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Effects of soil compaction, forest leaf litter and nitrogen fertilizer on two oak species and microbial activity

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Abstract

A greenhouse study examined the effects of soil compaction and forest leaf litter on the growth and nitrogen (N) uptake and recovery of red oak (*Quercus rubra* L.) and scarlet oak (*Quercus coccinea* Muencch) seedlings and selected microbial activity over a 6-month period. The experiment had a randomized complete block design with three replications. Ammonium ^{15}N-sulfate at 33 mg ^{15}N kg^{-1} was used to quantify seedling N uptake and recovery. After 6 months, seedlings were harvested and analyzed for dry matter production, total N, ^{15}N uptake and N derived from ^{15}N labeled fertilizer (Ndff). Soil enzyme activity and soil microbial biomass C and N were measured as indicators of microbial activity.

Soil compaction significantly decreased seedling height, dry matter production, and ^{15}N recovery of both oak species. Significantly greater N losses were observed in compacted pots compared with the non-compacted pots. Less ^{15}N was immobilized in the soil microbial biomass in the compacted pots than under non-compacted conditions, probably due to greater overall ^{15}N losses in the compacted conditions. Soil compaction significantly affected microbial activity by reducing acid phosphatase. Severe soil compaction decreased young tree growth and reduced N fertilizer uptake.

Keywords: Soil compaction; Forest leaf litter; Nitrogen; Microbial activity; Red oak seedling (*Quercus rubra* L.); Scarlet oak seedling (*Quercus coccinea* Muencch)

1. Introduction

There is a general concern that intensive forest harvesting may cause a considerable decline in future soil productivity (Ponder et al., 1999). Impacts of intensive harvesting operations may include soil compaction, surface soil structure degradation, decrease in nutrient availability due to biomass removals or erosion and increased sediment yield as a result of erosion (Dyrness, 1965; Moffat, 1991). Soil compaction, where the soil pore volume is reduced and pore size distribution may be changed, is one of the key forest disturbances being examined on soil and plant variables in a national study conducted by the U.S. Forest Service (Powers et al., 1990). This network of coordinated long-term experiments examines forest management practices that may affect long-term soil and site productivity (LTSP) through field studies (Ponder and Mikkelson, 1995; Stone and Elioff, 1998; Jordan et al., 1999). Greenhouse studies were conducted as preliminary

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studies to assess more accurately the impact of improper forest management practice on tree species, microbial activity, and nitrogen transformations.

Soil compaction may not pose a serious threat to established trees but may be detrimental to seedling growth and survival. Moehring and Rawls (1970) reported that compaction reduced the survival of trees in replanted areas by as much as 57%. When planted in compacted soils, young seedlings are more susceptible to water stress and N deficiencies (Youngberg, 1959; Reisinger et al., 1988).

In addition to reducing tree or seedling growth and establishment, severe soil compaction often affects nutrient availability, especially N. Nitrogen is needed for effective seedling growth and is often the most limiting nutrient. Any management practice which reduces N availability can change the productivity of that forest ecosystem. Both van der Linden et al. (1989) and Breland and Hansen (1996) found that soil compaction reduced N mineralization and N availability. Because of the possible creation of anaerobiosis under compacted soil conditions, generally more N is lost from the soil system. Denitrification is generally thought to be the likely process of N loss from compacted soil condition. The amount of N loss may vary widely among soils and ecosystems and the loss may be attributed to both denitrification and leaching.

The effect of soil compaction on the microbial activity varies. Soil compaction is generally thought to decrease microbial activity like soil respiration or enzyme activity, due to the air-filled pore spaces but the results of the few studies conducted varies (Dick et al., 1988; Wronski and Murphy, 1994; Startsev et al., 1998). Dick et al. (1988) showed that soil phosphatase activity was reduced in compacted forest sites in Oregon. Other microbial properties like soil microbial biomass carbon was unaffected or decreased depending on environmental conditions.

There is a need for studies that address the impact of soil disturbances on tree seedling growth, N transformations, and soil microbial activity in ecosystems like the Missouri Ozark, where very few studies have been conducted. This need led us to determine the effect of soil compaction, N fertilizer and surface-placed forest leaf litter additions on two different oak species and microbial activity in a controlled environment using ^{15}N as a tracer to follow the soil, plant, and microbial pools over a 6-month period.

2. Materials and methods

The experiment was conducted in a greenhouse located on the University of Missouri-Columbia campus for 6 months (May–November, 1998). The soil, a loamy-skeletal, mixed, mesic Typic Paleudults (Ultisol), used in the study was collected near Ellington, Missouri from the Department of Conservation, Carr Creek State Forest. The soil pH was 5.7, organic matter content 27 g kg^{-1}, total N was 1.30 g kg^{-1}. Because the soil contained rocks and small stones, it was air-dried and sieved before applying the compaction treatment using a drop hammer. The soil was uniformly compacted to a bulk density of 1.8 g dry soil cm^{-3} which was 9.3 kg of dry soil per pot using a drop hammer. The non-compacted pots received no compaction and its bulk density was 1.3 g dry soil cm^{-3} using 6.7 kg of dry soil per pot. Soil bulk densities were determined by the core method (Blake and Hartge, 1986).

The experiment was a randomized complete block design with three factors and three replications. The three factors used were soil compaction, forest leaf litter, and ^{15}N fertilizer. Treatments include severe compaction (C_1) and no compaction (C_0), forest leaf litter added (FLL_1-50 g per pot) and no forest leaf litter (FLL_0) and ^{15}N addition or no ^{15}N added to two tree species (T_1 and T_2). T_1 represented the red oak seedling, *Quercus rubra* L. and T_2 represented the scarlet oak seedling, *Quercus coccinea* Muencch. Severe and non-compacted treatments were selected to mimic current field conditions at the field site in Ellington, MO (Ponder and Mikkelson, 1995). Each oak seedling represented a tree species found at the field site. The forest leaf litter was dried leaves collected from the field site near Ellington, MO as a source of surface organic matter. The leaves were cut into fine parts (about 2 cm) and evenly spread across on top of the PVC pots on June 5 about 2 weeks following the planting of the oak seedlings. Pots were made from PVC pipes, 15.2 cm (diameter) × 36 cm long. The pots were attached with plastic mesh at one end of the pipe to support soil and provide drainage. The oak seedlings used had been pre-germinated for 2 days and planted to a depth of 4 cm. Care was taken during planting not to damage root tips on germinated seeds. The seedlings were watered on a specific schedule (every 3–4 days) to reduce soil moisture as

a factor. Pots were weighed gravimetrically to determine the appropriate quantity of water (500–800 ml pot^{-1}) to add to the compacted and non-compacted treatments. Tracer ^{15}N was used to quantify N uptake by oak seedlings, soil and microbial pools. Each pot received 16.5 mg ^{15}N kg^{-1}as ammonium sulfate (99.4 at.% enrichment) at 2 days and 15 days after planting. The total amount of ^{15}N added to each compacted pot was 307 and 222 mg to each non-compacted pot. Oak seedlings, red oak (*Quercus rubra* L.) and scarlet oak (*Quercus coccinea* Muencch), were grown for 6 months, harvested and analyzed for dry matter production, total N, and ^{15}N uptake. The oak seedlings were carefully collected, dried at 60 °C and grinded separately to prevent cross-contamination of ^{15}N. The plant samples were sent in separate vials for analyses to the Mass Isotope facility at the University of California-Davis.

During the harvest, soil samples were taken from the pots and kept cool until subsequent laboratory analyses. For each composite soil sample, soil moisture (MC, dried at 105 °C for 24 h), soil inorganic N (SIN, 0.5 K_2SO_4 extract), soil microbial biomass C (SMBC, Horwath and Paul, 1994) and soil microbial biomass N and ^{15}N (SMBN, Brookes et al., 1985a, b, respectively) were determined. Acid phosphatase and alkaline phosphatase were determined using the method of Tabatabai (1994).

Data were analyzed by ANOVA (SAS, 1989) and least significant difference (LSD) mean separation test was used where significant differences occurred.

3. Results

Oak seedlings in compacted pots began to emerge 6 days later than those in non-compacted pots. Fifty percent of the severely compacted pots (C_1) were replanted and seedling mortality was 70% before harvest. Mortality rate for both red and scarlet oak was similar in compacted pots. No replanting was done in the non-compacted pots and all seedlings were healthy at harvest.

3.1. Effect of treatments on plant and soil variables

Soil compaction significantly affected most of the plant and soil variables measured (Table 1). The uptake and recovery of ^{15}N in the plant (oak seedlings), forest leaf litter and most of the soil pools were significantly reduced. Total ^{15}N losses were significantly affected by soil compaction. Conversely, the application of forest leaf litter to the soil surface had no effect on the plant and soil variables measured. There was a significant interaction between compaction and forest leaf litter on ^{15}N uptake and recovery.

Table 1
Analysis of variance (*P*-values) for plant growth variables, forest leaf litter (FLL) and soil N uptake in a greenhouse study

Source of variation[a]	Plant[b]						^{15}N Uptake					
	Height	Total DM	Ndff	Ndfs	Plant	FLL	Total soil	Inorganic soil	Organic soil	SMB[c] soil organic fraction	Remaining soil organic fraction	Total ^{15}N losses
Compaction	0.0001	0.0001	0.008	0.008	0.0001	0.0004	0.0001	0.0002	0.0406	0.012	0.064	0.0001
FLL	0.844	0.167	0.018	0.018	0.136	0.0001	0.2625	0.9158	0.2498	0.219	0.296	0.2006
Compaction × FLL	0.730	0.500	0.284	0.283	0.051	0.0004	0.371	0.977	0.337	0.399	0.378	0.892
Tree species	0.0001	0.0002	0.040	0.040	0.0003	0.1911	0.096	0.073	0.680	0.281	0.738	0.898
Compaction × tree	0.0001	0.001	0.188	0.187	0.0019	0.4409	0.344	0.459	0.645	0.544	0.682	0.661
FLL × tree	0.3343	0.412	0.068	0.168	0.8853	0.1911	0.706	0.960	0.707	0.627	0.738	0.551
Compaction × FLL × tree	0.708	0.882	0.134	0.133	0.897	0.4409	0.040	0.142	0.253	0.571	0.255	0.089

Obtained by difference, remaining organic fraction.

[a] Soil compaction: without compaction, bulk density: 1.3 g cm^{-3}; with compaction, bulk density: 1.8 g cm^{-3}; forest leaf litter: without forest leaf litter, 0 g per pot, with forest leaf litter, 50 g per pot; tree species: red oak and scarlet oak.

[b] Total DM: total dry matter included roots, stems, and leaves; Ndff and Ndfs: nitrogen derived from fertilizer and from soil, respectively.

[c] SMB: Soil microbial biomass ^{15}N.

Table 2
Effects of soil compaction and oak seedling interactions on plant growth and percent recovery[a] after 6 months

Oak seedling	Plant Height (cm)		Plant total dry matter[b] (g)		^{15}N recovery (%)	
	C_0[c]	C_1[d]	C_0	C_1	C_0	C_1
Red Oak	73.3 a	10.2 c	42 a	3.3 c	41 a	3.8 c
Scarlet Oak	31.8 b	5.6 c	23 b	1.6 c	28 b	2.5 c

[a] Values having the same letter(s) are not significantly different by LSD at $P < 0.05$.
[b] Plant total dry matter includes roots, stems and leaves.
[c] C_0: without compaction, bulk density is 1.3 g cm^{-3}.
[d] C_1: with compaction, bulk density is 1.8 g cm^{-3}.

The significant effects of soil compaction and tree species interactions on plant growth (oak seedlings) on plant growth and total ^{15}N and percent recovery were observed (Table 2). Soil compaction significantly reduced oak height, total dry matter production, and percent ^{15}N recovery. The height of the red oak and scarlet oak were reduced about seven times more in the compacted pots compared with the non-compacted pots. A similar but more marked effect of compaction was seen on the total dry matter production of the red and scarlet oak seedlings. The compacted pots' total dry matter production was reduced more than 10 times that of the non-compacted pots. Red oak produced greater total dry matter production and grew taller than scarlet oak seedlings.

One of the goals of the study was to understand the impact of compaction on the uptake of N by oak seedlings. Severe soil compaction significantly reduced the uptake and recovery of the added ^{15}N (Table 2) in both the red and the scarlet oak. In compacted pots, ^{15}N recovery was measured about 3 and 4% for the scarlet oak and red oak, respectively. In the non-compacted pots, 41% of the N could be accounted for in the red oak and 28% for the scarlet oak. Regardless of treatment, the scarlet oak seemed to be more adversely affected by soil compaction than the red oak.

3.2. Interaction of treatments

There was a significant interaction between soil compaction, forest leaf litter additions and tree species on total ^{15}N percent recovery (Table 3). In general, soil compaction reduced ^{15}N recovery for both scarlet and red oak. When no forest leaf litter (FLL_0) was added to the soil surface, significantly greater ^{15}N was taken up and recovered in the non-compacted pots for both red and scarlet oak. When forest leaf litter (FLL_1) was added, no significant differences were observed between compacted and non-compacted pots for red oak. However, when forest leaf litter (FLL_1) was added to scarlet oak pots, significantly greater ^{15}N was recovered under non-compacted soil conditions. When the pots were not compacted, about two times as much ^{15}N was recovered. In general, the non-compacted pots tended to recover more of the added ^{15}N than in the compacted pots.

3.3. Effect of N source (fertilizer versus native soil N)

Nitrogen-15 was used as a fertilizer source to the oak seedlings. After a 6-month growing period, about 15–20% of the N in the oak seedlings were derived from the applied ^{15}N fertilizer and 80–85% were derived from the native soil N regardless of soil compaction, forest leaf litter additions or tree species (Table 4). Significantly greater N was derived from

Table 3
Effects of the different levels of soil compaction (C_0 and C_1)[a], forest leaf litter and tree species (red oak and scarlet oak) interaction effects on total soil ^{15}N recovery (%)[b]

Forest leaf litter[c]	Red oak		Scarlet oak	
	C_0	C_1	C_0	C_1
FLL_0	55 ab	29 c	58 a	41 c
FLL_1	42 bc	37 c	57 a	31 c

[a] C_0: without compaction, bulk density = 1.3 g cm^{-3}; C_1: with compaction, bulk density = 1.8 g cm^{-3}.
[b] Values with the same letter(s) are not significantly different using LSD at $P < 0.05$.
[c] FLL_0: without leaf litter added to pot (0 g); FLL_1: with leaf litter added to pot (50 g).

Table 4
Average effects of soil compaction, forest leaf litter, and oak seedlings on nitrogen derived from the fertilizer (Ndff) and N derived from the soil (Ndfs)[a]

Source of N (%)	Soil compaction[b]		Forest leaf litter[c]		Tree species[d]	
	C_0	C_1	FLL_0	FLL_1	T_1	T_2
Ndff	16 b	19 a	16 b	19 a	16 b	18 a
Ndfs	84 c	81 d	84 c	81 d	84 c	82 d

[a] Values with the same letter(s) are not significantly different using LSD at $P < 0.05$.
[b] C_0: without compaction, bulk density = 1.3 g cm^{-3}; C_1: with compaction, bulk density = 1.8 g cm^{-3}.
[c] FLL_0: without leaf litter added to pot (0 g); FLL_1: with leaf litter added to pot (50 g).
[d] T_1: red oak; T_2: scarlet oak.

the fertilizer in the compacted pots, where forest leaf litter had been added to the surface of the pots and in pots where scarlet oak was grown. The exact opposite was true for soil-derived N (NDFS). Significantly more N was derived form the soil when pots were non-compacted and no forest leaf litter was added. Red oak seedlings had significantly more N from the soil compared with the scarlet oak seedlings.

3.4. Fate of the ^{15}N additions

We were able to account for N pools based on soil compaction by using tracer ^{15}N. When pots were not compacted, about 90% of the ^{15}N was recovered in the measured soil and plant variables with about a 10% loss (Table 5). When pots were compacted, about 40% of the ^{15}N was found in the measured soil and plant pools with about 60% loss from the system. Regardless of soil compaction, most of the ^{15}N was found in the soil pools as expected. The organic and inorganic pools had significantly greater ^{15}N in the non-compacted pots compared to the compacted pots. For example, when pots were not compacted, about 17% of the ^{15}N was recovered in the inorganic soil pool. When soil was not compacted, the oak seedlings were able to capture 34% of available ^{15}N compared with about 3% when the soil was compacted.

3.5. Effect of treatments on microbial activity

We wanted to know the effect of soil compaction, forest leaf litter, addition of N and tree species on enzyme activity and soil microbial biomass C. Acid and alkaline phosphatase activity was determined under compacted and non-compacted conditions. Acid phosphatase was significantly reduced when the soil was compacted with no effect on the alkaline phosphatase (Table 6). The addition of forest leaf litter (FLL_1)

Table 5
Effect of soil compaction on oak seedling, forest leaf litter, and soil ^{15}N uptake and recovery averaged across all levels of treatments for the 6-month period[a]

Soil compaction treatments[b]	Plant[c]	FLL	Total	Inorganic	Organic	SMBN		
^{15}N uptake in soil pool (mg)[d]								
C_0	76 a	4 a	118 a	37 a	81 a	2.5 a		
C_1	7 a	6 b	77 b	11 b	66 b	1.3 b		
Percent ^{15}N recovery							Total (%)	Loss (%)
C_0	34 a	1.8 a	53 a	17 a	36 a	1.1 a	89 a	11 b
C_1	3.3 b	2.7 b	34 b	4.8 b	30 b	0.6 b	40 b	60 a

[a] Values with the same letter(s) are not significantly different using LSD at $P < 0.05$.
[b] C_0: without compaction, bulk density = 1.3 g cm^{-3}; C_1: with compaction, bulk density = 1.8 g cm^{-3}.
[c] FLL_0: without leaf litter added to pot (0 g); FLL_1: with leaf litter added to pot (50 g).
[d] Soil pool includes values listed under total, inorganic, organic, and SMBN.

Table 6
Effect of treatments on soil microbial biomass C and soil phosphatase activity[a]

Treatment[b]	SMBC[c] (μg C g per soil)	Soil phosphatase activity (μg *p*-nitrophenol per g soil h^{-1})	
		Acid	Alkaline
C_0	160 b	1773 a	393 cde
C_1	139 b	1591 c	471 abc
FLL_0	210 a	1741 a	505 a
FLL_1	133 b	1786 a	348 e
N_0	159 b	1652 b	442 bcd
N_1	140 b	1758 a	425 cd
T_1	161 b	1765 a	495 ab
T_2	145 b	1782 a	479 ab

[a] Values in a column having the same letter(s) are not significantly different by LSD at $P < 0.05$.

[b] C_0: without compaction, bulk density: 1.3 g cm^{-3}; C_1: with compaction, bulk density: 1.8 g cm^{-3}; FLL_0: without forest leaf litter, 0 g per pot; FLL_1: with forest leaf litter, 50 g per pot; N_0: without nitrogen; N_1: with nitrogen at 33 mg kg^{-1}; T_1: red oak; T_2: scarlet oak.

[c] SMBC: soil microbial biomass carbon.

affected alkaline phosphatase by significantly reducing its activity. On the other hand, acid phosphatase activity was significantly increased by the addition of the fertilizer (N_1). Tree species had no effect on the activity of either acid or alkaline phosphatase.

SMBC was also measured. Soil compaction had no effect on SBMC (Table 6). When the forest leaf litter was not added to the pots, significantly greater SMBC was observed in those treatments.

4. Discussion

Soil compaction reduced oak seedling germination, establishment and growth in this greenhouse study. Soil that is compacted through heavy traffic created by logging in the field or through simulated conditions as in this study may result in one or more of the following conditions: decreased aeration, altered soil moisture and increased soil strength (Reisinger et al., 1988). Because of the conditions created by compaction, the growth and survival of the oak seedlings were reduced. Hatchell et al. (1970) found in a greenhouse study that the establishment of loblolly pine seedlings was lower on compacted soil compared to non-compacted soils. Tworoski et al. (1983) found that the growth of white oak (*Quercus alba*) seedlings grown in a growth chamber was significantly reduced when the bulk density was increased from 1 to 1.5 Mg m^{-3}. Other greenhouse pot studies reported similar responses of other tree species on imposed or simulated compaction in controlled studies (Sands and Bowen, 1978; Corns, 1988; Jusoff, 1991). A number of field studies (Moehring and Rawls, 1970; Froechlich, 1979; Helms and Hipkins, 1986) have also examined the impact of soil compaction on tree growth. The results of those studies have been similar to pot or simulated studies. Trees or seedlings found in severely compacted areas could be stunted due to initial poor establishment and growth. Mortality rates for red oak (*Quercus rubra* L.) and scarlet oak (*Quercus coccinea* Muencch) were similar in the compacted pots in this study. For those oak seedlings that did survive, the species of the tree had a different response under compacted and non-compacted conditions. Red oak grew significantly better and took up more of the applied N in the non-compacted pots. This species has been shown to be more tolerant to shade conditions or other stresses than the scarlet oak (Hicks, 1998). The exact reasons for the growth response of red oak in this study are not known.

The amount of ^{15}N that could be taken up by the oak seedlings was severely hampered when the soil was compacted. Severe soil compaction significantly reduced the uptake and recovery of the added ^{15}N (Table 2) in both the red and the scarlet oak. The root systems of both plants were significantly stunted in the compacted soil, so uptake of the added N was hampered (data not shown). The soil compaction reduced the total soil pore volume and increased the probability of anaerobic conditions. This phenomena was observed when we examined the pools of soil ^{15}N, 60% of the added N was lost from the compacted pots compared to the 11% from the non-compacted pots (Table 5). Myrold (1999) states that about 20–30% of added N is taken up by trees and ground vegetation. Most of the fertilizer N (50–60%) is immobilized into soil organic matter and the remaining 10–30% is lost from the system. Our study under non-compacted conditions clearly mimics this pattern (see Table 5). Most of the ^{15}N was tied up in the organic pool whether the soil was compacted or not (30 versus 36%, Table 5). However, the inorganic pool was reduced in

the compacted pots because most of the N had probably been denitrified due to the conditions created by the compaction. Leaching may have been a problem compared to denitrification in both the compacted and the non-compacted pots. In the non-compacted pots, leaching may have been a more prevalent condition. Only 11% of the added ^{15}N was lost in the non-compacted pots while 60% was lost in the compacted pots suggesting that there had to be more than one loss mechanism for the added N. Since we did not measure leaching or denitrification, we are only suggesting that they may have been loss mechanisms with denitrification being the most likely loss process under the compacted soil conditions. In a laboratory study by Torbert and Wood (1992) on the effects of soil compaction on microbial activity and N losses, they found that greater N losses were observed with increasing bulk density, most likely due to denitrification.

About equal amounts (20%) of the added forest leaf litter was lost from both the compacted and the non-compacted pots. The addition of the FLL was not a significant factor alone but its significant interaction with other treatments affected the N released. Although in the forest leaf litter (FLL) a greater percentage of the ^{15}N was found in the compacted pots (2.7%), this N will be released as the leaf litter continues to decompose. Breland and Hansen (1996) studied the effects of compaction on nitrogen mineralization and microbial biomass using ^{15}N labeled clover on the surface of the soil in pots and found that after 98 days, the net mineralization of clover ^{15}N was reduced by 18% in the compacted pots compared with the non-compacted pots.

The ^{15}N found in the soil microbial biomass N pool (Table 5) in the compacted pots was about one half of the amount (1.3 mg) compared to the non-compacted pots (2.5 mg). Soil compaction reduced ^{15}N immobilization probably due to the significant loss of N in the compacted pots.

Our second major objective was to determine the effect of soil compaction, N fertilizer and forest leaf litter on selected microbial activity. Phosphatase (acid and alkaline) was measured as an indicator of enzyme activity in this soil. The compaction clearly reduced the acid phosphatase (which was more prevalent in this acid forest soil) than the alkaline phosphatase. Dick et al. (1988) study on soil enzyme activities in compacted and rehabilitated skid trail soils in Oregon showed a reduction in phosphatase activity in the 10–20 cm depth of the compacted site compared with their control plots. Their study also showed that SMBC was significantly decreased in compacted plots. Our study showed a 20% reduction in SMBC in the compacted pots. When we added the forest leaf litter to the surface of the soil, the SMBC was also significantly less compared to when we added no forest leaf litter (Table 6). Further study that would include time measurements would need to be done to appropriately answer this question in this particular study. In general, other treatment effects were quite variable on the selected microbial parameters. One limitation to the study was not being able to do a time measurement or at least to measure microbial activity in situ on a weekly basis.

5. Conclusions

The significant effects of compaction on the establishment, growth and survival of common tree species (oak) found in the central hardwood forests has been confirmed by this controlled study and other field studies (Ponder et al., 1999; Jordan et al., 1999). Furthermore, N uptake and recovery in oak seedlings were reduced in severely compacted soils and N losses were greater compared to non-compacted conditions. The likely N loss mechanism was probably denitrification with some minor losses through leaching. The effects of severe soil compaction on N transformations have been demonstrated under controlled conditions; however, the effects on microbial activity have only been partially answered. Severe soil compaction clearly reduced enzyme activity and N immobilization. Addition of N and forest leaf litter also affect microbial activity in this forest soil. Further studies will be required to more clearly separate out true differences in microbial activity under compacted conditions in a Missouri Ozark forest soil.

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