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Soil compaction and poultry litter effects on factors affecting nitrogen availability in a claypan soil

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Abstract

Soil compaction may affect N mineralization and the subsequent fate of N in agroecosystems. Laboratory incubation and field experiments were conducted to determine the effects of surface soil compaction on soil N mineralization in a claypan soil amended with poultry litter (i.e., Turkey excrement mixed with pine shavings as bedding). In a laboratory study, soil from the surface horizon of a Mexico silt loam soil was compacted to four bulk density levels (1.2, 1.4, 1.6 and 1.8 Mg m^{-3}) with and without poultry litter and incubated at 25 °C for 42 days. A field trial planted to corn (*Zea mays* L.) was also conducted in 2002 on a Mexico silt loam claypan soil in North Central Missouri. Soil was amended with litter (0 and 19 Mg ha^{-1}) and left uncompacted or uniformly compacted. Soil compaction decreased soil inorganic N by a maximum of 1.8 times in the laboratory study; this effect was also observed at all depths of the field trial. Compacted soil with a litter amendment accumulated NH$_4^+$-N up to 7.2 times higher than the noncompacted, litter-amended soil until Day 28 of the laboratory incubation and in the beginning of the growing season of the field study. Ammonium accumulation may have been due to decreased soil aeration under compacted conditions. Application of litter increased soil N mineralization throughout the growing season. In the laboratory study, soil inorganic N in unamended soil was negatively correlated with soil bulk density and the proportion of soil micropores, but was positively related with soil total porosity and the proportion of soil macropores. These results indicate that soil compaction, litter application and climate are interrelated in their influences on soil N mineralization in agroecosystems.
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Keywords: Compaction; Bulk density; Poultry litter; N mineralization; Claypan soil

1. Introduction

Increasing use of heavy equipment for agricultural production throughout the world has led to an increase in soil compaction on agricultural land creating crop production and environmental concerns (Soane and van Ouwerkerk, 1995; Entry et al., 1996; Abu-Hamdeh, 2003). Detrimental effects of compaction on soil physical properties for crop production include an increase in soil bulk density and decrease in total porosity and the proportion of larger pores to smaller pores (Motavalli et al., 2003). These physical effects of soil compaction may reduce plant growth and production primarily by restrictions in root growth, decreased soil water and nutrient availability and lower soil aeration (Domzal et al., 1991; Mapfumo et al., 1998; Arocena, 2000). Compaction may also increase nutrient movement into the environment by promoting surface runoff and gaseous losses (Brussaard and van Faassen, 1994; Soane and van Ouwerkerk, 1995).

Physical changes incurred by soil compaction also modify microhabitats for soil microorganisms

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potentially inhibiting their efficacy in soil nutrient cycling. Since N mineralization of organic materials is a critical process for plant N availability and soil N loss, the effects of soil compaction on N mineralization have been studied by several researchers (Torbert and Wood, 1992; Breland and Hansen, 1996; Jensen et al., 1996; De Neve and Hofman, 2000). Basic conclusions of previous research have been that N mineralization in compacted soil is affected by decreased soil aeration, reduced soil water infiltration and increased surface runoff (Lipiec and Stepniewski, 1995). Compaction may also alter several soil controlling factors for soil microbial activity, such as soil water content and temperature that affect the rate of many soil microbially mediated processes (Pengthamkeerati et al., 2005). For instance, during the early spring when soil is relatively wet, compacted soil may have a higher soil water content and lower soil temperature than noncompacted soil, which can result in a slower rate of N mineralization. In addition, cumulative N mineralization may also be reduced in compacted soils because of a lower quantity of available N substrates due to decreased production of plant residues induced by soil compaction (Entry et al., 1996; Motavalli et al., 2003).

Soil organic amendments may be a method to remediate soil compaction (Brussaard and van Faassen, 1994; Larson et al., 1994; Reicosky, 2002). Bulky organic materials applied to soil may directly reduce soil bulk density and compactability, increase soil porosity, rates of infiltration and water holding capacity, which may promote sufficient soil aeration and water for soil microorganisms and plants (Guerief, 1979; Brady and Weil, 2000; Mosaddeghi et al., 2000). In addition, adding organic materials with high N content, such as animal manure, into soil may minimize the effects of compaction on N availability. As a result, applied organic materials may enhance plant growth and soil microbial activity and microbially mediated processes, such as N mineralization.

Approximately 4 Mha of claypan soils are located in the Midwestern USA (Jamison et al., 1968). Claypan soils are characterized by an abrupt and large increase in clay content in the subsoil relative to the overlying soil (Jamison et al., 1968; Motavalli et al., 2003). In general, plant root growth is restricted in claypan soils by the high clay containing layer, which may consequently limit plant nutrient uptake (Jamison et al., 1968). In addition, the claypan soil limits drainage and causes perching of water in the topsoil (Blevins et al., 1996; Blanco-Canqui et al., 2002), and therefore, these soils are more readily saturated after rainfall events. These wet conditions, which are often observed in the spring,

may limit aerobic soil N transformations, thereby reducing the rate of soil N mineralization. Compacting claypan soils may further restrict water movement and soil aeration, which may cause more severe effects on soil N mineralization.

Little information is available on the effects of soil compaction and organic amendments on N mineralization in claypan soils. Motavalli et al. (2003) observed that N availability for growth of corn from an organic amendment was reduced by surface compaction in a claypan soil. However, they did not examine the effects of compaction and organic amendments on soil N mineralization. The objectives of this study were to: (1) investigate the effects of surface soil compaction and applied poultry litter on soil N mineralization in a claypan soil and (2) determine the relationship between soil inorganic N and soil physical properties at different soil bulk density levels.

2. Materials and methods

2.1. Laboratory incubation study

The claypan soil used in the incubation study was from the surface horizon of a Mexico silt loam (fine, smectitic, mesic Aerie Vertic Epiaqualfs) from the Bradford Agronomy Center (38°53′N, 92°12′W) in North Central Missouri. A bulk sample was taken from the 0–10 cm depth, air-dried, ground and sieved (2-mm mesh). Particle size distribution was 59 ± 4 g kg^{-1} sand, 711 ± 7 g kg^{-1} silt and 230 ± 3 g kg^{-1} clay. Selected soil properties were: pH (water) of 6.76 ± 0.02, 12.7 ± 0.4 g kg^{-1} total organic C and 1.19 ± 0.01 g kg^{-1} total Kjeldahl N.

Soil was amended with ground (2-mm mesh) poultry litter (total organic C = 161 ± 28 g kg^{-1}; total N = 17.5 ± 0.1 g kg^{-1}), composed of Turkey excrement and pine shavings as bedding, at levels of 0 and 28.3 g kg^{-1} soil on a dry weight basis, which resulted in an addition of 0 and 496 mg total N kg^{-1} soil, respectively. The poultry litter used in both the laboratory and field studies was collected shortly after a poultry house was cleaned out at the University of Missouri Rocheford Turkey Research Farm. The litter used in the laboratory study was dried in a forced-air oven at 70 °C and ground to pass a 1-mm sieve. In contrast, the litter used in the field study was not dried or ground.

Treated and untreated soil was moistened to 55% water-filled pore space (WFPS) by assuming a soil particle density of 2.65 Mg m^{-3} and maintained at this soil water content throughout the incubation period by

additions of water when needed. Treated soil was uniaxially compacted into 76 mm × 76 mm diam. soil cores to four levels of bulk density (1.2, 1.4, 1.6 and 1.8 Mg m^{-3}) by using a compaction cylinder and hydraulic press. All treatments had three replicates. Each core was placed in a plastic bag containing 20 cm^3 of water to maintain humidity. Soil core samples were kept in a dark constant temperature room at 25 °C and were periodically removed to add water and aerated for 45 min to 1 h. A set of soil cores was sacrificed at each sampling date and the whole soil removed from each core at 3, 7, 14, 21, 28 and 42 days after the start of the incubation. Soil samples were stored at 4 °C until analysis for soil NH_4^+-N and NO_3^--N. Soil inorganic N was calculated by summing NH_4^+-N plus NO_3^--N. Soils were extracted for inorganic N using 2 M KCl and the extracted solution was analyzed using a Lachat Quikchem Automated Ion Analyzer (Zellweger Analytics, 1992, 1993).

Three replicates of treated soil cores were prepared for assessing soil physical properties before the incubation. Soil cores were slowly saturated from the bottom up with de-aired solution (6.06 g l^{-1} CaCl$_2$ and 1.78 g l^{-1} MgCl$_2$) at a rate of 3 mm h^{-1} (Palmer, 1979; Blanco-Canqui et al., 2004). Soil cores were subsequently measured for saturated hydraulic conductivity (K_{sat}) by the constant- or falling-head method (Klute and Dirksen, 1986). Pore size distribution was determined by a water desorption technique with high-energy soil water retention (0 to −40 kPa).

Classification of pore sizes was macropores (>500 μm radius), coarse mesopores (25–500 μm radius), fine mesopores (5–25 μm radius) and micropores (<5 μm radius). After completing the determination of pore size distribution, about 20–30 g soil samples were removed from each core and oven-dried at 105 °C to determine gravimetric soil water content for calculating soil bulk density and total porosity.

2.2. Field study

This study was conducted during the 2002 growing season at the Bradford Agronomy Center in the same field from which the bulk soil was collected for the laboratory incubation study. The soil in this field was part of the Central Claypan Region located in Missouri and Illinois (Soil Conservation Service, 1981). A previous study showed the depth to the claypan at this field site varied between 25 and 30 cm (Motavalli et al., 2003). Initial soil characteristics are given in Table 1 (Motavalli et al., 2003). Daily and cumulative
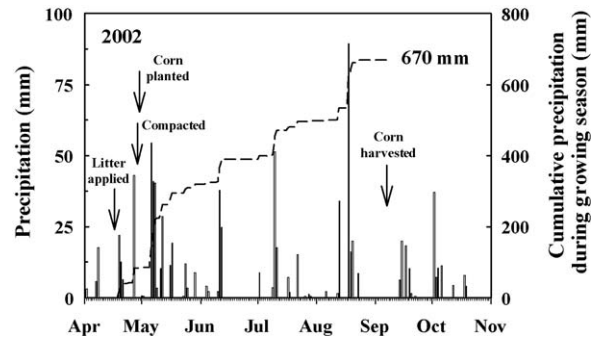

Fig. 1. Daily (bars) and cumulative precipitation (line) for the 2002 growing season at the Bradford Agronomy Center, University of Missouri. Arrows indicate times of litter application, compaction, planting and harvest events during the season.

precipitation data were also obtained from the Bradford Agronomy Center (Fig. 1).

The experimental design used was a split block design arranged in randomized complete blocks with four replications. The experimental plots were broadcast-applied with two levels of poultry litter (0 and 18.7 Mg litter ha^{-1} dry weight basis), containing an average of 305 ± 69 g kg^{-1} total organic C and 32 ± 4 g kg^{-1} total N. The poultry manure was a mixture of Turkey excrement and pine shavings used as bedding material. After incorporating litter into the soil twice with a disk implement to a depth of 10–15 cm, plots were uniformly surface-compacted zero and two times with a tractor-pulled wagon fixed with a 1.9 m^3 water tank filled with water that had an axle load of 2.9 Mg. Fallow plots were 3.0 m wide by 6.1 m long and planted plots were 3.0 m wide by 9.1 m long. Cropped plots were planted to corn (Zea mays L.) variety Pioneer Hybrid 33G26 at a density of 69,000 plants ha^{-1} in 76-cm rows. The fallow plots were maintained free of weeds by periodic applications of glyphosate. For the cropped plots, weed control was through recommended rates of pre-emergence herbicide applications of metolachlor and atrazine and when needed, post-emergence applications of nicosulfuron and mesotrione.

Soil samples were collected using an Uhland probe in aluminum cores measuring 76 mm × 76 mm diam. at depths of 0–10, 10–20 and 20–30 cm. The soil cores were then used to determine soil bulk density using the core method (Blake and Hartge, 1986), K_{sat} (Klute and Dirksen, 1986) and total porosity and pore size distribution (Danielson and Sutherland, 1986). Soil samples were collected periodically over the growing season using a stainless steel push probe and compositing 8–15 subsamples per plot at a depth of

Table 1
Selected initial soil properties of unamended soil at the Bradford Agronomy Center in 2000

Depth	pH (water)	Total organic C (g kg^{-1})	Total N (g kg^{-1})	Soil inorganic N		Texture		
				NH$_4^+$-N (mg kg^{-1})	NO$_3^-$-N (mg kg^{-1})	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})
0–10	6.04 ± 0.10[a]	15.7 ± 0.8	1.1 ± 0.1	3.2 ± 0.6	11.5 ± 1.6	57 ± 4	738 ± 15	206 ± 12
10–20	6.05 ± 0.16	14.7 ± 0.7	1.0 ± 0.1	3.0 ± 0.7	6.0 ± 1.9	50 ± 4	725 ± 19	225 ± 21
20–30	5.75 ± 0.33	13.5 ± 0.6	0.9 ± 0.1	3.1 ± 0.8	3.3 ± 1.8	36 ± 6	591 ± 83	373 ± 93

[a] Mean ± standard deviation.

0–10, 10–20 and 20–30 cm. One half of each soil sample was air dried, ground and passed through a 2-mm mesh sieve for chemical analysis and the other half was kept field moist and stored at 4 °C to determine gravimetric soil water content after drying at 105 °C. Air-dried soils were analyzed for soil inorganic N.

2.3. Statistical analysis

Analysis of variance was used for evaluating the effects of compaction and poultry litter applications on soil inorganic N, NH$_4^+$-N, gravimetric soil water content and selected soil physical properties for the laboratory incubationand the field experiments (SAS Institute, 2001). The statistical model used for the field experiment was repeated measures (split plot in space and time), except for soil physical properties. The multiple comparison test used was Fisher's (protected) LSD or Duncan's critical range at $P \leq 0.05$. Non-linear regression was used to model the relationship between net N mineralized in the laboratory incubation with time (Systat Software Inc., 2002) using the model: $N_t = N_0(1 - e^{-kt})$, where N_0 and N_t are the net inorganic N in the soil at initiation and at time (t) of incubation and k is the mineralization rate of N (day^{-1}).

Net N mineralized was determined by subtracting initial soil inorganic N (Day 0). The relationships between soil physical properties and soil inorganic N at 28 days of incubation were determined using Pearson linear correlation analysis and linear regression analysis for soil bulk density.

3. Results and discussion

3.1. Changes in soil physical properties with compaction in the incubation study

As expected, increasing soil bulk density from 1.2 to 1.8 Mg m^{-3} significantly reduced K_{sat} and total porosity, and shifted the proportion of macropores to nicropores (Table 2). Total porosity decreased approximately 25% and the proportion of soil micropores increased 45% by compaction of the soil from 1.2 to 1.8 Mg m^{-3} (Table 2). The effect of adding poultry litter on these soil physical properties was less consistent across the four soil bulk density levels, probably because soil bulk density levels were established after the litter was added to soil. The effects of organic amendments on soil physical properties are dependent on rate of application (Khaleel
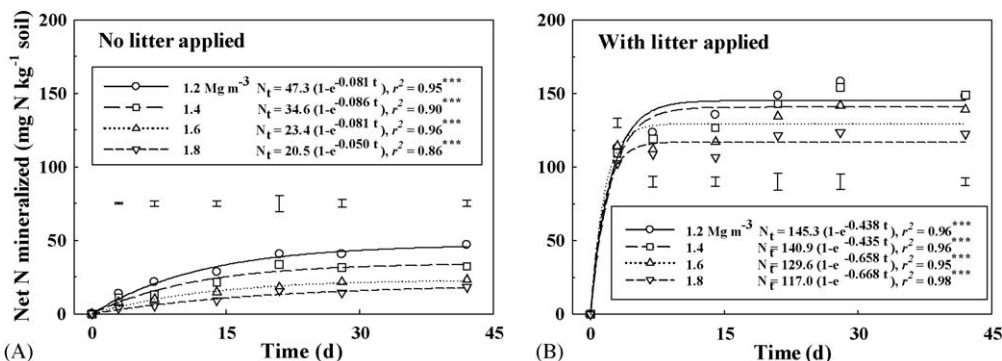

Fig. 2. Net soil inorganic N mineralized during 42 days with increasing soil bulk density under conditions of (A) no litter applied and (B) litter applied. Vertical bars indicate LSD$_{(0.05)}$. Lines are from non-linear regression models using first-order kinetics [$N_t = N_0(1 - e^{-kt})$, where N_0 and N_t are soil inorganic N (mg N kg^{-1} soil) initially and at time (t) of incubation and k is the N mineralization rate (day^{-1})]. [***]Significance at $P < 0.001$.

et al., 1981; Sommerfeldt and Chang, 1985), degree of mixing (Gupta et al., 1987) and rate of decomposition of added organic material (Guerief, 1979).

3.2. N mineralization in the incubation study

Increasing soil bulk density from 1.2 to 1.8 Mg m^{-3} significantly decreased soil inorganic N (NH_4^+-N + NO_3^--N) by 16–45% (Fig. 2A and B). Lower soil inorganic N induced by soil compaction indicates reduction of N mineralization as was also observed by Breland and Hansen (1996). In the unamended soil, NH_4^--N was not affected by soil bulk density (Fig. 3A). In contrast, NH_4^+-N in the litter-amended soil at a soil bulk density of 1.8 Mg m^{-3} was a maximum of 7.2 times higher than that observed at the 1.2 Mg m^{-3} soil bulk density level and this effect was observed until Day 28 of the incubation (Fig. 3B). De Neve and Hofman (2000) observed that NH_4^+-N increased with increasing bulk density for both crop-residue-amended and unamended soils.

3.3. First-order kinetic model for N mineralization in the incubation study

The relationship between net N mineralized and time at different bulk densities had high coefficient of determination ($r^2 > 0.86$) for both litter-amended and unamended soils (Fig. 2A and B). Potentially mineralizable N (N_0) decreased with an increase of soil bulk density, more so in unamended than amended soil (Fig. 2A and B). Due to more readily available N forms in applied litter, N_0 decreased less with increasing bulk density in litter-amended soil than in unamended soil. The decrease of N_0 indicates that N substrates may have been physically protected due to the effect of soil compaction and, therefore, were less accessible to soil microorganisms and N mineralization (Breland and Hansen, 1996). The rate of N mineralization was reduced in unamended soil at 1.8 Mg m^{-3} compared to 1.2 Mg m^{-3} (Fig. 2A), which indicated less favorable conditions, such as inadequate aeration.

3.4. Relationship between soil inorganic N and soil physical properties

Correlations between soil inorganic N at 28 days of incubation and soil physical properties were assessed separately for litter-amended and unamended soil (Table 3). Correlations between soil NH_4^+-N and soil physical properties were not significant. Soil inorganic N in unamended soil was negatively correlated with soil

Table 2
Effects of surface compaction and poultry litter application on selected soil physical properties measured before the initiation of the incubation

Bulk density (Mg m^{-3})	log K_{sat}[a] (cm h^{-1})			Total porosity (m^3 m^{-3})			Pore size distribution (m^3 m^{-3} as proportion of total porosity)												
							Macropores[b]			Coarse mesopores			Fine mesopores			Micropores		
	Check	Litter	LSD[c]	Check	Litter	LSD	Check	Litter	LSD	Check	Litter	LSD	Check	Litter	LSD	Check	Litter	LSD
1.2	2.20	1.83	0.34	0.546	0.547	ns	0.040	0.050	ns	0.231	0.218	ns	0.090	0.098	ns	0.639	0.634	ns
1.4	−0.42	−0.74	0.06	0.473	0.475	ns	0.025	0.045	0.019	0.037	0.049	ns	0.194	0.156	0.016	0.744	0.750	0.004
1.6	−1.62	−1.73	ns	0.434	0.444	0.004	0.023	0.007	ns	0.011	0.034	0.009	0.105	0.098	ns	0.861	0.861	ns
1.8	−2.04	−2.00	ns	0.406	0.414	ns	0.005	0.005	ns	0.021	0.015	ns	0.059	0.060	ns	0.915	0.920	ns
LSD	0.23	0.24		0.007	0.008		0.014	0.018		0.020	0.019		0.007	0.014		0.014	0.020	

ns: not significant.
[a] K_{sat} (saturated hydraulic conductivity).
[b] Macropores (>500 μm radius), coarse mesopores (25–500 μm radius), fine mesopores (5–25 μm radius) and micropores (<5 μm radius).
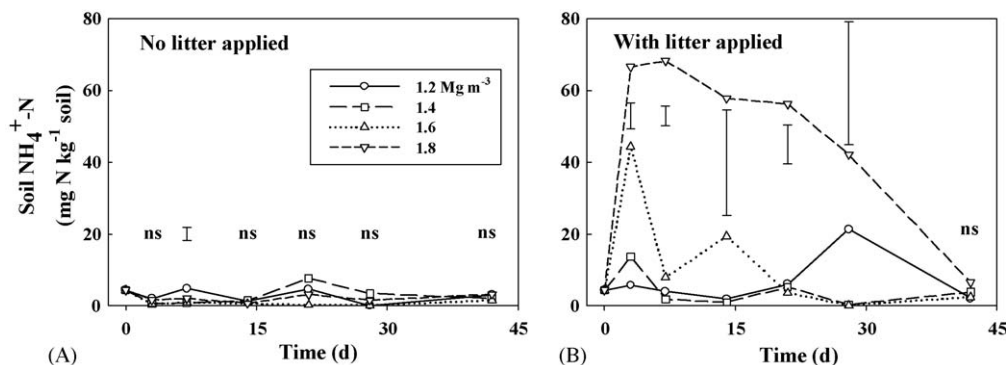[c] LSD is least significant difference at $P < 0.05$.

Fig. 3. Soil NH_4^+-N during 42 days of incubation as affected by bulk density under conditions of (A) no litter applied and (B) litter applied. Vertical bars indicate $LSD_{(0.05)}$.

bulk density and proportion of soil micropores and positively correlated with K_{sat}, total porosity and proportion of macropores. In litter-amended soil, soil inorganic N was negatively correlated with soil bulk density and positively correlated with total porosity. The slopes of soil inorganic N regressed upon bulk density were not significantly different between amended (soil inorganic N = $-61.82 \times$ soil bulk density + 250; $r^2 = 0.80^{***}$) and unamended (soil inorganic N = $-47.58 \times$ soil bulk density + 112; $r^2 = 0.95^{***}$) soil. Therefore, soil N mineralization could be predicted based on soil bulk density.

Soil compaction may have reduced the accessibility of soil microorganisms to substrates and water by shifting pore distribution to a smaller pore size class.

With compaction, soil aeration was reduced and soil microbial processes may have been restricted. However, addition of an organic substrate may have mitigated some of these compaction effects by stimulating microbial activity due to addition of biologically labile substrate.

3.5. Changes in soil physical properties with compaction and litter amendment in the field study

As was observed in the incubation study, surface compaction in the field study significantly decreased K_{sat}, total soil porosity and proportion of macropores and coarse mesopores in soil (Table 4). Soil bulk density and proportion of micropores were increased with compaction. All effects of soil compaction were limited to the 0–10 cm depth. The effect of applied poultry litter on soil physical properties was not significant at any depth.

3.6. Soil mineral N and gravimetric soil water content in the field study

The main effects of compaction, cropping (fallow or planted areas), poultry litter application and sampling time were significant for NH_4^+-N, soil inorganic N and gravimetric soil water content (except for litter treatment), but not consistent among depths (Table 5). A two-way interaction between sampling date and compaction or cropping or litter application was mostly observed to a depth of 20 cm (Table 5).

In general, soil NH_4^+-N was lower with cropping than fallow only in the 20–30 cm depth ($P = 0.05$; Fig. 4), while soil inorganic N was lower with cropping than fallow at all depths (Fig. 5; Table 5). Lower soil water content was also found with cropping than fallow in the 0–10 and 20–30 cm depths (Fig. 6; Table 5),

Table 3
Correlation coefficients (r) between soil inorganic N at 28 days of the incubation in litter-amended and unamend soils and soil physical properties

Soil physical property	n	Soil inorganic N	
		Unamended	Amended
Bulk density	12	-0.98^{***}	-0.90^{***}
log K_{sat} [a]	4	0.96^{*}	0.79 ns
Total porosity	4	0.99^{**}	0.98^{*}
Macropores[b]	4	0.95^{*}	0.89 ns
Coarse mesopores	4	0.83 ns	0.70 ns
Fine mesopores	4	0.39 ns	0.73 ns
Micropores	4	-0.99^{**}	-0.92 ns

ns: not significant.

[a] K_{sat} (saturated hydraulic conductivitiy).

[b] Macropores (>500 μm radius), coarse mesopores (25–500 μm radius), fine mesopores (5–25 μm radius) and micropores (<5 μm radius).

[*] Significance at $P < 0.05$ level.

[**] Significance at $P < 0.01$ level.

[***] Significance at $P < 0.001$ level.

Table 4
Main effect of compaction on selected soil physical properties in the field study in 2002

Soil properties	Soil depth (cm)								
	0–10			10–20			20–30		
	Non-compacted	Compacted	$P > F$	Non-compacted	Compacted	$P > F$	Non-compacted	Compacted	$P > F$
Bulk density (Mg m^{-3})	1.27	1.40	0.02	1.42	1.49	0.33	1.34	1.34	0.96
K_{sat} (cm h^{-1})	127.97	33.31	0.06	10.23	4.65	0.61	3.05	5.86	0.52
Total porosity (m^3 m^{-3})	0.521	0.470	0.03	0.462	0.436	0.32	0.494	0.492	0.95
Macropores[*]	0.048	0.022	0.02	0.025	0.015	0.53	0.018	0.012	0.53
Coarse mesopores[*]	0.144	0.088	0.09	0.064	0.054	0.76	0.055	0.070	0.68
Fine mesopores[*]	0.097	0.082	0.25	0.067	0.055	0.12	0.072	0.056	0.13
Micropores[*]	0.711	0.808	0.01	0.844	0.876	0.54	0.855	0.862	0.83

Macropores (>500 μm radius), coarse mesopores (25–500 μm radius), fine mesopores (5–25 μm radius) and micropores (<5 μm radius).

[*] Expressed in m^3 m^{-3} as a proportion of total porosity.

indicating significant corn uptake of N and water, especially later on in the cropping season. Cropping of corn had less effect on NH$_4^+$-N, possibly because NH$_4^+$-N was a less favorable form for plant root uptake compared to NO$_3^+$-N.

Compaction significantly increased NH$_4^+$ in the 0–10 and 10–20 cm depths (Fig. 4). Higher NH$_4^+$-N was observed in amended, compacted soil at the beginning of growing season (June/July), attributable to an immediate increase of NH$_4^+$-N after addition of litter
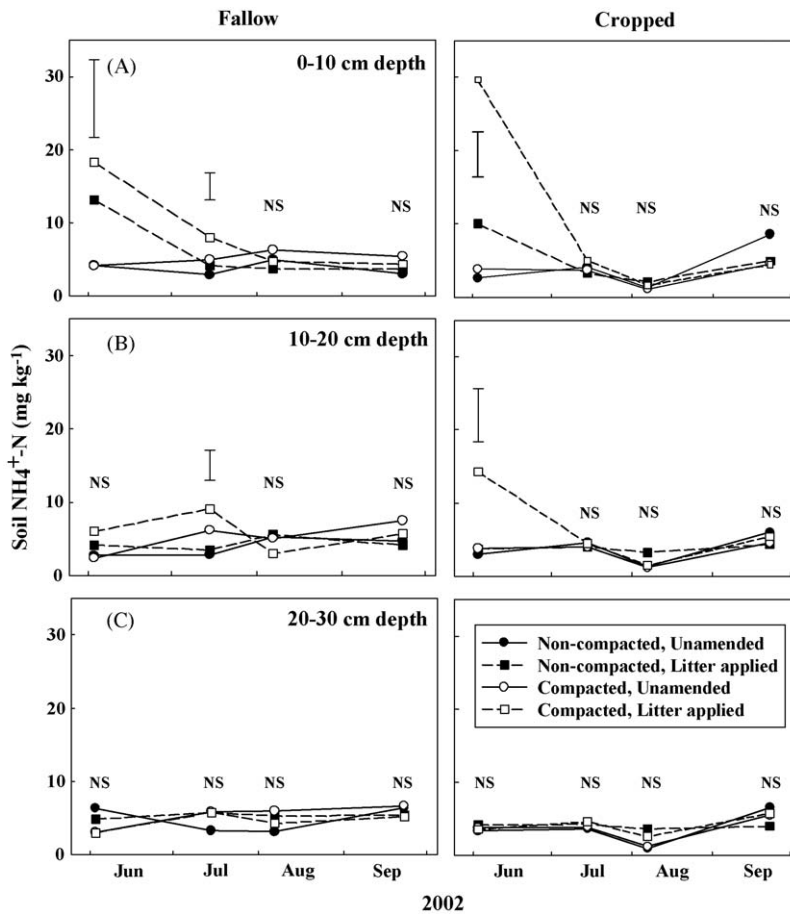

Fig. 4. Soil NH$_4^+$-N as affected by compaction and poultry litter application at (A) 0–10 cm, (B) 10–20 cm and (C) 20–30 cm depth under fallow and with corn cropping during the 2002 growing season. Vertical bars indicate Duncan's critical range at $\alpha = 0.05$ and ns is not significant.
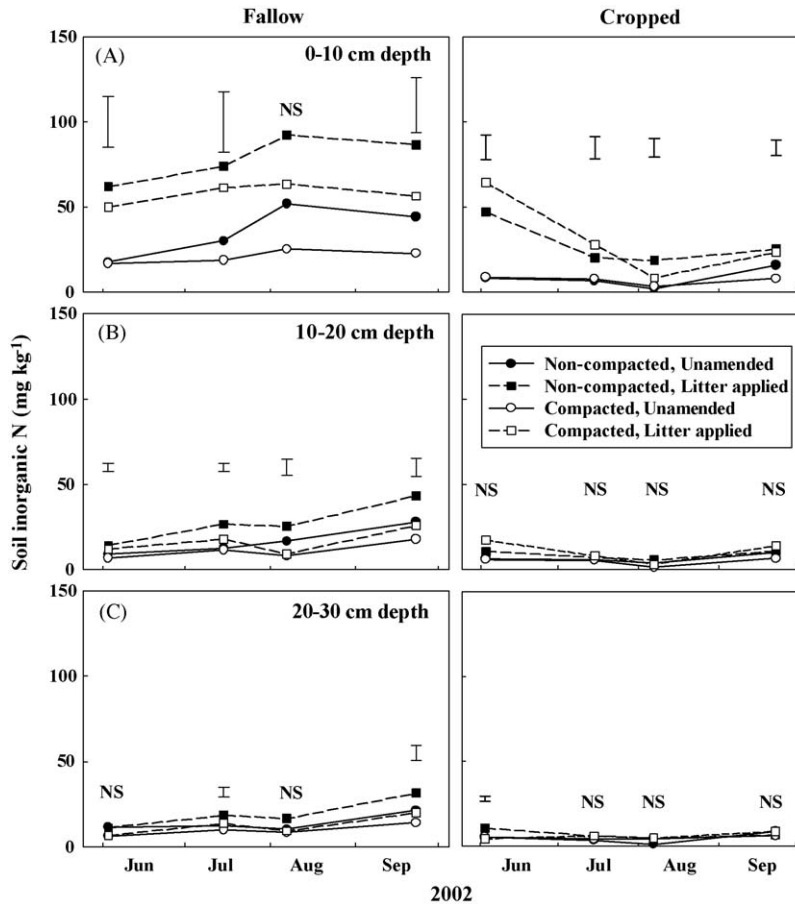
Fig. 5. Soil inorganic N as affected by compaction and poultry litter application at (A) 0–10 cm, (B) 10–20 cm and (C) 20–30 cm depth under fallow and with corn cropping during the 2002 growing season. Vertical bars indicate Duncan's critical range at $\alpha = 0.05$ and ns is not significant.

and possible reduction in soil aeration due to compaction. This observation was also in agreement with the results found in the incubation study.

Reduced levels of soil inorganic N with compaction were observed in both litter-amended and unamended soils to a depth of 30 cm throughout the growing season, especially in fallow (Fig. 5). With cropping, the effect of compaction on soil inorganic N was more pronounced in the 0–10 cm depth. Previous research has shown lower net N mineralization in compacted than noncompacted soil under pasture (Jensen et al., 1996). The reduced impact of compaction on soil inorganic N with cropping may be attributed to higher N uptake by corn.

Lower soil inorganic N in fallow, compacted soil may have been due to several reasons. Reduced N mineralization in compacted soil may be attributed to restricted soil aeration, decreased soil water content and microbial inaccessibility to water, particularly in the upper soil depth. In claypan soils, low soil aeration is

often a feature even in noncompacted soil. Jamison et al. (1968) observed O_2 diffusion into a wet claypan was greatly restricted due to the fine porosity of claypan soils, even though it was not compacted. Therefore, the effect of compaction on soil aeration and N mineralization may be more severe in claypan soils. Restricted soil aeration in compacted soil may also have led to N loss through denitrification (Ball et al., 1999). This is of interest because soil NO_3^- concentration can be elevated above the claypan layer (Blevins et al., 1996), which may lead to higher rates of denitrification.

In general, soil water content in the litter-amended, compacted soil was higher in the 0–20 cm depth early in the season and then became lower later in the year relative to the noncompacted soil under fallow (Fig. 6). Compaction may have initially reduced water loss through evaporation at the soil surface, but once the soil became dry, compacted soil had less ability to recharge water. Jamison et al. (1968) also reported that claypan

Table 5
Analysis of variance of soil NH_4^+-N, soil inorganic N (SIN) and gravimetric soil water content (SWC) for main and interactive effects of soil compaction, cropping (fallow or planted areas), treatment (poultry litter) and sampling time (month)

| Source of variation	$P > F$								
	0–10 cm[a]			10–20 cm[a]			20–30 cm[a]		
	NH_4^+-N	SIN	SWC	NH_4^+-N	SIN	SWC	NH_4^+-N	SIN	SWC
Soil compaction (C)	0.004	0.14	0.006	0.01	0.004	0.17	0.89	0.01	0.08
Cropping (P)	0.60	<0.001	0.028	0.27	<0.001	0.13	0.05	<0.001	0.007
C × P	0.94	0.11	0.33	0.67	0.003	0.90	0.98	0.02	0.71
Treatments (Trt)	<0.001	<0.001	0.06	0.03	<0.001	0.33	0.55	<0.001	0.15
C × Trt	0.01	0.94	0.86	0.09	0.54	0.20	0.57	0.13	0.43
P × Trt	0.47	0.04	0.28	0.25	0.02	0.07	0.52	0.04	0.07
C × P × Trt	0.07	0.53	0.73	0.13	0.01	0.80	0.42	0.59	0.54
Time	<0.001	0.46	<0.001	0.04	<0.001	<0.001	0.01	<0.001	<0.001
C × time	0.001	0.008	0.05	0.01	<0.001	0.18	0.30	0.11	0.12
P × time	0.01	<0.001	<0.001	0.002	<0.001	<0.001	0.23	<0.001	<0.001
C × P × time	0.005	0.87	0.58	0.005	0.10	0.65	0.34	0.15	0.12
Trt × time	<0.001	0.008	0.50	0.002	0.03	0.82	0.13	0.28	0.92
C × Trt × time	0.002	0.79	0.98	0.02	0.08	0.75	0.35	0.55	0.14
P × Trt × time	0.12	0.006	0.18	0.21	0.004	0.15	0.72	0.03	0.62
C × P × Trt × time	0.16	0.44	0.26	0.31	0.68	0.43	0.51	0.13	0.81

[a] Depth.
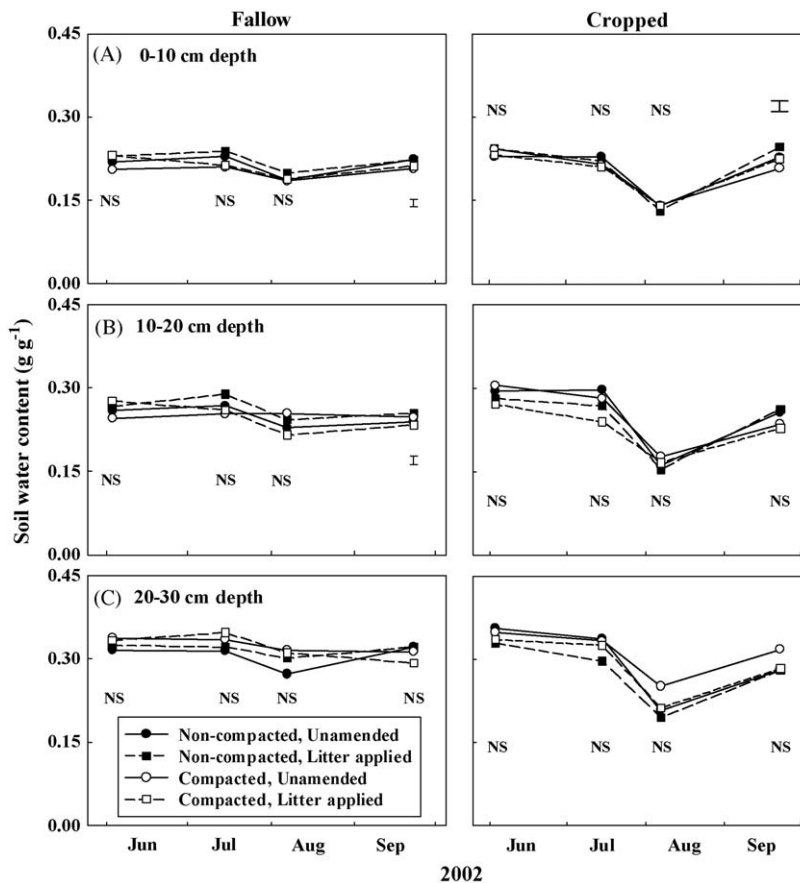
Fig. 6. Soil water content as affected by compaction and poultry litter application at (A) 0–10 cm, (B) 10–20 cm and (C) 20–30 cm depth under fallow and with corn cropping during the 2002 growing season. Vertical bars indicate Duncan's critical range at $\alpha = 0.05$ and ns is not significant.

soils could restrict water movement and increase water storage capacity when wet, but water recharge under dry conditions would be limited due to the low rate of water infiltration. As a result, compaction in claypan soils may cause variable effects on soil water content during the growing season. Compaction had less effect on soil water content with cropping, due to soil water uptake by corn roots. Therefore, restriction of N mineralization in compacted soil may have partly been a result of lower (but inconsistent) soil water content in the upper soil horizons.

Litter application increased NH_4^+-N to a depth of 20 cm (Fig. 4) and soil inorganic N at all depths (Fig. 5), but had no significant effect on gravimetric soil water content (Table 5). More readily available forms of N may have been provided by litter, resulting in a sharp increase in soil inorganic N immediately after application. Litter application may enhance rates of soil N mineralization and overcome the negative effects of compaction on N mineralization. This result was also in agreement with previous research (Paul and Beauchamp, 1996; Nyakatawa et al., 2001). Motavalli et al. (2003) observed, in the same experimental site in 2000 and 2001, higher soil inorganic N in poultry litter-amended soils compared to unamended soils, and also found that silage and grain yield increased with increasing rate of poultry litter. However, in their study, surface compaction reduced silage and grain yield.

4. Conclusions

Results of this study provide for a better understanding of the effects of compaction and organic amendments on N mineralization in claypan soils. Surface soil compaction reduced rates of N mineralization in claypan soils, possibly because of reduced soil aeration and variable soil water content during the growing season. In addition, the negative effect of soil compaction on N mineralization may have been due to a reduction of N_0, as a result of the physical protection of N substrates from soil microorganisms. Under controlled soil water content and temperature in the laboratory, changes in soil bulk density were a good predictor of soil N mineralization. Application of poultry litter enhanced rates of soil N mineralization by promoting more favorable conditions for soil microorganisms. Therefore, addition of organic amendments may minimize the negative effects of soil compaction by increasing N mineralization and N availability for crops in agricultural soils. However, the effects of both soil compaction and litter application on soil N

mineralization were mitigated by climatic variation experienced under field conditions.

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