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# Soil protection value of winter crops and reduced tillage on clay loams

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**Abstract.** Experiments to reduce soil physical degradation were carried out at Joniskelis Research Station of the Lithuanian Institute of Agriculture over the period 1998–2002. The soil of the experimental site is characterised as glacial lacustrine clay loam on silty clay *(Gleyic Cambisol)*. The following was investigated: Factor A. Crop rotations with different proportions of winter and spring crops (1. Without winter crops; 2. Winter crops 25%; 3. Winter crops 50%; 4. Winter crops 75%; 5. Winter crops 100%), growing annual and perennial grasses, spring and winter wheat, triticale, and barley. Factor B. Soil tillage systems: 1. Conventional (primary soil tillage was performed by ploughing); 2. Sustainable (after grasses the soil was ploughed, after other preceding crops the soil was loosened without inverting the topsoil).

Our experimental evidence suggests that increasing winter crops in the crop rotation reduced compaction of the topsoil from high to moderate, maintained up to 37.3% of higher productive moisture reserves, improved water to air ratio, and increased the crop rotation productivity up to 44.7%. The application of reduced primary tillage in a sustainable system had persistence of high soil compaction and 8.0% lower air-filled porosity at the bottom of the topsoil, but the whole topsoil reached physical maturity more evenly in the spring. The grain yield of cereals was 6.4% lower compared with the yield after conventional soil tillage. On these clay loam soils, spring cereals were more sensitive (poorer performance) to reduced soil tillage compared with winter cereals.

**Key words:** clay loam *Cambisol*, crop rotations, soil tillage, winter crops, physical properties, crop yield

## INTRODUCTION

Soil is the primary component of biogeocenosis. The productivity of biogeocenosis can be judged by the soil fertility. The use of economically more efficient but heavier tractors and agricultural machinery, and the application of new technological principles in soil tillage require higher requirements for soil physical properties. Consequently, in contemporary agriculture soil must be resistant to all degradation factors, and soil properties must meet the requirements of sophisticated, input-saving and sustainable crop cultivation technologies (Arvidsson & Feiza, 1998; Bondarev, 1990; Horn et al., 2000; Schafer-Landefeld et al., 2004).

The main type of physical degradation of heavy soils is compaction. The elimination of negative effects of soil compaction by deep loosening, cultivation of deep-rooted crops, etc. is not always sufficiently effective. Clay loam and clay soils, noted for higher susceptibility to compaction, tend to densify more when spring and especially row crops are grown (Maiksteniene, 1997; Horn et al., 2000; Kladivko, 2001).

Physical degradation of heavy soils considerably deteriorates their physical and technological properties. With increased soil cohesion, hardness, plasticity, and stickiness, soil resistance to tillage as well as energy input increase. Therefore, it is vital to improve heavy soils' physical properties, apply proper primary and pre-sowing soil tillage methods, choose the best-suited crops and their preceding crops and other soil and crop management practices that determine cultivation conditions for the crops grown (Maiksteniene, 1997; Etana et al., 1999; Mueller et al., 2003).

In Scandinavian countries, with soils susceptible to compaction, it is recommended to grow more winter crops whose soil preparation, sowing and harvesting operations are usually performed in a dry period, since dry soils are more resistant to compaction. When a field is covered by plants for a longer period, the soil properties are less deteriorated by climatic factors (Yamoah et al., 1998; Etana et al., 1999; Dabney et al., 2001; Palojarvi & Nuutinen, 2002).

Heavy soils are characterised by high comparative resistance to mechanical tillage, and much energy input is required for this. Energy input for soil tillage is markedly reduced by replacing ploughing with non-inversion tillage. In Sweden it was found that, on heavy soils, the replacement of ploughing by non-inversion tillage is more effective for winter crops than for spring crops. Most authors maintain that tillage without inversion of the plough-layer results in improved agrophysical, agrochemical and biological properties of the upper topsoil layer, however, the soil properties tend to deteriorate at the bottom of the topsoil (Arvidsson & Feiza, 1998; Aura, 1999; Rasmussen, 1999; Tebrugge & During, 1999).

The objectives of the present research were to study the feasibility of reduced soil tillage and the expansion of winter crops area in crop rotations and to assess the results relative to soil protection and crop productivity.

## MATERIALS AND METHODS

Complex research on soil tillage systems and the feasibility of expanding winter crops area in the crop rotation was conducted at Joniskelis Research Station of the Lithuanian Institute of Agriculture during the period 1998–2002.

**Soils.** The experiments were carried out on drained, clay loam on silty clay with deeper lying sandy loam *Endocalcari-Endohypogleyic Cambisol*, whose parental materials are glacial lacustrine sediments. Clay particles < 0.002 mm in $A_a$ horizon (0–30 cm) made up 27.0%, in $B_1$ horizon (52–76 cm) – 51.6%, in $C_1$ horizon (77–105 cm) – 10.7%, in $C_2$ horizon (106–135 cm) – 11.0%. The soil in the plough-layer (0–25 cm) is neutral ($pH_{KCl}$) and has a humus content of 2.20%.

**Experimental design and parameters.** The experiments were performed according to the scheme: **Factor A. Crop rotations with different proportions of winter and spring crops:** 1. Without winter crops (1). Annual grasses; (2). Spring wheat; (3). Spring triticale; (4). Spring barley). 2. 25% winter crops (1). Perennial grasses; (2). Spring wheat; (3). Spring triticale; (4). Spring barley, undersown crop). 3. 50% winter crops (1). Perennial grasses; (2). Winter wheat; (3). Spring triticale; (4). Spring barley, undersown crop). 4. 75% winter crops (1). Perennial grasses; (2). Winter wheat; (3). Winter triticale; (4). Spring barley, undersown crop). 5. 100% winter crops (1). Perennial grasses; (2). Winter wheat; (3). Winter triticale; (4). Winter barley, undersown crop). **Factor B. Soil tillage systems:** 1. Conventional (primary soil tillage is performed by ploughing by a mouldboard plough). 2. Sustainable (after grasses the soil for wheat is ploughed by a mouldboard plough; after cereals non-inversion soil tillage is applied for all crops). The experiment was established using the fully expanded crop rotation method, where each rotation had all the members of the rotation every year and with 4 replications.

**Crops and agricultural practices.** In the experiment, we grew vetch (*Vicia sativa L.*) 'Kurshiai' and oats (*Avena sativa L.*) 'Jaugila' mixture; red clover (*Trifolium pratense L.*) 'Vyliai' and timothy (*Phleum pratense L.*) 'Gintaras II' mixture; spring wheat (*Triticum aestivum L.*) ,'Munk'; winter wheat (*Triticum aestivum Host.*) 'Shirvinta'; spring triticale (*Triticosecale Wittm.*) 'Gabo'; winter triticale (*Triticosecale Wittm.*) 'Tewo'; spring barley (*Hordeum vulgare L.*) 'Ula'; and winter barley (*Hordeum vulgare L.*) ,'Moldavskyj-16'.

While performing the primary soil tillage (factor B) in the conventional soil tillage system, the soil was ploughed with a mouldboard plough with skimmers at 23–25 cm depth. In the sustainable soil tillage system, the soil was ploughed by a mouldboard plough at the same depth only for wheat after grasses, and after all the other preceding crops the soil was loosened by a non-inversion method at the same depth as ploughing, using a combined stubble breaker. The other operations were carried out following the conventional soil and crop management practices.

**Experimental methods.** In the year of the trial establishment, the soil was tested for humus content (Tjurin method) and $pH_{KCl}$ (potentiometrical method), (Agrochemical methods of soil research. 1975). Each year the following were estimated: a) soil agrophysical properties in the 0–15 and 15–25 cm topsoil layers in the second half of the growing season of crops: (1) soil bulk density (Kachinski method) (Rastvorova, 1983); (2) air-filled porosity (according to Dolgov), (Rastvorova, 1983); b) soil hydrophysical properties before sowing in spring and in the second half of the growing season of crops: (1) moisture content in the 0–15 and 15–25 cm layers (weighing method), (Rastvorova, 1983); (2) total and productive (available to plants) moisture reserves (according to Dolgov) (Rastvorova, 1983), and c) the yield of primary production of all crops.

The effects of the treatments on the compaction of topsoil of clay loam soil were assessed as follows: 1) low compaction with the mean topsoil equilibrium bulk density – ≤1.3 Mg $m^{-3}$, 2) moderate compaction – 1.3-1.5 Mg $m^{-3}$, 3) high compaction – >1.5 Mg $m^{-3}$ (Bondarev, 1990). The critical topsoil compaction limit of clay loam was considered to be the soil bulk density of 1.35 Mg $m^{-3}$ (Muller, 1986; Lehtveer & Nugis, 1992). Physical maturity of clay loam soil, when it is most suitable for tillage, occurred at 17.5% (w/w) of moisture (Maiksteniene, 1997).

The experimental data were processed by ANOVA and STATENG (* - 95%, ** - 99% probability level) (Tarakanovas, 1999). Significant differences are presented at the 95% probability level.

**Agrometeorological conditions.** The growing seasons in 1998 and 2001 were characterised by a moisture excess, whereas the years 1999, 2000 and 2002 were droughty.

## RESULTS AND DISCUSSION

***The effects of soil tillage and proportions of winter crops in the crop rotation on soil physical properties***

**Soil bulk density.** In the second half of each crop growing season, we estimated the soil bulk density as a major indicator of the soil physical state and the possible effect of other factors on it. In the first year of the crop rotations (1999), the soil bulk density in the upper (0–15 cm) topsoil layer tended to increase with an increase in the proportion of winter crops in the crop rotation. In the crop rotations with 75 and 100% winter crops, this indicator was higher by 6.9 and 5.6%, respectively, than in the crop rotation grown with only spring crops, corresponding to a high compaction (soil bulk density >1.5 Mg $m^{-3}$), and exceeded the critical compaction limit (soil bulk density 1.35 Mg $m^{-3}$) by 14.1 and 12.6% (Table 1). A longer effect was noticed when increasing the amount of winter crops the bulk density at the end of the rotation consistently declined in the lower part (15–25 cm) of the topsoil. Here the soil bulk density in the crop rotations with 100, 75 and 50% winter crops was lower by 5.8, 4.5 and 4.5%, respectively, compared to the rotation with spring crops only. Furthermore, it corresponded to moderate compaction (soil bulk density 1.3-1.5 Mg $m^{-3}$) and exceeded the critical compaction limit by only 8.9, 10.4, and 10.4%.

Comparing the data of topsoil bulk density and its relation to compaction level and critical limit at the end and beginning of the rotation, we noted that without winter crops and with 25% winter crops the results were very similar but when increasing winter crops to 50, 75 and 100% the soil bulk density tended to decline in the upper topsoil layer by 5.3, 7.1 and 5.3% and in the bottom layer by 4.5, 5.1 and 6.4%, respectively. The level of compaction declined from high to moderate, and exceeded the critical limit only twice on average (Table 1). Our experimental evidence indicates that increasing winter crops in the crop rotations reduces the harmful technological effect on heavy soils and the physical degradation of soils.

With conventional ploughing, soil bulk density per rotation declined and, at the end of the rotation, corresponded to moderate compaction in both layers of the topsoil. In the sustainable soil tillage system with reduced primary tillage, high compaction still persisted in the lower part of the topsoil.

**Soil moisture and moisture reserves.** Possibilities to maintain adequate moisture parameters in heavy soils are of special relevance both for crop emergence and establishment, and technological measures such as soil tillage and performance of other agricultural practices.

It is noteworthy that prior to soil tillage in the spring the moisture content at the bottom of the topsoil, unlike that of the upper layer, in clay loam soil exceeded physical maturity (17.5%) by 7.1–9.4%. Therefore, the threat of overcompacting this layer during the pre-sowing soil tillage and sowing remains as long as soil protection requirements are disregarded in the technologies.

In the sustainable soil tillage system, the application of reduced ploughless soil tillage for spring cereals after winter triticale or spring wheat resulted in more uniform drying of both layers of the topsoil due to a better capillary regime. Therefore, this system has less chance to compact the bottom of the topsoil during the period of spring operations compared with mouldboard ploughing.

**Table 1.** Effect of soil tillage and winter crops on soil bulk density and indices of compaction in 1999 and 2002.

| Treatment | Depth cm | Soil bulk density Mg $m^{-3}$ | | | |
|---|---|---|---|---|---|
| | | at the beginning of rotation | exceeding of critical compaction limit % | at the end of rotation | exceeding of critical compaction limit % |
| Proportion of winter crops % (**Factor A)** | | | | | |
| 0 | 0–15 | 1.44 | 6.7 | 1.42 | 5.2 |
| | 15–25 | 1.57 | 16.3 | 1.56 | 15.6 |
| 25 | 0–15 | 1.46 | 8.1 | 1.44 | 6.7 |
| | 15–25 | 1.58 | 17.0 | 1.54 | 14.1 |
| 50 | 0–15 | 1.50 | 11.1 | 1.42 | 5.2 |
| | 15–25 | 1.56 | 15.6 | 1.49 | 10.4 |
| 75 | 0–15 | 1.54 | 14.1 | 1.43 | 5.9 |
| | 15–25 | 1.57 | 16.3 | 1.49 | 10.4 |
| 100 | 0–15 | 1.52 | 12.6 | 1.44 | 6.7 |
| | 15–25 | 1.57 | 16.3 | 1.47 | 8.9 |
| Soil tillage systems **(Factor B)** | | | | | |
| 1.Conventional | 0–15 | 1.49 | 104 | 1.42 | 5.2 |
| | 15–25 | 1.56 | 15.6 | 1.50 | 11.1 |
| 2. Sustainable | 0–15 | 1.49 | 10.4 | 1.44 | 6.7 |
| | 15–25 | 1.58 | 17.0 | 1.52 | 12.6 |
| | | $LSD_{05}A$ | $LSD_{05}B$ | | |
| At the beginning of rotation | 0–5 | 0.062 | 0.050 | | |
| | 15–25 | 0.073 | 0.059 | | |
| At the end of rotation | 0–15 | 0.062 | 0.051 | | |
| | 15–25 | 0.068 | 0.056 | | |

In droughty years (1999–2002), increasing the proportion of winter crops resulted in better persistence of soil moisture and more abundant reserves of total and especially productive (available to plants) moisture in the second half of the crops growing season. In the crop rotation with 100 % winter crops, the reserves of productive moisture in the topsoil were 37.3% higher, compared to the rotation with spring crops only (18.4 mm).

The relationship between the productive moisture reserves at the bottom of the topsoil during the second half of the crops growing season and soil bulk density ($r = -0.516^{*}$, $y = 47.475 – 26,506x$) was moderate and inverse.

**Soil air-filled porosity.** With reduced soil tillage there was a reduction of soil air-filled porosity in the topsoil in the second half of the crop growing season. In the upper topsoil layer the porosity declined slightly, and in the bottom layer it declined 8.0%, compared with conventional soil tillage (Table 2).

With increasing the proportion of winter crops, air-filled porosity in the second half of the crops growing season usually declined or was the same in all topsoil layers. This resulted from an increase in the moisture content and a longer period after the primary and pre-sowing soil tillage for winter crops compared with spring crops.

**Table 2.** Effect of soil tillage and winter crops on soil moisture and air-filled porosity in the second half of the growing season. Average of 1999–2002.

| Proportion of winter crops % **(Factor A)** | Depth cm | Soil tillage systems **(Factor B)** 1. conventional | | 2. sustainable | | Average of **Factor A** | |
|---|---|---|---|---|---|---|---|
| | | moisture | air-filled porosity | moisture | air-filled porosity | moisture | air-filled porosity |
| | | % | | | | | |
| 0 | 0–15 | 14.5 | 24.0 | 14.5 | 23.8 | 14.5 | 23.9 |
| | 15–25 | 14.7 | 21.1 | 14.7 | 19.2 | 14.7 | 20.2 |
| 25 | 0–15 | 14.4 | 25.5 | 14.5 | 23.8 | 14.5 | 24.7 |
| | 15–25 | 14.8 | 20.1 | 14.6 | 18.9 | 14.7 | 19.5 |
| 50 | 0–15 | 14.8 | 23.2 | 15.0 | 22.1 | 14.9 | 22.7 |
| | 15–25 | 15.1 | 20.2 | 15.4 | 18.6 | 15.3 | 19.4 |
| 75 | 0–15 | 15.4 | 22.2 | 15.3 | 21.3 | 15.4 | 21.8 |
| | 15–25 | 15.6 | 19.7 | 15.9 | 17.8 | 15.8 | 18.8 |
| 100 | 0–15 | 16.0 | 20.6 | 15.5 | 21.4 | 15.8 | 21.0 |
| | 15–25 | 16.1 | 19.4 | 16.1 | 18.2 | 16.1 | 18.8 |
| Average of **Factor B** | 0–15 | 15.0 | 23.1 | 15.0 | 22.5 | 15.0 | 22.8 |
| | 15–25 | 15.3 | 20.1 | 15.4 | 18.5 | 15.4 | 19.3 |
| $LSD_{05}$ | | moisture | | | air-filled porosity | | |
| | | A | B | AB | A | B | AB |
| | 0–15 | 1.55 | 1.36 | 1.64 | 1.73 | 1.69 | 1.51 |
| | 15–25 | 1.27 | 1.11 | 1.34 | 1.42 | 1.51 | 1.25 |

**Moisture to air ratio in the soil.** On heavy clay soils, it is vital to maintain proper moisture to air ratio to achieve satisfactory plant growth. Lithuanian experimental evidence suggests that, on a clay loam soil, the best conditions are created when moisture occupies 60%, and air 40% of the pores. Therefore, the optimum moisture to air ratio was considered to be 1.5:1. Reduced soil tillage in the sustainable system determined slightly more favourable moisture to air ratio at the bottom of the topsoil, compared with the conventional soil tillage system. When increasing the proportion of winter crops in the crop rotations, moisture to air ratio consistently improved in both layers of the topsoil.

***The effects of soil tillage systems and winter crops proportion in the crop rotations on the yield of crops***

**Productivity of crop rotations.** Soil tillage systems did not exert any significant effect on average crop productivity during the whole 4-year rotation. When increasing winter crops proportion in the crop rotation, the total average productivity of all crops increased, and in the crop rotation with 100% winter crops the increase was by 44.7% higher than in the crop rotation composed of only spring crops (Table 3). Expansion of the proportion of winter crops gave a higher increase in grass yield compared with cereals. Moreover, with increasing the proportion of winter crops, the difference in the crop productivity between sustainable and conventional soil tillage systems declined, and it was as low as 2.4% in the crop rotations with 100% winter crops.

**Table 3.** Effect of soil tillage systems and the proportion of winter crops on productivity of rotations according to dry matter yield of crop primary production. Average data of 1999–2002.

| Proportion of winter crops % **(Factor A)** | Soil tillage systems **(Factor B)** | | | | Average of **Factor A** | |
|---|---|---|---|---|---|---|
| | 1. Conventional | | 2. Sustainable | | | |
| | t $ha^{-1}$ | relative values | t $ha^{-1}$ | relative values | t $ha^{-1}$ | relative values |
| 0 | 3.66 | 100 | 3.28 | 89.6 | 3.47 | 100.0 |
| 25 | 4.62 | 100 | 4.21 | 91.1 | 4.42 | 127.4 |
| 50 | 4.76 | 100 | 4.50 | 94.5 | 4.63 | 133.4 |
| 75 | 4.98 | 100 | 4.81 | 96.6 | 4.90 | 141.2 |
| 100 | 5.08 | 100 | 4.96 | 97.6 | 5.02 | 144.7 |
| Average of **Factor B** | 4.62 | 100 | 4.35 | 94.2 | 4.49 | 129.3 |
| $LSD_{05}$A 0.493 | $LSD_{05}$B 0.312 | | $LSD_{05}$AB 0.697 | | | |

**Cereal productivity.** When growing cereals according to the sustainable soil tillage system, the total average grain yield per rotation was 6.4% lower, compared with the conventional technology (4.09 t $ha^{-1}$). The application of reduced soil tillage in the sustainable system had a marked effect on grain yield reduction in the crop rotations with prevalent spring crops. Spring cereals on clay loam soils were more susceptible to the reduction of primary soil tillage compared with winter cereals. With increasing winter crops proportion in the crop rotations, the total average cereal grain yield consistently increased, however, in the crop rotations with 75 and 100% winter crops it did not differ significantly.

**The correlation between crop yield and soil properties.** Averaged experimental data revealed a strong direct correlation between the total average yield of crop rotation crops and productive moisture reserves in the topsoil layer ($r = 0.753^*$, $y = 1.174 + 0.215x$) and subsoil layer ($r = 0.703^*$, $y = 0.791 + 0.556x$) and a moderate direct correlation between the average yield of crop rotation crops and total moisture reserves in the topsoil ($r = 0.694^*$, $y = -6.591 + 0.196x$) and in subsoil ($r = 0.647^*$, $y = -10.057 + 0.559x$).

## CONCLUSIONS

1. Increasing winter crops in crop rotations on clay loam soils during a four-year rotation resulted in a consistent reduction of soil bulk density in the bottom layer of the topsoil. When growing from 50 to 100% of winter cereals during a four-year rotation it is possible to reduce topsoil compaction from high to medium by exceeding the critical compaction limit only twice. In the sustainable soil tillage system with minimum tillage, higher soil bulk density remained in the lower topsoil layer that corresponded with high compaction.

2. With minimum tillage (no ploughing), the topsoil of the clay loam soil dried more evenly in the spring before sowing, while after the conventional mouldboard ploughing the bottom layer of the topsoil remained wetter than the upper layer for a longer period. Increasing of winter crops in the crop rotation provided better preservation of the total and productive moisture reserves in droughty years.

3. Reduced primary soil tillage resulted in reduction of air-filled porosity in the topsoil, compared with mouldboard ploughing, however, the moisture to air ratio remained favourable.

4. Increasing winter crops increased the productivity of crop rotations. As a result, the proportion of winter crops on clay loam soils can be expanded by up to 75–100%.

5. With a minimum tillage sustainable system, the total average cereal grain productivity per rotation was 6.4% lower than that obtained with the conventional soil tillage system. Spring cereals grown on these clay loam soils were more susceptible to minimum primary soil tillage compared to winter cereals.

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