Influence of compaction from wheel traffic and tillage on arbuscular mycorrhizae infection and nutrient uptake by Zea mays

James A. Entry1, D. Wayne Reeves2, Eric Mudd1, William J. Lee1, Elizabeth Guerard1 and
Emily L. Raper2
1Department of Agronomy and Soils, 202 Fancher Hall, Auburn University, AL 36849-5412, USA; 2US
Department of Agriculture, PO Box 189, Auburn, AL 36831-3439, USA

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Abstract

Interactive effects of seven years of compaction due to wheel traffic and tillage on root density, formation of arbuscular mycorrhizae, above-ground biomass, nutrient uptake and yield of corn (Zea mays L.) were measured in a coastal plain soil in eastern Alabama, USA. Tillage and soil compaction treatments initiated in 1987 were: (1) no tillage; (2) soil compaction from tractor traffic with conventional tillage (CCT); (3) soil compaction from tractor traffic with no-tillage (CNT), and; (4) no soil compaction from tractor traffic with no-tillage (NCNT). The study was arranged as a split plot design with compaction from wheel traffic as main plots and tillage as subplots. The experiment had four replications. In May 1990 (90 days after planting), June (70 days after planting), root biomass and root biomass infected with arbuscular mycorrhizae was lower in treatments that included the NCNT treatment than the other three treatments. In June and July (109 days after planting), corn plants that received CCT treatment had less above-ground biomass, root biomass and root biomass infected with mycorrhizae than the other three treatments. Within compacted treatments, plants that received no-tillage had greater root biomass and root biomass infected with mycorrhizae in May and June than plants that received conventional tillage. Corn plants in no-tillage treatments had higher root biomass and root biomass infected with mycorrhizae than those in conventional tillage. After 7 years of treatment on a sandy loam soil, the interactive effects of tillage and compaction from wheel traffic reduced root biomass and root biomass infected with mycorrhizae but did not affect plant nutrient concentration and yield.

Introduction

Agricultural production systems in the southeastern United States include intensive tillage for weed control, incorporation of fertilizer and weed control. Nutrients are retained to a greater degree in no-till soil conservation tillage systems because soil organic matter and soil microorganisms are less disturbed than in plowed systems. No-till systems promote C accumulation at the soil surface due to lack of incorporation of crop residues. Wood and Edwards (1992) found that organic C and N were 67% and 66%, respectively, in the top 10 cm of soil when soybean (Glycine max L. Merr.), wheat (Triticum aestivum L.) and corn (Zea mays L.) were grown under a no-till rather than a conventionally tilled system. Wood et al. (1991) found that initiation of no-till resulted in higher soil organic carbon, soil organic N and less NO3-N in the top 40 cm of soil. In the 40 to 180 cm depth less NO3-N was found in the no-till system indicating that no-till farming may reduce NO3 losses below the root zone. The availability of soil nutrients was greater under conservation tillage than under conventional tillage system on an Appalachian Plateau soil in northeast Alabama (Edwards et al., 1992). Hargrove (1985) and Follett and Peterson (1988) reported greater extractable Ca, Mg,
The site is located at the E V Smith Alabama Agricultural Experiment Station Research Farm near Montgomery, Alabama, USA (32° 24.5'N, 85° 57'W). Tillage and compaction treatments have been implemented since 1987 on a Norfolk loamy sand (fine, loamy, siliceous, thermic Typic Kanhidult). Treatments were: 1) soil compaction from tractor traffic with conventional tillage (C,CT), 2) soil compaction from tractor traffic with no-tillage (C,NT), and 3) soil compaction from tractor traffic with conventional tillage (NT,CT), 2) no soil compaction from tractor traffic (NC,NT). The study was arranged as a split plot design with compaction from wheel traffic as the main plots and tillage systems as subplots. The experiment had four replications. Soil compaction and tillage treatments were imposed on a corn (Zea mays L.) - soybean (Glycine max (L.) Merr.) rotation with a winter cover crop of crimson clover (Trifolium incarnatum L.) system.

Field operations

Soil samples were grown in 1993, followed by a winter crimson clover cover crop, with corn grown in the summer of 1994. Plots were 21.3 m long x 6.1 m wide. In all years field operations were carried out using an experimental wide-frame tractor vehicle that was able to compact the soil on wheel-traffic treatments (Reeves et al., 1992). During the fall the tractor was driven over the plots to simulate planting of the cover crop and any required fertilizer applications. The experiment was designed to measure the interactive effects of tillage and compaction due to wheel traffic on root density, soil microbial biomass, arbuscular mycorrhizae, nutrient uptake and yield of corn.

Materials and methods

Field procedures

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The analysis of variance indicated that the interactive effects of compaction from wheel traffic and tillage on bulk density, aboveground biomass, root biomass, and P, K, Ca, Mn, and Fe uptake by corn plants were significant at $\alpha = 0.05$; therefore interactions must be considered in treatment comparisons (Saedecor and Cochran, 1980). Contrasts on planned comparisons among individual treatment means were determined using the Least Square Means test. Differences were judged significant at $\alpha = 0.05$. Residuals were equally distributed with constant variances.

Results

Soil bulk density was higher in treatments that received compaction from wheel traffic, regardless of tillage method (Table 1). Soil C and total N in the 0–10 and 10–20 cm depths did not differ with compaction or tillage method. Soil C and N averaged 4.97 g and 0.63 kg soil$^{-1}$, respectively, in 0–10 cm depth and 3.46 and 0.46 g kg soil$^{-1}$, respectively, in 10–20 cm depth. Aboveground biomass of corn in May was greater in soils that did not receive compaction from wheel traffic regardless of tillage treatment (Table 1). In June and July, corn plants that received C.C.T treatment had less above-ground biomass than the other three treatments. Tillage or compaction treatments did not affect soil microbial biomass which averaged 0.48 g C kg$^{-1}$ in the 0–10 cm depth over June and July. Compaction from wheel traffic and tillage did not affect the percentage root area infected with arbuscular mycorrhizae. In May and June, root biomass and root biomass infected with mycorrhizae was higher in the NC,NT treatment than the other three treatments (Table 2). Plants from plots that received the C.C.T treatment had less root biomass and root biomass infected with mycorrhizae than mycorrhizae than plants in conventional tillage. In July, within compaction from wheel traffic treatments, plants in no-tillage had more root biomass and root biomass infected with mycorrhizae than plants in conventional tillage. In July, within compaction from wheel traffic treatments, plants in no-tillage had more root biomass and root biomass infected with mycorrhizae than plants in conventional tillage. Tillage and compaction from wheel traffic treatments did not affect N, P, K, Ca, Mg, Mn, Fe, Cu, B and Zn concentration in uppermost ear leaves. The uppermost ear leaves to the tassel contained 41 g N, 5.2 g P, 18.6 g K, 5.6 g Ca, 4.0 g Mg, 69 mg Mn, 156 mg Fe, 4 g Cu, 59 g B and 9 g Zn kg$^{-1}$. Tillage and compaction from wheel traffic did not affect the amount of N, Ca, B or Zn uptake of corn plants (Table 3). Phosphorus uptake was highest when plants received NC,NT treatment and lowest in corn plants that received the C.C.T. treatment. Potassium uptake was highest when corn plants received the no-tillage treatments, regardless of whether compaction from wheel traffic was applied. Calcium uptake was highest in corn plants that did not receive compaction from wheel traffic, regardless of tillage practice. Magnesium and Fe uptake was lowest when corn plants received the C.C.T. treatment compared to the other three treatments.

Soil water maintained in traffic middles for the 35 day period beginning at tasseling was greater in treatments that received compaction from wheel traffic that those that did not receive compaction (Fig 1). This was especially true for the compaction from wheel traffic with conventional tillage treatment. There was a traffic by tillage interaction in that, within compaction from wheel traffic treatments, soil water content was generally higher in the conventionally tilled treatment than in the no-tillage treatments. However, in the absence of compaction from wheel traffic, soil water content was generally higher, especially after rainfall events, in no-tillage treatments as compared to conventionally tillage treatments. This is likely due to less runoff and/or greater infiltration in no-tillage treatments following heavy rainfall events. This can be seen in Figure 1 following the rainfall events 86 to 88 days after planting.

Discussion

Although the interaction of soil compaction from wheel traffic and conventional tillage resulted in less root biomass, root biomass infected with arbuscular mycorrhizae and above ground biomass there was no difference in nutrient concentration or grain yield of above ground biomass of corn plants. Other studies have found that no-till systems have resulted in higher yields than conventionally tilled systems. Van Doren et al. (1976), Hargrove (1985), Dick et al. (1991) and Maskins et al. (1994) found that no-till systems yielded from 10 to 20% more corn than comparable conventionally tilled systems. Edwards et al. (1988) found that corn yields in a no-till system were 30% lower than in a conventional tillage system in the first year of their study; however, in the following 3 years corn, soybean and wheat yields were higher when grown in a no-till than a conventional tillage system.
Table 3: Nutrient uptake (kg ha⁻¹) of Zea mays as affected by comparison from wheel traffic and tillage treatments

<table>
<thead>
<tr>
<th>Treatment from wheel traffic &amp; conventional tillage</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Mn</th>
<th>Fe</th>
<th>Cu</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparison</td>
<td>156a</td>
<td>20.3c</td>
<td>139.4b</td>
<td>50.2b</td>
<td>48.0a</td>
<td>0.76b</td>
<td>1.69b</td>
<td>0.09a</td>
<td>0.09a</td>
</tr>
<tr>
<td>No comparison from wheel traffic with tillage</td>
<td>157a</td>
<td>23.6b</td>
<td>166.4a</td>
<td>62.3a</td>
<td>63.9a</td>
<td>1.16a</td>
<td>2.22a</td>
<td>0.10a</td>
<td>0.08a</td>
</tr>
<tr>
<td>Comparison from wheel traffic with no tillage</td>
<td>151a</td>
<td>23.0b</td>
<td>180.9a</td>
<td>53.9b</td>
<td>50.5a</td>
<td>1.18a</td>
<td>2.02a</td>
<td>0.10a</td>
<td>0.07a</td>
</tr>
<tr>
<td>No comparison from wheel traffic with no tillage</td>
<td>152a</td>
<td>31.5a</td>
<td>182.7a</td>
<td>65.0a</td>
<td>49.9a</td>
<td>0.97ab</td>
<td>1.84b</td>
<td>0.12a</td>
<td>0.09a</td>
</tr>
</tbody>
</table>

*a,b,c,d,e,f,g,h,i,j,k,l,m,n,o,p,q,r,s,t,u,v,w,x,y,z: values followed by the same letter are not significantly different as determined by the least square means test (p<0.05).

Figure 1: Rainfall and volumetric soil water content from infilled mid-row position of corn during a 35 day period beginning at time of emergence as affected by comparison from wheel traffic and tillage systems. DAP - Days after planting.

According to Bandel (1983), 3 to 6 years are required for corn yields from no-till to equal the yield of corn in conventional tillage systems; after this time yields from no-till consistently exceed those under conventional tillage. In a 20 year study, average corn yields from a conventional tillage system were higher than corn yields from a no-till system during the first 7 years, but yields from corn grown in conventional systems were consistently higher than in conventionally tilled systems after those 7 years (Isimeli et al., 1994).

We found that tillage and compaction from tractor traffic treatments had no effect on soil microbial biomass. These results are not consistent with several other studies. Soil microbial biomass averaged 57% higher in the top 7.5 cm of soil in no-tillage systems than in conventionally tilled systems at 7 sites in the southeastern United States (Doran, 1987). Linn and Juren (1984) found higher populations of anaerobic bacteria in the top 7.5 cm of soil in no-tillage systems than in conventionally tilled systems. Barea et al. (1992) found that active fungal and bacterial biomasses were 12 to 27% higher in no-tillage systems than in conventionally tilled systems. These tillage systems were implemented in sandy soils in a humid to mesic climate, yet may not have been in soil long enough for soil to accumulate substantial quantities of organic materials to result in elevated microbial biomass to a 10 cm depth.

Tillage and compaction from tractor traffic treatments had no effect on mycorrhizal infection of corn roots. Other studies have found that crop rotation and tillage affect populations and distribution of mycorrhizal fungi in soil and mycorrhizal formation of plants. McGonigle and Miller (1993) reported higher arbuscular mycorrhizal infection in corn early in the growing season (8–9 leaf stage) under no-till systems than moldboard plowing systems. Douss et al. (1993) found that no-tillage soybean and corn systems resulted in higher populations of Glomus occultum, but that conventional tillage resulted in greater numbers of Glomus etunicatum and Glomus spp. spores in the soil. Abbott and Robson (1991) found that there were arbuscular mycorrhizal fungi spores in the top 8 cm of no-till soils the conventionally tilled soils; however, conventionally tilled soils had greater amounts of arbuscular mycorrhizal fungi spores at the 8–15 cm soil depth than no-till soils. In this study, we did not sample corn roots until 49 days after planting (15–20 leaf stage). Although conventional tillage operations increase the numbers of arbuscular mycorrhizal spores in the soil, results of this study suggest that after 7 years of comparison from wheel traffic with conventional tillage, sufficient mycorrhizal structures associated with dead roots from the previous crop and/or sufficient numbers of spores are present in the soil to fully colonize corn roots. After 7 years of treatments the interactive effects of tillage and compaction due to wheel traffic seem to have little effect on microbial biomass, root area infect

References
Spatial distribution of ectomycorrhizal mats in coniferous forests of the
Pacific Northwest, USA

Robert P. Griffiths, Gay A. Bradshaw, Barbara Marks and George W. Lienkaemper

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Abstract

Ectomycorrhizal mats in forest soils have a wide global distribution and have been noted as potentially important elements in forest soil nutrient cycling. To elucidate the relationship between ectomycorrhizal mats and their environment, we undertook field studies and spatial analyses of mat distributions at different spatial scales. We used two experimental approaches to study mat-forming ectomycorrhizal fungi in coniferous forests of the Pacific Northwest in the United States. In the first approach, ectomycorrhizal mats and other forest floor features were mapped in 2 x 10 m plots and digitized into a geographical information system (GIS) for spatial pattern analysis. In order to examine large-scale phenomena, a second approach involving smaller sites was taken; soil cores were taken along 30-m transects, and distance to the closest living potential host tree was calculated for each core. Mat patterns were studied at two scales: (1) within-stand level (e.g. variability attributed to distribution of other species, forest floor attributes, and understorey vegetation); and (2) stand level (e.g. variability expressed along a succession gradient). Mat distribution was influenced by: (1) the proximity of one mat to another; (2) the distance from the mat to the closest living tree; (3) the density of living trees in a stand; and (4) the successional stage of the stand. Although GIS analysis indicated that mats of different morphologies did not physically overlap, there was a tendency for clustering of mats. No apparent correlations were observed between forest floor features and mats located within the 2 x 10 m grids. On the scale of tens of meters, mats decreased with distance from the closest potential host tree. Spatial patterns of mat distributions in harvested sites suggest that these mats may persist at least 2 years after their host trees have been cut. For Gastrodia mats, total mat area, size, and frequency differed with stand age.

This study has demonstrated the importance of both spatial and forest stand age as the natural distribution of mycorrhizal fungi is examined. Results suggest the need for more research directed at greater-order scales (e.g. stand and watershed) that will provide accurate information for managing forests to ensure their survival and normal function.

Introduction

Ectomycorrhizal fungi play an important role in preserving species diversity by providing host trees with necessary nutrients from mineral soil and soil organ-