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The impact of soil tillage minimization on sandy light loam soil

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Abstract. Experiments conducted during the period 2001–2005 at the Lithuanian Institute of Agriculture, were designed to evaluate the effects of plough and ploughless soil tillage and methods of sowing on an *Endocalcari-Endohypogleyic Cambisol* and to estimate their effects on soil physical properties and cereal yield. The experiment was set up in 2001 after pea harvesting. Our experimental evidence suggests that different soil tillage and sowing methods had a significant effect on soil structure, soil bulk density, soil penetration resistance, total and air-filled porosity, soil moisture and yield. In cereal crop rotation when winter wheat had been direct drilled after peas into minimally tilled soil the yield increased by 9.7%, when it had been direct drilled the yield tended to increase, compared with conventional soil tillage; the spring barley yield was 14.7% and 7.9% lower compared with conventional tillage; when it had been direct drilled the yield tended to increase compared with conventional tillage. When oats were direct drilled a non-significant yield reduction trend was observed, and when sown into minimally tilled soil the yield was similar (5.77 t ha^{-1}) to that produced in the conventional soil tillage treatment (5.84 t ha^{-1}). When peas were grown, both these simplified tillage methods significantly declined the yield, when peas were direct drilled, the yield declined by 44.0% and by 21.7% when drilled into minimally tilled soil by a direct drill.

Key words*:* soil tillage, direct drilling, soil physical properties, crop yiel

INTRODUCTION

Reduced soil tillage is a very important means intended to minimise fuel consumption, machinery wear, soil erosion and compaction. Energy and time consumption can be cut down by reducing ploughing depth, replacing ploughing by soil loosening or by direct drilling into stubble or into minimally tilled soil. Mouldboardless implements exert a negative effect on limnoglacial clay soil properties and on the productivity of agrocenoses (Maikštėnienė,1997). Research findings indicate that simplification of soil tillage and application of direct drilling caused changes in soil physical properties: increased soil bulk density (Douglas, 1980), especially in the first three years of the experiment (Ellis et al., 1982), and soil hardness (Pollard & Elliot, 1981; Ellis et al., 1982; Hill, 1985). Soil penetration resistance like many other soil physical properties determine plant growth and development. With increasing soil penetration resistance, energy input for tillage of such soil increases and penetration of plant roots into the soil is impeded (Arvidsson, 1997). Tests on soil penetration resistance conducted on silty loam showed that when soil had been ploughed for ten years, its penetration resistance in the 10 cm depth was 0.5 MPa, and in unploughed soil it was 1.4 MPa (Cannell, 1985). Emerging plants are most sensitive to soil penetration resistance. When the plants are well rooted, soil penetration resistance is less important. Critical soil penetration resistance limit, when plant roots are not able to penetrate deeper into the soil, depends on soil texture and crops grown. Some authors indicate this limit to be 3.6 MPa (Ehlers et al., 1983), others – 2.0 MPa (Taylor et al., 1966). Research done at LIA in Dotnuva shows that soil penetration resistance exerts a direct effect on barley yield, and soil bulk density and air permeability affect the yield not directly but through the interaction with penetration resistance (Cesevičius et al., 2005). The trials of Stancevičius et al. (2003) conducted during 1997–1999 revealed that in light loam lying on sandy loam, covered by moraine clay Endohypogleyi-Eutric Planosol having replaced deep ploughing (23–25 cm) by shallow ploughing (12–14 cm) or by deep or shallow ploughless soil tillage, soil bulk density and moisture did not change significantly at different barley crop growth stages. It was noted that when the soil is direct drilled it absorbs moisture more slowly and in droughty conditions is able to preserve it in the ploughlayer. In such soil water is utilized more effectively than in conventionally tilled soil (Sakar et al., 2007).

The yields of agricultural crops using reduced soil tillage are rather controversial. In Latvia on heavy loam soils during 2001–2002, the application of direct drilling reduced the yield of spring barley and spring barley undersown with red clover and timothy by 27.1% and 8.3%, respectively (Ausmane et al., 2004). In Poland on light-textured soils during 1978–1980 it was determined that when maize had been sown into an unploughed soil the yield declined by 9% (Dzienia & Sosnowski, 1989). Some literature sources indicate that the use of direct drilling gave the same winter wheat and maize yield as ploughing at a normal depth (Hipps & Hodgson, 1987). In the USA Hill (1990) reported that on light-textured soils maize yield was significantly higher in direct drilled treatments. In Lithuania research on direct drilling into untilled soil was started several years ago in cultivated, productive, light loam with a low weed incidence in Dotnuva: When winter wheat had been continuously grown for two, three and four years, and had been direct drilled, the yield declined by 27.2%, 18.3% and 10.2%, respectively (Šimanskaitė, 2007). The data from 2003–2004 indicate that in direct drilling treatments the yield of spring barley was by 8.5% lower than in the case of mechanical soil tillage (Cesevičius et al., 2005). In Raudondvaris, the data averaged over 2002–2005 showed no significant differences between cereal grain yield: it was most stable in the treatments minimally loosened by a stubble cultivator and disk harrow. The direct drilling tests conducted during 2000–2003 showed that chopped straw reduced the amount of the fine soil fractions (<2 mm) and increased the amount of larger fractions (> 10 mm). The lowest weed incidence was identified in direct drilled treatments, the highest, in ploughed soil. The lowest barley and winter wheat yield was obtained in the treatments in which straw was removed and the seed was direct drilled. When direct drilling into unloosened stubble with straw not removed, the yield declined within the error limit (Germanas & Bakasėnas, 2004; Lukošiūnas K., 2005). Experiments designed to compare sugar beet direct drilling and sowing into ploughed and cultivated soil conducted at the Lithuanian University of Agriculture revealed that when sugar beet had been direct drilled into light loam, soil moisture at seed placement depth was by 4.4–5.6% higher than in ploughed and cultivated soil; the yield and quality parameters differed insignificantly (Šarauskis & Romaneckas, 2002).

The objective of our tests was to study the feasibility of replacement of the conventional (autumn) soil tillage system (stubble breaking and deep ploughing) by up-to-date, more economical, less labour-intensive and less time-consuming soil tillage systems; to evaluate the effects of plough and ploughless soil tillage and methods of sowing and to estimate their effects on soil physical properties and cereal yield.

MATERIALS AND METHODS

Experiments were conducted at the Lithuania Institute of Agriculture in Dotnuva during 2001-2005. The soil of the experimental site is sandy light loamy Endocalcari - Endohypogleyic Cambisol. Soil agrochemical characteristics: during the experimental period the soil was medium-rich in phosphorus and potassium (available P_2O_5 and K_2O 141 amounted to 178 and 113–137 mg kg^{-1} soil), pH_{KCl} 6.8–7.3. The experiments were set up in 2001 after harvesting of peas. The experimental design was as follows: treatment 1 (control treatment) – stubble breaking by a plough at the 10–12 cm depth, ploughing by a plough with a ploughlayer's densifier at 22–25 cm, sowing by a disc drill; treatment 2 – ploughing by a plough with a ploughlayer's densifier at the 20–22 cm depth, sowing by a disc drill; treatment 3 - stubble breaking by a combined stubble breaker SL-4 at the10–12 cm depth, ploughing by a plough with a ploughlayer's densifier at the 22–25 cm depth, sowing by a disc drill; treatment 4 – stubble breaking by a combined stubble breaker SL-4 at the 10–12 cm depth, ploughing by a plough with a ploughlayer's densifier at the 22–25 cm depth, sowing by a direct drill (stubble drill); treatment 5 - stubble breaking by a combined stubble breaker at the 10–12 cm depth, sowing by a direct drill; treatment 6 - herbicide application on an untilled soil, sowing by a direct drill. In experiments treatments 1, 2, 3 in 2001–2005 were sown by a 3m-wide sowing machine "Saxonia"; treatments 4,5,6 were sown by a combined disk Swedish 4m-wide direct drill "Super Rapid Väderstad". In the sixth treatment after preceding crops harvesting stubble was left and the soil was not tilled until sowing; before sowing, the stubble was sprayed with the herbicide Roundup 4 l ha^{-1}. In the third and fourth treatments the stubble was broken by a versatile combined stubble breaker SL-4 at the 10–12 cm depth. The combined stubble breaker was fitted with three types of working parts: in the front, wide arrow coulters, behind them a disk row of disk harrow and in the rear, rollers. In the experiment the soil of the first, second, third, fourth and fifth treatments were ploughed by a mouldboard plough with semi-helical mouldboards with a ploughlayer's densifier hitched to a John Deere tractor (130AE). Prior to soil tillage phosphorus and potassium fertilisers ($P_{90}K_{90}$) were applied. Nitrogen fertilisers N_{30+60} were applied in spring. Before sowing, the soil of the plots of the other experimental treatments was cultivated by a Germinator at the 6–8 cm depth. Crop management was performed following the technological requirements set for the crops grown. In the experiment the tests were done in a cereal crop rotation with the following crop sequence: winter wheat 'Širvinta', spring barley 'Luokė', oats 'Jaugila', peas 'Profi'. In experiment II the straw was chopped and spread on the plots. The field experiments were set up in four replications, the plots were arranged randomly. Crop yield was determined for each experimental plot. Grain yield was adjusted to 15% moisture content.

Soil samples for physical analyses were collected before the primary (main) soil tillage, after soil tillage, in spring after resumption of vegetation (tillering stage) and after crop harvesting. To estimate the changes in soil physical properties the samples were taken from the ploughlayer's 0–10 cm and 10–20 cm depth before soil tillage, at tillering stage and upon completion of vegetation.

To assess the changes in soil structure as affected by soil tillage the samples were taken from the ploughlayer's 0–10 cm and 10–20 cm depth, and soil bulk density was determined every 5 cm. Physical analyses of the soil samples were made using the following methods: structure and its stability in water by Savinov; soil penetration resistance was determined by an instrument Fieldscout at each plot's 10 places at 0–5, 5–10, 10–15 and 15–20 cm depths, bulk density by Kachinski 100 cm^3 by cylindrical drill; total and air-filled porosity by calculation method from bulk density, solid phase density and moisture (Vadiunina & Korčiagina, 1986); soil moisture by weight method by drying at a constant +105^{o}C temperature.

The data of soil physical analyses, weed incidence in the crop stand and yield were processed by the analysis of variance method (Clewer & Scarisbrick, 2001), using computer software (Tarakanovas & Raudonius, 2003).

RESULTS AND DISCUSSION

Soil physical properties. Soil structure. The experimental data suggest that in well-tamed *Endocalcari-Endohypogleyic Cambisol* the macrostructure changed due to the soil tillage (Table 1). At the beginning of the rotation (20-08-2002) the greatest amount of valuable soil structural aggregates 0.25–5.0 mm in size was found in the 0–10 cm layer (34.5%) and 29.0% in the 10–20 cm layer. In the last year of the crop rotation in the differently tilled treatments the amount of valuable soil aggregates of 0.25–5.00 mm increased. The largest amount was identified in the treatments ploughed before sowing: 43.5% in the 0–10 cm layer and 37.1% in the 10–20 cm layer (Table 1). The lowest amount of valuable soil aggregates was found in the direct drilled unploughed treatments. The amount of water stable aggregates larger than 0.25 mm in the minimally tilled soil by ploughless implements and sown by a direct drill, as well as in the soil sown without tillage, significantly increased in the 0–10 cm layer by 13.5% and 12.0 %, and in the 10–20 cm layer were by 9.6% and 9.8% higher compared with conventional soil tillage.

In all treatments the amount of aggregates larger than 1 mm was higher compared with conventional soil tillage. These aggregates are very valuable from the agronomic point of view since they maintain soil friability and improve the water regime. Research done on a wide range of west European soil types suggests that when reduced (minimal) soil tillage had been used for several successive years the soil aggregate stability in the topsoil was improved more than in ploughed soils (Douglas et al., 1980; Pollard, 1981; Boone et al., 1984).

Table 1. The effect of different soil tillage and sowing methods on soil structure, Dotnuva, 18-08-2005.

Treatment	Depth cm	Structural aggregates, %				Water stable aggregates %	
		> 5mm, incl.	<10mm	0.25-5 mm	< 0.25 mm	> 0.25 mm	> 1mm
2001-08-20							
Soil structure before trial estab lishment	0-10 10-20	63.8 70.1	- -	34.5 29.0	1.70 0.90	57.7 60.5	11.5 15.5
2005-08-18							
1.Stubble breaking ploughing,sowing by a disk drill	0-10 10-20	55.3 65.9	33.3 40.3	41.5 32.4	3.18 1.67	43.5 48.7	6.98 7.27
2.Ploughing just before sowing sowing by a disk drill	0-10 10-20	53.8 61.1	28.6 33.0	43.5 37.1	2.64 1.73	53.0 55.2	10.65 13.09
3.Stubble breaking by a combined stubble breaker, ploughing, sowing by a disk drill	0-10 10-20	60.3 70.9	34.9 42.2	36.6 27.6	3.03 1.51	52.3 53.4	9.85 9.09
4.Stubble breaking by a combined stubble breaker, ploughing, sowing by a direct drill	0-10 10-20	56.6 73.2	30.7 46.5	39.7 25.2	3.63 1.60	51.7 52.8	8.88 8.97
5.Stubble breaking by a combined stubble breaker, direct drilling	0-10 10-20	68.0 72.3	39.9 45.9	29.7 26.3	2.10 1.35	56.0 58.3	14.47 17.16
6.Roundup application on untilled soil, direct drilling	0-10 10-20	59.0 71.6	30.2 42.7	38.5 26.6	2.50 1.65	55.8 58.5	14.97 16.34
LSD_{05}	0-10 10-20	14.02 9.78	16.00 12.694	13.49 9.79	1.068 0.722	7.40 4.34	4.331 5.084

Soil bulk density is one of the values that changes most under natural and anthropogenic effects. Soil bulk density after sowing in experiments was lowest in the conventional tillage system. In the direct drilling treatments the soil bulk density increased at the beginning of the rotation in the year 2001 only in the 0–10 cm layer by 0.08 Mgm^{-3} (LSD_{05} 0.08); in the last year of the crop rotation (18-08-2005) the soil bulk density tended to decline in all soil tillage systems tested, except for direct drilling where in the topsoil it increased by 0,11 Mgm^{-3} or by 8.33%, and in the 10–20 cm depth showed a trend of increasing by 0.04 Mgm^{-3} (or 2.81%), compared with the conventional tillage (treatment 1) (Table 2).

Table 2. The effect of different soil tillage systems and sowing methods on soil physical properties, on the end of crop rotation, Dotnuva, 18-08-2005.

Treatment	Depth cm	Soil bulk density Mg m^{-3}	Soil moisture %	Soil porosity %	
				Total	Air-filled
1. Stubble breaking, ploughing, sowing by a disk drill	0-10 10-20	1.32 1.42	15.7 17.5	49.8 46.2	29.0 21.4
2. Ploughing just before sowing, sowing by a disk drill	0-10 10-20	1.26 1.35	16.0 18.3	52.2 48.7	32.0 24.0
3.Stubble breaking by a combined stubble breaker, ploughing, sowing by a disk drill	0-10 10-20	1.33 1.41	16.0 17.8	49.5 46.4	28.3 21.4
4. Stubble breaking by a combined stubble breaker, ploughing, sowing by a direct drill	0-10 10-20	1.31 1.40	14.9 17.2	50.0 46.8	30.3 22.7
5. Stubble breaking by a combined stubble breaker, direct drilling	0-10 10-20	1.34 1.46	16.1 17.2	49.0 44.5	27.4 19.5
6.Roundup application on untilled soil, direct drilling	0-10 10-20	1.43 1.46	15.2 17.1	45.8 44.6	24.1 19.9
LSD_{05}	0-10 10-20	0.106 0.101	1.19 0.63	4.02 3.85	5.99 5.11

Soil total and air-filled porosity is an important soil characteristic on which water and air regime and plant growth conditions are dependent. Experimental findings show that when the soil had been tilled using various methods, the conditions of total soil porosity were good. In the experiment in the 0–10 cm layer it ranged from 49.5% to 50.0% (Table 2), it was slightly lower (44.5– 48.7%) in the bottom 10–20 cm layer, except for the sixth treatment, when direct drilled, where total porosity significantly declined in the topsoil layer by 4.0 percentage units, while only in the subsoil layer was a reduction trend determined, compared with conventional soil tillage. The data averaged over four years indicate that in experiments when using various soil tillage systems there was sufficient content of air-filled pores (19.5– 32.0%), compared with conventional soil tillage; when zero tillage – direct drilling was applied a reduction trend was observed (Table 2).

Soil moisture in experiment in the last year of the crop rotation (2005) did not change significantly throughout the whole ploughlayer (Table 2).

Crop yield. In the experiments (Table 3) in 2002, when winter wheat was grown in the cereal crop rotation, the best yields (5.86 t ha^{-1}) were obtained when sown after peas by a direct drill into minimally tilled soil; when sowing into untilled soil and spraying the stubble with roundup 4 l ha^{-1}, the yield increasing trend persisted, compared with the check treatment. Spring barley requires conventional soil tillage.

Table 3. The effect of primary soil tillage simplification and sowing methods on cereal yield Dotnuva, 2002–2005.

Treatment	Grain yield t ha^{-1}							
	Winter wheat t ha^{-1}	%	Spring barley t ha^{-1}	%	Oats t ha^{-1}	%	Peas t ha^{-1}	%
1	5.34	100.0	4.43	100.0	5.84	100.0	3.43	100.0
2	5.53	103.6	3.92	88.5	4.62	79.1	2.28	66.5
3	5.61	105.1	4.86	109.7	5.83	99.8	3.49	101.7
4	5.84	109.4	4.82	108.8	5.74	98.3	3.28	95.6
5	5.86	109.7	3.78	85.3	5.77	98.8	2.72	79.3
6	5.66	106.0	4.08	92.1	5.53	94.7	1.92	56.0
LSD_{05}	0.458		0.546		0.631		0.479	

The best yields in 2003 were obtained in treatments 3 and 4; in the direct drilling treatments (treatment 6) a reduction trend was observed (7.9%), and in the drilling into minimally tilled soil by a direct drill (treatment 5) the lowest yield was obtained, by 14.7% lower compared with the conventional soil tillage. When oats were grown in 2004 the highest yield was produced in the conventionally tilled treatment 1. When oats were direct drilled a yield reduction trend was observed, and when oats were drilled into the minimally tilled soil, the yield was the same as in the conventionally tilled soil – 5,84 t ha^{-1} and 5,77 t ha^{-1}, respectively. When legume crops are grown in a cereal crop rotation, direct drilling and drilling into minimally tilled soil are completely unsuitable, since the yield of peas declined by 44.0% and 20.7%, respectively, compared with the conventional autumn soil tillage. Ploughing just before sowing by mouldboard ploughs fitted with a ploughlayer's densifier (treatment 2) is suitable when winter wheat is grown in a cereal crop rotation after peas. For spring barley, oats and peas this soil tillage method is unsuitable since the yield declined by 11.5%, 20.9% and 33.5%, respectively, compared with conventional tillage.

CONCLUSIONS

1. The structure of a well-tamed sandy light loam soil changed in relation to the different soil tillage systems and sowing methods used. In the cereal crop rotation at the end of the crop rotation the content of valuable structural aggregates of 0.25–5.0 mm diameter when direct drilled and drilled into minimally tilled soil by a direct drill tended to decline. In the cereal crop rotation when direct drilled into the soil loosened by mouldboardless implements, as well as when drilled into stubble, the content water stable structural aggregates larger than 0.25 mm increased in the 0–10 cm layer by 13.5% and 12.0%, respectively and in the 10–20 cm layer the content of these aggregates was by 9.6% and 9.8% higher, compared with the conventional soil tillage. The content of structural aggregates larger than 1mm in all soil tillage systems tested was higher than in the conventional tillage system.

2. In the direct drilling treatments the soil bulk density increased at the beginning of the rotation only in the 0–10 cm layer by 0.08 Mgm^{-3} (LSD_{05} 0.08); in the last year of the crop rotation the soil bulk density tended to decline in all soil tillage systems tested, except for direct drilling where in the topsoil (0–10 cm layer) it increased by

0,11 Mgm^{-3} or by 8.33%, and in the 10–20 cm depth it showed a trend of increasing by 0,04 Mgm^{-3} compared with the conventional tillage.

3. In the direct drilling treatments total soil porosity declined significantly in experiments only in the 0–10 cm soil layer. Air-filled porosity significantly declined in the 0–10 cm layer at the end of the rotation by 4.9%, in the 10–20cm layer a trend of reduction was observed.

4. Different soil tillage systems and sowing methods applied in the treatments where winter wheat had been continuously grown for four years affected soil moisture: when direct drilled it declined significantly by 0.96 percentage units in the first year of growing throughout the whole ploughlayer in the 0–10cm layer and by 1.16 percentage units in the 10–20 cm layer, compared with conventional tillage; in the fourth year soil moisture was similar in the different soil tillage systems applied. In the cereal crop rotation soil moisture declined by 1.2 percentage units in the 10–20cm layer, and in the 0–10cm layer there were no changes in soil moisture; in the last year of rotation soil moisture did not change significantly in the whole ploughlayer, compared with the conventional soil tillage.

5. In the cereal crop rotation when winter wheat was sown after peas into minimally tilled soil the yield increased by 9.7% and tended to increase when direct drilled; the yield of spring barley was by 14.7% and 7.9% lower, compared with conventional tillage; when oats were direct drilled, a trend of yield reduction was observed, and when sown by a direct drill into minimally tilled soil the yield was similar (5.77 t ha^{-1}) to that obtained in conventionally tilled soil (5.84 t ha^{-1}). When peas were grown, both of these reduced soil tillage methods significantly lowered the yield: when peas were direct drilled, the yield declined by 21.7% and by 44.0% when sown by a direct drill into minimally tilled soil.

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