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Soil microbial activity as influenced by compaction and straw mulching**

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Abstract. Field study was performed on Haplic Luvisol soil to determine the effects of soil compaction and straw mulching on microbial parameters of soil under soybean. Treatments with different compaction were established on unmulched and mulched with straw soil. The effect of soil compaction and straw mulching on the total bacteria number and activities of dehydrogenases, protease, alkaline and acid phosphatases was studied. The results of study indicated the decrease of enzymes activities in strongly compacted soil and their increase in medium compacted soil as compared to no-compacted treatment. Mulch application caused stimulation of the bacteria total number and enzymatic activity in the soil under all compaction levels. Compaction and mulch effects were significant for all analyzed microbial parameters ($P<0.001$).

Keywords: soil compaction, straw mulch, enzymatic activity, bacteria number

INTRODUCTION

Modern agriculture is based on an intensive use of agricultural equipment for soil handling and application of fertilizers and pesticides, which size and mass is increasing. Intense traffic of agricultural machinery causes compaction and, as a consequence, changes in various parameters of the soil environment (Hamza and Anderson, 2005). By effects on soil structure, porosity, aeration and water movement, compaction appreciably affected soil biological activity. Compaction can influence on the number and activity of microorganisms (Lee *et al.*, 1996). In a study of Jordan *et al.* (2003) severe soil compaction significantly reduced enzyme activity and N immobilization in the soil microbial biomass. However, in another study despite a significant increase in bulk density due to wheel traffic, compaction and tillage system had no consistent effect on bacterial or fungal biomass in a sandy soil (Entry *et al.,* 1996). Ikeda *et al.* (1997) found that compaction affected qualitatively microbial populations on plant roots through significant increase in the number of cultivable bacteria and *Pseudomonas fluorescens* in a highly compacted soil in comparison to loosely compacted soil.

Application of plant residues into soil have beneficial effects on a number of soil properties such as: structure, organic matter content, water capacity, and lowered soil temperature and moisture fluctuation. Study of Tu *et al.* (2006) showed enhanced content of microbial biomass and its activity in soil under straw mulch conditions in relation to non-mulched soil.

Soil enzymes are divided into two groups, endo- and ecto-enzymes, according to whether functioning is intra- or extra-cellular (Karaca *et al.*, 2000). Microbial enzymes have essential functions in the soil and have been used to measure the influence of soil management and quality (Brzezińska *et al.*, 2001; Gajda, 2010; Riffaldi *et al.*, 2003). Soil enzymes and microbial activities are sensitive biosensors of environmental changes (Jezierska-Tys *et al.*, 2010; Pupin *et al.*, 2009). Generally, compaction and mulch effects on soil microbial properties were studied separately.

The aim of the field studies was to determine the effects of soil compaction, straw mulching and their interaction on microbial parameters of soil under soybean.

MATERIALS AND METHODS

The studies were conducted on soil derived from loess at the experimental fields of the University of Life Sciences in Lublin (51°15'N, 22° 35'E) Poland. The soil was a Haplic Luvisol, with a clay, silt and sand content for the 0-20 cm

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soil layer of 70, 290, and 640 g kg^{-1}, respectively. The soil acidity measured in H_2O reached 5.9 of pH unit, and the organic matter content measured for the plough layer (20 cm depth) was 11.5 g kg^{-1}. Long-term (30 years) history of cultivation included crop rotation with selected cereals (barley and wheat), root crops and papilionaceous crops grown under a conventional tillage.

Soil compaction treatments were obtained using wheel tractor (Ursus C-360, 3.4 Mg) passes: no compacted (NC=0 passes), moderately (MC=3 passes) and strongly (SC=5 passes) compacted soil. Compaction was done 2 weeks before sowing and after spring tillage operations that included cultivation to 18-20 cm depth followed by harrowing. A contact area stress and a rear axis load of wheel tractor were 135 kPa and 22.6 kN, respectively. During the compaction soil water content in the plough layer was 18.5% w/w corresponding to a soil water potential of -30 kPa.

Each compaction treatment remained as unmulched and mulched. Wheat straw chopped into approximately 3-5 cm long pieces was used as a mulch and was applied 3 days after soybean (*Glycine max* (L.) Merr.)) sowing, on the soil surface at the rate of 0.5 kg m^{-2}. The plots (1.8×2.1 m) were organized randomly within each compaction level. Each of the study treatment (totally 6) had 6 replicates of plots. Fertilization was applied uniformly to all the plots before wheeling at a rate of 54-70-80 kg ha^{-1} NPK.

Data were collected in the year 2008 which was the third year of this experiment. Disturbed soil samples were collected from 5-15 cm layer from the centre of the soybean rows, 3 times during the vegetation period of soybean: (T1) at 3rd-node (V3) stage, (T2) at full pod (R4) stage of soybean development and (T3) after soybean harvest. Soil was sieved through a 0.2 cm mesh sieve and stored at 4°C before analysis.

Total bacteria number was determined with the plate method on a medium with soil extract and K_2HPO_4. Dehydrogenases were determined according to Thalmann (1968) method, modified by Alef and Nannipieri (1995) after soil incubation with 2,3,5 triphenyl-tetrazolium chloride (TTC) and measuring the triphenyl formazan (TPF) absorbance at 485 nm. Protease activity was determined by the Ladd and Butler (1972) method, modified by Alef and Nannipieri (1995) with measurement of the concentration of tyrosine released by soil after 1 h incubation at 50ºC with a TRIS-HCl (pH 8.1) casein solution. The tyrosine concentration was measured at 578 nm. Alkaline and acid phosphatases were determined according to Tabatabai and Bremner (1969) method after soil incubation with p-nitrophenyl phosphate disodium and measuring the p-nitrophenol (PNF) absorbance at 400 nm. For each microbiological analysis three replicates per treatment were done. Results were based on oven-dry (105°C) mass of soil.

Core samples of 100 cm^3 volume and 5 cm diameter (4 replicates) were taken 2 days after wheeling from the layer of 0-40 cm, at 10 cm intervals. Bulk density was determined after drying of cylinders at 105°C to constant mass.

Statistical analysis was performed using STATISTICA 8.0 (StatSoft, Inc.). Data were subjected to analysis of variance ANOVA at the 0.05 probability level to asses statistical significance of compaction, mulch and their interactive effects.

RESULTS

Soil bulk density increased with increase in compaction level (Table 1). The impact of tractor passes was the most pronounced in the 0-10 cm soil layer where bulk density was 1.29 Mg m^{-3} under NC and 15.5 and 22.5% greater under MC and SC, respectively. The differences between the treatments were smaller in deeper soil layers.

Generally, total number of bacteria and all enzyme activities showed significant temporal variations (Figs 1, 2). There was a decrease tendency in the number of bacteria with time under most of the treatments (Fig. 1). Analyzing the seasonal activity of dehydrogenases may note increase

Table 1. Soil bulk densities as a function of the com- paction (n=4)

Treatment	Bulk density (Mg m^{-3}) at depth (cm)			
	0-10	10-20	20-30	30-40
NC	1.29 (0.05)*	1.49 (0.04)	1.61 (0.04)	1.60 (0.08)
MC	1.49 (0.02)	1.55 (0.03)	1.60 (0.01)	1.63 (0.03)
SC	1.58 (0.03)	1.59 (0.03)	1.61 (0.03)	1.62 (0.03)

*Standard deviation.

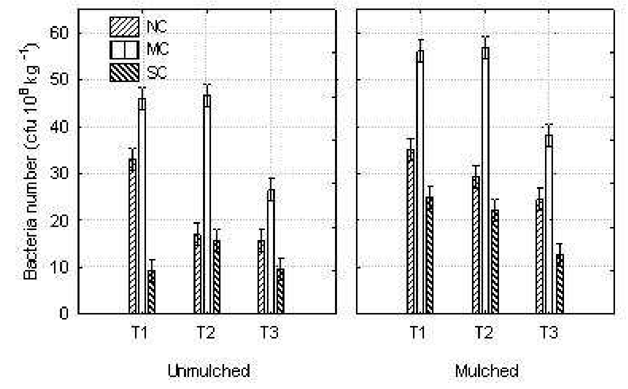

Fig. 1. Dynamics of bacteria number in unmulched and mulched plots as a function of soil compaction. Bars represent 95% confidence interval (P<0.05).

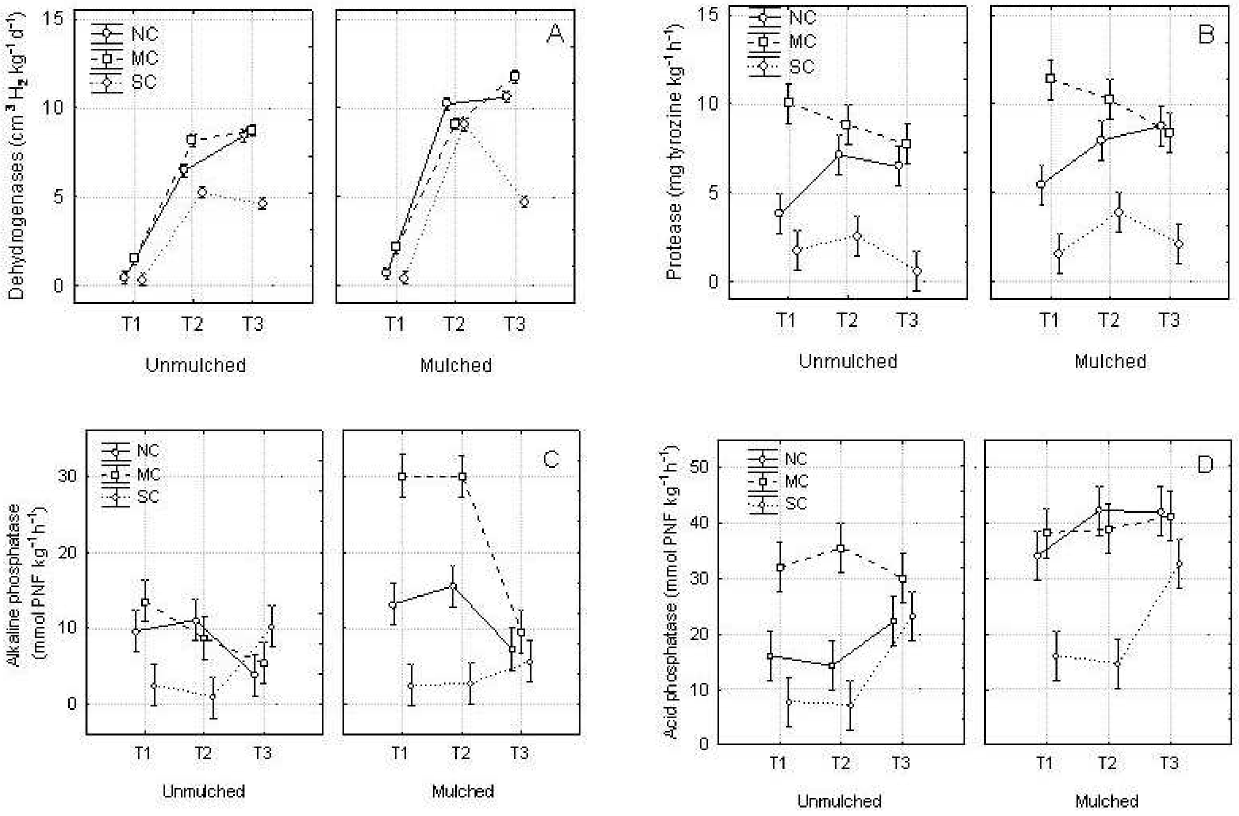

Fig. 2. Dynamics of dehydrogenases (A), protease (B), alkaline (C) and acid (D) phosphatases activities as a function of soil compaction and mulching.

Table 2. Mean values of microbial parameters as influenced by soil compaction and mulch treatments

Dependent variable	Unmulched			Mulched		
	NC	MC	SC	NC	MC	SC
Bacteria number (10^8 cfu kg^{-1})	22.0 d	39.7 b	11.5 e	29.6 c	50.4 a	20.0 d
Dehydrogenases (cm^3 H_2 kg^{-1} d^{-1})	5.1 d	6.1 c	3.4 e	7.2 b	7.6 a	4.7 d
Protease (mg tyrosine kg^{-1} h^{-1})	5.8 c	8.9 a	1.6 d	7.4 b	10.0 a	2.5 d
Phosphatases (mmol PNP kg^{-1} h^{-1})						
alkaline	8.2 c	9.3 bc	4.6 d	12.0 b	23.2 a	3.6 d
acid	17.6 cd	32.6 b	12.7 d	39.5 a	39.5 a	21.1 c

Different letters within the same variable indicate significant differences ($P<0.05$).

of the studied enzyme activity, particularly under unmulched and mulched NC and MC treatments, during vegetation period of the soybean (Fig. 2A). In general, the greatest number of total bacteria and enzymes activities were noted under MC and the lowest under SC in all sampling times, regardless of mulching. This effect was the most evident with respect to bacteria number, activity of dehydrogenases and protease.

Mean values of parameters studied (Table 2) indicated the greatest both number of bacteria and all enzyme activities under MC and the lowest under SC, irrespective of mulching. Differences in bacteria number and protease and dehydrogenases activities between NC, MC and SC were statistically significant ($P<0.05$) under unmulched and mulched soil. In respect to alkaline phosphatase the difference between NC, MC and SC was significant under mulched soil. Mean values indicated that application of the straw caused increase nearly all parameters analyzed (except alkaline phosphatase under SC). This increase ranged from 12.4 to 149.5%, depending on compaction level and parameter, and generally was lower under MC than NC and SC.

Increase of bacteria total number and dehydrogenases and acid phosphatase activities by mulch was statistically significant ($P<0.05$) under all compaction levels (Table 2).

Among analyzed microbial parameters the most sensitive to soil compaction was protease under unmulched soil and alkaline phosphatase under mulched soil. However, the greatest mulch effect we observed with respect to alkaline phosphatase. In general, compaction affected total bacteria number and enzyme activities to a higher extent than mulching. The effects of compaction and mulching were significant ($p<0.001$) for all analyzed microbial parameters, and dehydrogenases and alkaline and acid phosphatases activities were significantly affected by C×M interaction (Table 3). Bacteria total number and protease and phosphatases activity were significantly correlated with the soil compaction (negative correlation). Total number of bacteria and phosphatases activity were also significantly correlated with mulch application (positive correlation) (Table 4).

Table 3. Results of two-way ANOVA of soil microbial characteristics by compaction (C), mulch (M) and their interactions

Dependent variable	C	M	CxM
Bacteria number (10^8 cfu kg^{-1})	***	***	NS
Dehydrogenases (cm^3 H_2 kg^{-1} d-1)	***	***	**
Protease (mg tyrosine kg^{-1} h^{-1})	***	***	NS
Phosphatases (mmol PNP kg^{-1} h^{-1})	***	***	***
alkaline	***	***	***
acid	***	***	***

*P<0.05, **P<0.01, ***P<0.001, NS – no significant.

Table 4. Correlation coefficients

Dependent variable	C	M
Bacteria number (10^8 cfu kg^{-1})	-0.278 *	0.302 *
Dehydrogenases (cm^3 H_2 kg^{-1} d-1)	NS	NS
Protease (mg tyrosine kg^{-1} h^{-1})	-0.542 ***	NS
Phosphatases (mmol PNP kg^{-1} h^{-1})		
alkaline	-0.294 *	0.336 *
acid	-0.391 **	0.511 ***

Explanations as in Table 3.

DISCUSSION

Soil compaction may cause problems by changing porosity in the soil. This has effects on biological activity, especially on enzymatic activity of the soil and may have negatively influenced on the plants and roots growth. Compaction can influence on the plant-available nutrients because the number and activity of microorganisms may be changed (Lee *et al.*, 1996). Li *et al.* (2003) indicated a reduction of biomass and microbial activity in compacted soils. The community of total bacteria was sensitive to the increase in soil density. The results of our study showed decrease of bacteria total number in the strongly compacted soil, compared to no compacted and medium compacted soil. This effect may be explained by an anaerobic conditions in a strongly compacted soil. The obtained results confirm the effects of an earlier published research for compacted soil. The community of total bacteria is also sensitive to the increase in soil density, therefore increase in soil compaction may cause a restriction of the growth of total number of soil bacteria. According to Smeltzer *et al.* (1986) population of bacteria were significantly larger in control than in compacted soil. The effect of compaction in reducing bacteria population had been also observed by Pupin *et al.* (2009). In contrary, Shestak and Busse (2005) showed that the community of bacteria benefited from increased density, probably due to adaptation to the new soil conditions.

The results of presented study showed tendency towards a reduction of the studied enzymes activities in strongly compacted soil compared to no compacted and medium compacted soil. Buck *et al.* (2000) and Dick *et al.* (1988) also detected reduction in dynamic processes, such as enzymes activities, especially dehydrogenases and phosphatases activities in compacted soils. According to Taylor *et al.* (2002) and Kremer and Li (2003) the reduction in the enzymatic activity may be a consequence of the decrease in total bacteria number with increased soil compaction. Since soil compaction decreases the activity of hydrolytic enzymes activity, nutrient availability and plant growth are consequently affected (Pupin *et al.*, 2009). Generally, the results of our study confirm this tendency.

In our study mulch application enhanced soil enzymes activity as compared to unmulched soil. This could partially results from improvement of water availability by mulching through reducing evaporation. Mean soil water contents (%, vol.) measured daily from the time of soybean sowing to T3 sampling time by TDR in the layer of 0-20 cm were 19.4, and 19.9 in NC and SC unmulched soil respectively, and 22.4 and 21.2 in NC and SC mulched soil, respectively. The results of our study indicated that the negative impact of soil compaction on enzymatic and microbial activity was lower in treatments with straw mulch. These results may be explained by the incorporation to soil of available nutrients and organic carbon compounds with straw. Buck *et al.* (2000) also concluded that mulch quality is important and have influence on reduction of negative effect of soil compaction on soil properties. Considering importance of enzyme activities for nutrient availability to crop, stimulation of soil enzymes by mulch application could be one of the reason of greater soybean yield in relation to unmulched soil observed in the same experiment by Siczek and Lipiec (2011).

CONCLUSIONS

1. Bacteria total number and enzymatic activity in soil under soybean decreased in sequence: medium, no compacted and strongly compacted soil.
2. Straw mulch application stimulated enzymatic activity and bacteria counts under all compaction levels.
3. Compaction effect on analyzed microbial parameters was greater than the effect of mulching.
4. The effects of compaction and mulching were significant for all analyzed microbial parameters
5. Significant interactive effect of compaction and mulching on dehydrogenases and alkaline and acid phosphatases activities were stated.

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