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Effect of tractor traffic and N fertilization on the root morphology of grass/red clover mixture

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ABSTRACT

Tractor traffic and related soil compaction may create unfavourable growing conditions for the development of roots and above-ground biomass production. It can be expected that higher N fertilization and higher below-ground biomass production can remediate soil physically degraded by wheel compaction. The main objective of this study was to investigate the interaction between tractor traffic and N fertilization of a clover/grass mixture during the period from 2010 to 2012. The experiment was established in a split-plot design with fertilization as a main plot and tractor passes as a subplot. The N fertilizer treatments used were: untreated control (N0), 80 kg N ha^{-1} (N80) and 160 kg N ha^{-1} (N160). Four compaction treatments were applied using the following numbers of tractor passes: untreated control (P0), two passes (P2), four passes (P4) and six passes (P6). Root samples were collected in the autumn of 2010, 2011 and 2012 and their morphometric parameters were calculated after measurement of the root length, using image analysis: root length density (RLD), mean root diameter (MRD), specific root length (SRL) and root dry matter (RDM).

Heavy tractor traffic significantly affected the physical parameters of the soil. The highest value of bulk density was recorded in the 10–20 cm soil layer with the P6 treatment (1.582 g cm^{-3}), being approximately 10% higher compared with the P0 treatment at the same depth. The tractor wheeling increased penetration resistance in the 0–20 cm soil layer. The maximum value of penetration resistance (2.98 MPa) was recorded for the P6 treatment, in the 5–10 cm soil layer.

The differences between root parameters caused by fertilization and compaction treatments were observed only in the 5–15 cm soil layer. The roots in the upper, 0–5 cm, soil layer were not affected by soil compaction or nitrogen fertilization. The tractor passes reduced biomass and length of the roots. In the 5–10 cm soil layer the highest value of the RDM was noticed with the P0 treatment (0.00241 g cm^{-3}), whilst it decreased to 0.00144 g cm^{-3} for the P6 treatment. In the 10–15 cm the maximum value for the RDM was also recorded in the P0 whereas the minimum was in the P4. The higher N rates play unfavourable role in root development what reflected in their morphometric parameters. The use of nitrogen reduced the RDM. The main difference was noticed between the N160 treatment (0.00230 g cm^{-3}) and two others: namely, N0 and N80, totalling 0.00298 and 0.000287 g cm^{-3}, respectively. Similar reductions were also observed for the RLD. The results in root morphology did not indicate significant interaction between tractor passes and the N fertilization level.

According to the regression model, the optimum condition for root growth could be meet when nitrogen fertilization is at the level of approximately 50 kg N ha^{-1}. At this N rate red clover/grass mixture produces the highest below ground biomass what can play favourable role in remediation of compacted soil.

1. Introduction

In the past decades, agricultural production systems have tended to increase the number of passes made and the loads carried on agricultural vehicles, resulting in a potential for increased soil compaction. Soil compaction is now recognized as one of the main factors that can lower crop yields and is therefore a serious agricultural problem. Compaction leads to soil structure degradation, which results in a deterioration in its physical properties such as a bulk density and soil strength, measured as penetration resistance (Hamza and Anderson, 2005).

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Many researchers agree that soil compaction leads to plant yield reduction (Whalley et al., 2008) including decreased production of perennial forage crops (Głąb, 2008). This yield decline is the consequence of both soil compaction and injury to shoots caused by wheel traffic. For perennial crops, where the soil is subjected to heavy traffic loads without a tillage operation, soil compaction is likely to become a more severe problem. Soil strength is increased year-after-year and all machine traffic during field operations causes direct damage to plants, which are deemed to be as important a factor in contributing to decreased plant yield as soil compaction.

Moreover, perennial forage crop production demands very intense vehicular activity, especially during crop harvesting operations (Jorajuria and Draghi, 1997). On the other hand, it has also been reported that yields of perennial plants were not always reduced by compaction and are indeed sometimes larger in compacted than non-compacted soil (Frost, 1998). These trends could be attributed to better water and nutrient supply and recovery of soil pore systems (Scott et al., 2005).

The physical properties of the soil are degraded by compaction that damages not only shoots, but also influences root growth and development. Soil compaction increases mechanical impedance, creates unfavourable growing conditions for roots and restricts the supply of oxygen, water and nutrients (Chen and Weil, 2010; Głąb and Kopeć, 2009). A common response of the root system to increasing bulk density is to decrease in length, concentrating roots biomass in the upper layer and decreasing rooting depth (Lipiec et al., 2003). Strongly compacted soils are usually penetrated by roots utilizing cracks, fissures and biopores (macropores formed by earthworms). This provides an advantage to elongating roots but also results in a heterogeneous root distribution. However, changes in root system appearance do not necessarily cause an alteration in above-ground growth or yields (Kristoffersen and Rile, 2005). Overall, it is very difficult to quantify consistently the relationship between root growth and plant yield in field trials.

The author in his previous research (Głąb, 2005), found that the roots of perennial plants, especially legumes, can positively influence the physical properties of soil on strongly compacted soils, because they improve water retention properties and can therefore, be used for recultivating soils that have suffered physical degradation. Particular species differ in their impact on soil environments mainly due to their root morphology. The roots of *Trifolium repens* generate better results in improving the water retention of compacted soil than *Trifolium pratense* and *Medicago sativa* (Głąb, 2005). Changes in soil physical properties should be prescribed to live root activity and the presence of organic matter derived from dead roots. According to Celik et al. (2004), the exogenous organic matter in the soil leads to an improvement of water retention. This is also confirmed by Grosbellet et al. (2011) who further linked it to changes in soil structure.

During the last two decades the economic and political changes have resulted in more intensive forms of agricultural production, which in turn requires a higher level of fertilization (Gibon, 2005). Many studies stated that increasing N fertilization affects root growth (De Giorgio and Fornaro, 2012; Fageria and Moreira, 2011). Indeed this relationship can suggest that higher N fertilization and higher below-ground biomass production can remediate compacted soil.

However, there is some evidence that this relationship is more complex. Costa et al. (2002) reported that greater root length and root surface area were obtained at medium nitrogen levels and that both, high and very low fertilization reduced root growth. Similar effects were also confirmed by Jung et al. (2011). However, the current stage of knowledge concerning a root system's response to environmental factors is still insufficient and should be improved in order to increase crop productivity in agroecosystems.

In our experiment it was hypothesized that (i) tractor traffic changes the soil's physical properties which can alter plant root distribution over depth, (ii) N fertilization affects root biomass production, and (iii) roots biomass and their activity play a beneficial role in improving physically degraded soil. Our objective was to evaluate the relationship between the soil compaction stress, different intensity of nitrogen fertilization and root system biomass and morphology. During the field trial, the research mainly focused on root system morphometric parameters such as root length density, root diameter, root dry matter and specific root length.

2. Materials and methods

2.1. Site, location and climate

This study was conducted as a field experiment located in Mydlniki near Krakow, Poland (50°04′ N, 19°51′ E, 211 m a.s.l., slope: 2°) over a three-year period (2010–2012). The climate of the experimental site is temperate-continental. Average annual precipitation reaches 881 mm per year and the mean daily temperature is 7.7 °C. The field experiment was located on sandy loam Mollic Fluvisol (IUSS Working Group WRB, 2007). Table 1 presents some soil characteristics.

2.2. Field trial design and treatments

The soil before compaction by vehicles was ploughed in autumn 2009 and harrowed in March 2010 for seedbed preparation, in which seeds of a grass/clover mixture were sown. Experimental plots (9 m^2) were established with four replications in a split-plot design, with fertilization as a main plot and compaction as a subplot. Each plot was sown with a mixture of 10 kg ha^{-1} of perennial ryegrass (*Lolium perenne* L.) cv. Diament, 13 kg ha^{-1} of meadow fescue (*Festuca pratensis* Huds.) cv. Skra, 3 kg ha^{-1} of timothy (*Phleum pratense* L.) cv. Skala, 2 kg ha^{-1} of Kentucky bluegrass (*Poa pratensis* L.) cv. Skiz and 2 kg ha^{-1} of red clover (*T. pratense* L.) cv. Nike.

The N fertilizer (ammonium nitrate, 34% N) treatments used were: untreated control (N0), 80 kg N ha^{-1} (N80) and 160 kg N ha^{-1} (N160). The grass/clover mixture was harvested three times per year. The doses of nitrogen were applied in March and after the first and second harvest in proportions of 50, 25 and 25%, respectively. The phosphorus and potassium fertilization always comprised 40 kg P_2O_5 ha^{-1} (triple super phosphate, 46% P_2O_5) and 80 kg K_2O (potassium chloride, 60% K_2O). These doses were applied every year in March and after the second harvest. No organic fertilization was applied on the experimental plots.

Four compaction treatments were applied using the following number of tractor passes: untreated control (P0), two passes (P2), four passes (P4) and six passes (P6). The URSUS C-360 tractor

Table 1
Mean ± SD of soil physical and chemical properties of Mollic Fluvisol from the trial location (0–30 cm layer).

pH (KCl)		6.5 ± 0.1
Organic C	g kg^{-1}	12.5 ± 0.8
Total N	g kg^{-1}	1.39 ± 0.11
C:N ratio		9.0 ± 0.9
P	mg kg^{-1}	107.2 ± 4.2
K	mg kg^{-1}	138.0 ± 6.3
Mg	mg kg^{-1}	67.9 ± 4.1
Solid particle density	g cm^{-3}	2.56 ± 0.05
Sand	g kg^{-1}	560 ± 8.2
Silt	g kg^{-1}	270 ± 4.9
Clay	g kg^{-1}	170 ± 3.6
Texture		Sandy loam