적은 질소가 용탈이 되었다.

주요어: 질소, 용탈, 답압에너지, 켄터키블루그래스