Role of amendments in modifying clayey soil physical properties under conventional and reduced tillage in northern Lithuania

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Abstract. Investigations to improve clayey soil physical properties and conditions for applying reduced tillage to spring crops were carried out at Joniskelis Experimental Station of the Lithuanian Research Centre for Agriculture and Forestry in a glacial lacustrine clay loam on silty clay soil with deeper-lying sandy loam (*Endocalcari–Endohypogleyic Cambisol*). Amendments for soil improvement were the following: farmyard manure – 60 t ha^{-1}, green manure – 27 t ha^{-1} and lime mud – 10 t ha^{-1} were incorporated by a mouldboard and segment plough at 0.25 and 0.40 m depths for winter crops twice every third year. Conventional mouldboard ploughing at 0.25 m and reduced ploughless tillage at 0.25 and 0.15 m depths was applied to spring crops after incorporation of amendments. The incorporation of amendments resulted in the decrease of soil bulk density, improvement of soil aeration and water conductivity. Ploughing by a segment plough, especially with incorporation of amendments, improved the subsoil physical properties and water conductivity. However, the segment ploughing resulted in a worsening of topsoil properties due to mixing the subsoil layer with topsoil. Lime mud was more effective for subsoil improvement. Reduced ploughless tillage determined the decrease of soil porosity, worsening the soil structure and seedbed quality. Incorporation of amendments, especially farmyard manure, helps to avoid or lessens the negative effect of reduced tillage on the clayey soil physical condition and on the decrease of the spring crop yield.

Key words: clayey soil, amendments, conventional and reduced tillage, soil physical properties, crop yield

INTRODUCTION

Today, agriculture should sustain itself by maintaining soil fertility, protecting groundwater, developing renewable energies, and adapting farming systems to climate change. Farming systems should use fewer inputs and resources without drastically reducing yields (Lichtfouse et al., 2009). The application of new technological principles in tillage and the use of economically more efficient but heavier tractors and agricultural machinery raise higher requirements for soil physical properties. Soil physical properties are linked mainly with organic constituents that are often considered to be the main indicator of soil fertility (Pernes–Debuyser & Tessier, 2004).

Compaction is the main type of physical degradation of soil (Horn et al., 2000; Reintam et al., 2009). Such a negative phenomenon is especially typical on clayey soils, because, as a rule, they are not resistant to compaction. Great compaction of heavy soils results in a considerable worsening of their physical and technological properties. Therefore it is vital to improve clayey soils' physical properties by incorporation of various organic or inorganic amendments as ameliorants (Balesdent et al., 2000; Horn et al., 2000; Kirchman & Gerzabek, 2000; Palojarvi & Nuutinen, 2002; Janusauskaite et al., 2008). On clayey soil, organic matter glues the tiny soil particles together into larger aggregates, increasing pore space. This increases soil oxygen levels and improves soil drainage, which increases the rooting depth, allowing roots to reach a larger supply of nutrients and water (Wagner et al., 2007).

Reduced tillage is a commonly used crop management system (Holland, 2004). However, yields, especially of spring sown crops, may be initially decreased when clayey soils are converted from a conventional ploughing to a reduced tillage system (Pietola & Tanni, 2003). Most authors maintain that tillage without inversion of the plough layer results in improved physical, chemical and biological properties of the upper topsoil layer, however the soil properties tend to deteriorate at the bottom of the topsoil (Rasmussen, 1999; Feiza & Cesevicius, 2006; Feiziene et al., 2007). Therefore, the aims of this study were to analyse the feasibility of improving the clayey soil physical condition by incorporation of amendments before applying the reduced tillage system.

MATERIALS AND METHODS

Site and soil description. This research was conducted from 1997-2003 at Joniskelis Experimental Station of the Lithuanian Research Centre for Agriculture and Forestry situated on the northern part of Central Lithuania's lowland (56°21' N, 24°10' E) on drained, clay loam on silty clay with deeper lying sandy loam *Endocalcari-Endohypogleyic Cambisol*, whose parental rock is glacial lacustrine clay. Clay particles (< 0.002 mm) in A_a horizon (0–0.30 m) made up 27.0%, in B_1 horizon (0.31–0.51 m) – 59.6%, in B_k horizon (0.52–0.76 m) – 51.6%, in C_1 horizon (0.77–1.05 m) – 10.7%, humus content in A_a horizon – 2.3%, in B_1 horizon – 0.6%. During the last 40 years, the annual means of temperature and total precipitation were 6.1°C and 547.4 mm.

Experimental design and parameters. Trial design: **Factor A.** Amendments: 1. Without amendments; 2. Farmyard manure – 60 t ha^{-1}; 3. Green manure – 27 t ha^{-1}; 4. Lime mud – 10 t ha^{-1}. **Factor B.** Incorporation methods of amendments: 1. With a mouldboard plough at 0.25 m depth; 2. With a segment plough at 0.40 m depth. **Factor C.** Primary tillage after the incorporation of amendments: 1. Mouldboard ploughing at 0.25 m depth; 2–3. Reduced ploughless tillage at 0.25 and 0.15 m depths. The plots were 6 m wide and 20 m long. Replications: 4.

General and environmental conditions. In the experiment we grew winter wheat *(Triticum aestivum* Host*)* (1998 and 2001), spring barley *(Hordeum vulgare* L.*)* (1999 and 2002), a vetch (*Vicia sativa* L.*)* and oat *(Avena sativa* L.*)* mixture (2000) and field pea *(Pisum sativum* L.*)* (2003). The incorporation of soil amendments was carried out twice (in 1997 and 2000) during the experimental period before growing winter wheat. Segment ploughing while incorporating soil amendments was performed with special accessories (a bent share of the mouldboard type and a cutting knife) attached to the mouldboard plough. While performing the segment ploughing, the bent share cuts out the cracks (0.15 m deep and 0.08 m wide) in the subsoil. For the reduced ploughless tillage a combined stubble breaker was used. The growing seasons in 1998 and 2001 were characterized by excess moisture, in 2003 – by optimum moisture, whereas the years 1999, 2000 and 2002 were droughty. In this paper we present the results of the second experimental period (2000–2003) when the complex of practices was investigated once more in the field experiment.

Measurements and assessments. In every experimental year the following were estimated: a) soil physical properties (from 4 replications and in 2 places per plot before harvesting): 1) soil bulk density and porosity (Kachinski method), 2) soil structure (Savinov method); b) seedbed quality parameters (from 4 replications and in 2 places per each plot immediately after sowing in spring) (according to Kritz & Hakansson); c) soil hydrophysical properties: 1) moisture content (from 4 replications and in 5 places per each plot before pre–sowing tillage in spring) (weighing method), 2) water conductivity (from 4 replications and in 1 place per each plot before autumn tillage) (Nesterov method); d) the yield of crops. The experimental data were processed by ANOVA. Significant differences are presented at 95% probability level.

RESULTS AND DISCUSSION

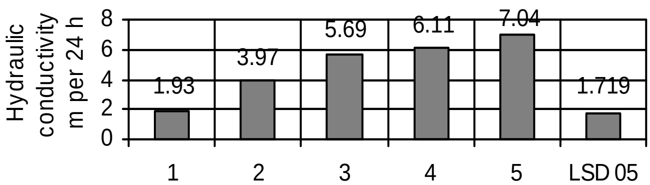
Physical properties of soil. Physical soil protection requires the avoidance of soil compaction. Therefore, clayey soils, noted for higher susceptibility to physical degradation, must be improved and the soil properties must meet the requirements of sustainable tillage technologies (Balesdent et al., 2000; Palojarvi & Nuutinen, 2002). Our experiments showed that soil amendments of organic and inorganic origin had a greater effect on the improvement of the soil physical properties (bulk density, total and air–filled porosity, structure) in topsoil than in subsoil. The positive effect of farmyard manure and lime mud lasted for three years and the effect of green manure one or two years after their incorporation. Only lime mud was effective for subsoil improvement (Table 1).

Table 1. Effects of amendments on soil porosity.

Amendments	Soil layer m	Total porosity, %			Air–filled porosity, %		
		2001	2002	2003	2001	2002	2003
Without amendments	0–0.15	43.1	45.7	43.9	16.9	29.5	25.3
	0.15–0.25	42.6	41.9	40.7	15.3	20.7	20.1
	0.25–0.35	43.2	43.3	42.6	14.3	20.1	21.6
Farmyard manure	0–0.15	44.2	46.9	44.9	18.2	32.4	26.7
	0.15–0.25	43.8	43.3	42.5	16.2	22.7	22.4
	0.25–0.35	43.6	43.4	42.7	15.1	20.6	21.1
Green manure	0–0.15	44.2	47.7	43.8	18.6	32.1	25.3
	0.15–0.25	43.8	43.1	41.3	16.0	21.5	21.3
	0.25–0.35	43.9	43.8	42.2	15.2	20.4	21.1
Lime mud	0–0.15	44.4	46.6	44.8	19.3	31.4	26.6
	0.15–0.25	43.4	43.2	42.6	16.4	22.8	23.1
	0.25–0.35	43.6	43.8	43.7	15.8	22.3	23.6
LSD_{05}	0–0.15	1.05	1.90	2.18	1.65	2.88	3.36
	0.15–0.25	1.34	1.59	1.80	1.64	1.96	2.61
	0.25–0.35	1.22	0.95	1.10	1.62	2.02	1.86

While applying segment ploughing at 0.40 m depth for incorporation of amendments we observed the decrease of bulk density and increase of total and air-filled porosity in subsoil during the whole three-year period. However, in the first year after such tillage the soil structure (according to the structural index) at the bottom (0.15–0.25 m) of the topsoil was by 19.0% poorer, compared with conventional ploughing (the structural index – 0.21) (data not shown). While incorporating the farmyard manure, green manure and lime mud by the segment plough at 0.40 m depth the water conductivity in the subsoil in the first year of influence increased by 2.95, 3.17 and 3.65 times respectively, as compared to the conventional ploughing without the incorporation of amendments (Fig. 1). Segment ploughing increased the water conductivity in the subsoil by 3.26 times; however, the water conductivity in the topsoil was by 44.8% poorer, compared with conventional ploughing (data not shown). The influence of the incorporation of amendments on the water conductivity in the topsoil increased even more in the third (final) year of influence. The worsening of the soil structure and water conductivity in the topsoil after segment ploughing was determined by mixing poorer quality clayey subsoil with more structured and more water conductive topsoil.

In the clayey soils it is very important to secure a good germination of spring crops, because with dry conditions in the topsoil there is little available water content for plants,approaching plant-wilting moisture content. The transition from conventional to reduced tillage usually leads to decreased yield of spring sown crops. According to Finnish scientists, the main reason for this is a coarse seedbed, and therefore poorer germination of cereal seed due to poor contact with the coarse soil aggregates and smaller reserves of the moisture (Pietola & Tanni, 2003).



Treatment: 1. Mouldboard ploughing without amendments; 2. Segment ploughing without amendments; 3. Segment ploughing with farmyard manure; 4. Segment ploughing with green manure; 5. Segment ploughing with lime mud.

Figure 1. Effects of amendment incorporation on subsoil hydraulic conductivity.

Reduced ploughless tillage following the incorporation of amendments determined the increase of soil bulk density and the decrease of total porosity only in the first year, however, the soil structural index was poorer every year, compared with mouldboard ploughing (data not shown).

The results of our investigations suggest that after reduced ploughless autumn tillage, the soil in spring before sowing was more shallowly tilled, and the roughness of the seedbed bottom was greater compared with mouldboard ploughing. Nevertheless, the content of soil structural aggregates >5 mm increased and the content of valuable (2–5 mm) soil aggregates decreased in the seedbed (0–0.05 m). Structurality of the seedbed (according to the structural index) was worse through reduced tillage at 0.25 and 0.15 m depths for spring barley by 9.2% in both cases, for field pea – by 24.0%

and 16.0% respectively as compared to ploughing (data not shown). The application of reduced tillage to spring crops in our study resulted in the deterioration of seedbed quality, reduction of soil porosity and later, however, more uniform drying (according to moisture content) of the topsoil before pre-sowing tillage in spring compared with ploughing. The incorporation of amendments in individual cases helped to avoid the deterioration of soil physical properties under reduced tillage conditions.

Crop yield. The application of soil amendments increased the winter wheat (2001), spring barley (2002) and field pea (2003) grain yield: farmyard manure – by 9.2, 12.7 and 15.3%, green manure – by 6.1, 7.2 and 8.7%, lime mud – by 4.5, 8.0 and 9.3% respectively, as compared to the soil in which the amendments were not applied. Segment ploughing at 0.40 m depth had a positive effect on winter wheat yield, but was negative on the yield of field pea. When growing cereals according to reduced tillage at 0.25 and 0.15 m depths, the spring barley grain yield was lower by 13.5% and 15.6%; grain yield of field pea – by 26.9% and 30.7% respectively, compared with conventional ploughing (Table 2). Consequently, our findings show that spring sown cereals were susceptible to the reduction of autumn clay loam tillage. Feiza & Cesevicius (2006) found that reduced tillage can result in reduction of cereal yield even on sandy loam soils under Lithuania's conditions. The incorporation of amendments in our experiment, especially farmyard manure in individual cases, helped to avoid the crop yield reduction or decreased the negative influence caused by the application of reduced tillage. Therefore, efforts focused on improving clayey soil properties are of great importance during the conversion to a reduced tillage system.

Table 2. Effects of soil amendments and tillage methods on grain yield Mg ha^{-1}.

Treatment	2001	2002	2003
	winter wheat	spring barley	Field pea
Amendments (Factor A)			
Without amendments	5.11	3.63	3.21
Farmyard manure	5.58	4.09	3.58
Green manure	5.42	3.89	3.49
Lime–mud	5.34	3.92	3.51
LSD_{05}A	0.063	0.082	0.132
Incorporation methods of amendments (Factor B)			
With a mouldboard plough at 0.25 m depth	5.30	3.89	3.59
With a segment plough at 0.40 m depth	5.42	3.88	3.31
LSD_{05}B	0.036	0.047	0.076
Soil tillage after incorporation of amendments (Factor C)			
Ploughing at 0.25 m depth	5.42	4.30	4.27
Reduced tillage at 0.25 m depth	5.36	3.72	3.12
Reduced tillage at 0.15 m depth	5.32	3.63	2.96
LSD_{05}C	0.051	0.067	0.108

CONCLUSIONS

The incorporation of amendments, farmyard and green manures, and lime mud, determined the improvement of clayey topsoil and subsoil physical properties and crop yield increase. The influence of the improvement lasted longer from farmyard manure and lime mud, shorter – from green manure. Segment ploughing, while loosening subsoil at 0.40 m depth, improved the physical properties of this layer, however, due to mixing poorer subsoil with topsoil, it deteriorated the physical state of upper soil layers and had no positive effect on crop yield. Although the application of reduced ploughless tillage resulted in the reduction of soil porosity, deterioration of structure and seedbed quality, the topsoil dried later, however more evenly, in spring, and the spring crop yield decreased. The incorporation of amendments decreased the negative influence on the deterioration of soil physical condition and on the reduction of the spring crop yield caused by reduced tillage.

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