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Impact of cultivation method on the soil properties in cereal production

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Abstract. The aim of present paper is to give an overview about results collected in 2012–2014 related to impact of cultivation method on the cereal field soil properties. Experiments were conducted on Estonian farmers' production fields to compare no-till and plough-based tillage practices. Studied properties were among others soil bulk density, structure, water content, microbial activity and weeds seeds content.
The bulk density, gravimetric moisture content and structure of soil from 0–10, 10–20 and 20–30 cm layers were evaluated. For microbial activity an enzyme dehydrogenase, which occurs in all viable microbial cells, was determined in soil layers 0–10 and 10–20 cm. Soil samples were taken from 0–25 cm layer to determine weed seeds content. Seeds were extracted from the soil using a flotation-method. The seeds were counted and species identified under the microscope.
The cultivation method has significant impact on some soil properties and insignificant to other. Cultivation method had no significant impact on ratio of agronomically preferred soil particles (2–4.75 mm). No-tilled fields soil bulk density had no differences between layers except 0–10 layer in Pärnumaa ($p < 0.05$). Soil bulk density differences ($p < 0.05$) between layers occurred in Soth-Viljandimaa and Pärnumaa tilled soils, in which plough pan in layer 20–30 cm was noticeable.
In average the abundance of weeds seeds was higher on no-tilled fields, compared to tillage accordingly 60,975 and 29,250 weed seeds m^{-2} ($p < 0.003$).
Results showed higher soil dehydrogenase activity in the no-tilled soils layer 0–10 cm than in 10–20 cm layer ($p < 0.05$). In the tillage the dehydrogenase activity had no significant difference between soil layers.

Key words: no-till, tillage, soil physical properties, soil dehydrogenase activity, weed seeds.

INTRODUCTION

In Estonia 9% of arable land was cultivated with direct drilling method by inquiry made in 2010 (PMS602, 2010) and the interest to use that technology is increasing because of farmers hope to reduce production costs and work time with that. However, farmers suffer under lack of sufficient information related with possibilities to use direct drilling in Estonian agroclimatic and soil conditions, which are very heterogeneous despite of small area of country. There is no comprehensive research made in Estonia to study different aspects of no-till technology and which can be used as support for decisions related to selection and usage of tillage method and machines; and taking into account agroclimatic, economic, ecologic, technical and soil-derived aspects.

In Europe the no-till and tillage studies have been carried out for a long period (Soane et al., 2012). The results have pointed out some disadvantages for both cultivation methods. Kassam et al. (2009) found that the ploughing may result loss of soil structure, while Munkholm et al. (2003) found the no-till tend to increase soil bulk density. In northern Europe no-till raised up a problem in delay of spring-sowing due to the fact that in spring the soil surface of no-tilled fields is covered with plant residues, which slow down the warming up of the soil (Mikkola et al., 2005; Soane et al., 2012).

Through the changes of soil physical property and plant residues distribution the biological processes in soil depend on the tillage practices (Bogužas et al., 2010; Janušauskaite et al., 2013). The measurement of soil enzymatic activity could be used as an indicator of tillage management induced changes on soil microorganisms (Watts et al., 2010). Dehydrogenase is an enzyme that occurs in all viable microbial cells (Nannipieri, 1994) and therefore soil dehydrogenase activity (DHA) is widely used to describe overall soil microbial activity (Wolinska & Stepniewska, 2012).

Soil weed seed bank is the main source of weed infestation in any crop. Tillage affects the vertical weed seed distribution in a soil profile (Chauhan & Johnson, 2009). Moving the soil on field encourages germination of weeds seeds stored in the soil. Tillage systems cause changes in the density and composition of soil weed seedbank (José-Mariá & Sans, 2011), especially in weed seed composition in the upper 0–15 cm soil layer (Barberi and Lo Cascio, 2001). Feldman et al. (1997) and Tørresen et al. (2003) reported that weed seed densities in the upper soil surface in no-till and reduced tillage systems were higher than in ploughed systems. In contrast, Unger et al. (1999) concluded, that tillage method does not affect seed density. Similar results were found by Ruisi et al. (2015) who noted that tillage system had no effect on the size of the weed seedbank, but altered both its composition and the distribution of seeds within the soil profile.

The aim of this study was to evaluate the response of soil physical properties, microbiological activity and weed seed content to no-till and tillage practices in different Estonian agroclimatic and soil conditions.

MATERIALS AND METHODS

The field experiment was carried out in 2012–2014 on the commercial fields in Estonia. The trial plots were located on seven location, different farmers' fields. The fields were selected on the principle that in all sites the comparison pairs of tillage and no-till fields locate closely (under the similar weather conditions) and have similar soil characteristics (Table 1). For observations a study area with size 1 ha was selected from each field. Crops grown on the fields are presented in Table 2. During 2012–2014 the average use of pesticides in no-till and tillage fields were in correspondingly as follows (active ingredient kg ha^{-1}): pesticides 1.1 and 0.9, of them glyphosate 0.53 and 0.26. In investigated fields different mineral fertilizers were used during study, only in 2013 spring in Tartumaa the liquid cattle manure at the rate 30 t ha^{-1} was used. The fertilisation and plant protection strategy were decided by farmers managing the fields and it depended from farm production plan. Same strategies were used in Soth-Viljandima comparison pair and in Jõgevamaa comaprision pair, but different by region.

Tillage based on mouldboard ploughing to a depth of 20 cm. The no-till fields in North- and South-Viljandimaa, Valgamaa and Põlvamaa have not been ploughed over ten years and in Pärnumaa and Tartumaa during two and in Jõgevamaa one year.

Table 1. Soil characteristics on experimental territories

Location	No-till					Tillage			
	Depth, cm	C_{org} %	Sand %	Clay %	Silt %	C_{org} %	Sand %	Clay %	Silt %
North-Viljandi	0–10	1.6	53	13	34	2.8	47	12	41
	10–20	1.5	44	13	43	2.8	50	11	39
South-Viljandi	0–10	1.6	60	9	31	1.5	66	7	27
	10–20	1.4	60	8	32	1.4	77	4	19
Valgamaa	0–10	1.4	69	8	23	1.5	84	4	12
	10–20	1.6	66	7	27	1.5	75	5	20
Põlvamaa	0–10	1.7	56	7	37	1.0	69	8	23
	10–20	1.4	57	7	36	1.2	68	8	24
Tartumaa	0–10	1.8	47	9	44	1.8	48	9	43
	10–20	1.4	51	10	39	1.9	49	10	41
Jõgevamaa	0–10	1.9	35	11	54	1.9	35	11	54
	10–20	2.0	37	11	52	2.0	37	11	52
Pärnumaa	0–10	4.0	67	23	10	3.1	68	23	9
	10–20	3.1	71	20	9	2.8	72	21	8

Notes. One composite sample was collected from every experimental territory. Organic carbon (C_{org}) content in soils was measured by NIRS method. Soil texture was measured in the soil science and agrochemistry laboratory of Estonian University of Life Science.

Table 2. Cultivated crops in no-till (NT) and conventionally tilled (CT) fields in 2012–2014

Location	Treatment	2012	2013	2014
North-Viljandi	NT	spring barley	spring rape	spring wheat
	CT	spring barley	spring rape	spring wheat
South-Viljandi	NT	spring rape	winter wheat	spring barley
	CT	spring rape	winter wheat	spring barley
Valgamaa	NT	winter wheat	oats	winter wheat
	CT	winter wheat	oats	spring rape
Põlvamaa	NT	–	winter wheat	spring barley
	CT	–	winter wheat	spring barley
Tartumaa	NT	–	spring wheat	spring wheat
	CT	–	oats	clover
Jõgevamaa	NT	–	oats	winter wheat
	CT	–	oats	winter wheat
Pärnumaa	NT	–	spring barley	spring rape
	CT	–	spring barley	spring rape

Soil bulk density, moisture content and structure

The soil physical properties, i.e. bulk density (Mg m^{-3}), soil gravimetric water content (kg kg^{-1}), soil structure and water stable aggregates (%) in the 5 points of the Z-scheme were observed at fields. Each measurement point was established by GPS equipment. The measurements were made in soil layers 0–10, 10–20 and 20–30 cm.

The soil bulk density and gravimetric soil moisture content are evaluated by cylinder (100 cm^3). The soil structure K_{str} (Nugis, 2010; Nugis et al., 2014) is evaluated by USA Standard Testing Sieve and also by method of Swedish University of Agricultural Sciences (Hakansson, 1983; Kritz, 1983) by which the soil has been sieved in the moist conditions. For this the soil samples were collected from above mentioned fields. The soil has been sieved also in the dry conditions by full set of abovementioned sieve's equipment with corresponding sieves with diameter of bores (9.5; 4.5; 2.0; 1.0; 0.425; 0.250; 0.150 and 0.075 mm). The ratio of water stable aggregates (%) from soil aggregates with diameter of particles between 0.250–1.0 mm were evaluated from same samples. The ratio (soil dry sieving) of soil water stable aggregates (%) is calculated with equation:

$$W_r = \frac{m_a}{100M} \qquad (1)$$

where: m_a – total mass of soil upon sieves with diameter of bores 0.425 mm and 0.250 mm, in which the aggregates of soil have been remaining on these sieves; M – total mass of the soil upon full set of abovementioned sieves.

The ratio of soil structure K_{str} (soil moist sieving) was calculated with equation:

$$K_{str} = \frac{s_{ad}}{s_{un1} + s_{un2}}, \qquad (2)$$

where: s_{ad} – percentage of soil particles with diameter between 2–4.75 mm (agronomically preferred soil structure); s_{n1} – percentage of soil particles with diameter < 2 mm (agronomically not-preferred soil structure); s_{n2} – percentage of soil particles with diameter > 4.75 mm (also agronomically not-preferred soil structure).

Weed seed bank in the soil

The weed seed bank was sampled at the end of August after crop harvest. From each plot 10 soil samples were taken from 0–25 cm soil layer. Samples of each plot were mixed together in a bucket and bagged. For analysis, the samples were sieved to remove stones and air-dried. Seeds were extracted from a 300 g portion of the soil sample using a flotation-based method (Gross & Renner, 1989). 53% solution of K_2CO_3 was used as the flotation solution (specific gravity 1.56 g ml^{-1}). Weed seeds were counted and species identified under the microscope.

Soil dehydrogenase activity

Soil samples from Valgamaa and South-Viljandimaa no-till and tillage fields were taken in 2012–2014 and from North-Viljandimaa, Põlvamaa and Tartumaa in 2013–2014 of April, before cultivation. Soil samples (0.5 kg) from each treatment in six or nine replications (three in each year) were taken by a random method from the 0–10 and 10–20 cm soil layers with a 1 cm ∅ auger. Each soil sample was composite of 20 sub-samples. Samples were sieved (2 mm) and stored at 4 °C until they were analysed in laboratory.

Dehydrogenase activity (DHA) was measured in accordance to Tabatabai (1982). Soil samples (5 g) incubated at 30 °C for 24 h in the presence of an alternative electron acceptor (triphenyltetrazoliumchloride). The red-tinted product triphenylformazan (TPF) was extracted with acetone and measured in a spectrophotometer at 546 nm.

Data analyses

Soil physical parameter results were based on five (structure K_{str} and water stable soil aggregates) or fifteen (soil bulk density and gravimetric water content) sample replicates. All soil dehydrogenase activity results were based on six (North-Viljandimaa, Põlvamaa and Tartumaa) or nine (Valgamaa and South-Viljandimaa) soil sample replicates. The data were analyzed by ANOVA. For the soil physical parameters and dehydrogenase activity the Tukey-Kramer Honest Significant Difference (HSD) test was used via the software *JMP 5.0.1.2* (SAS, 2002).

RESULTS AND DISCUSSION

Soil bulk density, gravimetric moisture content and structure

The soil bulk density is important parameter to describe the soil physical status. The moderate bulk density which enhances root growth is 1.3–1.5 Mg m^{-3} (Tracy et al., 2012), but its depends also on the soil texture and the content of organic matter (Guimarães et al., 2002). In this study the average soil bulk density for all years, sites and depths was similar to both tillage systems (no-till – 1.54 and tillage – 1.52 Mg m^{-3}) (Table 3). The highest soil bulk density in all three investigated soil layers (Table 1) were measured on Valgamaa conventionally tilled field (0–10 cm – 1.65, 10–20 cm – 1.65, 20–30 cm – 1.75 Mg m^{-3}) (Table 3) which soil has high sand and low silt and clay content.

In 0–10 cm soil layer occurred lower soil bulk density in South-Viljandimaa and Pärnumaa tilled fields compared to no-till fields, which were not ploughed over ten and two years (Table 3). The lower soil bulk density in tillage than no-till fields soil was also found by Munkholm et al (2003) and Saoirse et al (2013). In South-Viljandimaa and Pärnumaa 20–30 cm layer was soil bulk density in no-tilled field similar to the conventionally tilled field or remained even lower. The higher bulk density in conventionally tilled soils 20–30 cm layer could be explained with formation of plough pan. The plough pan can create impenetrable layer to growing roots of cultured plant (Soane et al., 2012).

During study the average soil gravimetric water content for all treatments, depths and years was 0.209 kg kg^{-1} (Table 3). Considerably lower soil gravimetric water content in 0–30 cm soil layer (0.199 kg kg^{-1}) was measured in tilled soils compared to no-till (0.220 kg kg^{-1}). Higher soil moisture content in no-till soils cold be due to the plant residues covering soil surface and therefore hindering the solar radiation access and soil evaporation. This effect may cause serious delay of the spring-sowing and thus decrease of yield in no-till systems (Mikkola et al., 2005; Soane et al., 2012).

Table 3. Mean values of soil bulk density, gravimetric water content, structure and water stable aggregates in no-till (NT) and conventionally tilled (CT) fields (n = 15)

Location	Depth cm	Bulk density, Mg m^{-3}		Gravimetric moisture content, kg kg^{-1}		Structure, K_{str} 0–20 cm (n = 5)		Water stable aggregates, % 0–20 cm (n = 5)	
		NT	CT	NT	CT	NT	CT	NT	CT
N-Viljandi	0–10	–	–	–	–	0.72^{abc}	$0.71^{a–d}$	8.4^{cd}	$10.7^{a–d}$
	10–20	–	–	–	–				
	20–30	–	–	–	–				
S-Viljandi	0–10	1.44^{cd}	1.29^{e}	$0.236^{a–e}$	$0.220^{b–f}$	0.33^{cde}	$0.47^{a–e}$	8.4^{cd}	15.1^{ab}
	10–20	1.45^{cd}	1.40^{d}	$0.212^{c–g}$	$0.206^{e–h}$				
	20–30	1.49^{cd}	1.58^{b}	$0.208^{d–h}$	$0.183^{f–i}$				
Valga-maa	0–10	1.54^{bc}	1.65^{ab}	$0.217^{c–f}$	$0.172^{g–j}$	0.16^{e}	0.23^{e}	9.9^{cd}	$13.7^{a–d}$
	10–20	1.56^{bc}	1.65^{ab}	$0.193^{e–i}$	0.150^{ij}				
	20–30	1.64^{ab}	1.75^{a}	0.167^{hij}	0.131^{j}				
Põlva-maa	0–10	–	–	–	–	0.86^{a}	$0.66^{a–d}$	17.5^{a}	16.7^{ab}
	10–20	–	–	–	–				
	20–30	–	–	–	–				
Tartu-maa	0–10	–	–	–	–	$0.42^{b–e}$	$0.60^{a–e}$	4.0^{e}	7.4^{de}
	10–20	–	–	–	–				
	20–30	–	–	–	–				
Jõgeva-maa	0–10	–	–	–	–	0.81^{ab}	0.79^{ab}	7.5^{de}	9.1^{cd}
	10–20	–	–	–	–				
	20–30	–	–	–	–				
Pärnu-maa	0–10	1.40^{d}	1.31^{e}	0.265^{a}	$0.253^{a–d}$	0.31^{de}	0.38^{cde}	4.0^{e}	8.0^{cd}
	10–20	1.65^{ab}	1.41^{d}	$0.252^{a–d}$	0.262^{ab}				
	20–30	1.65^{ab}	1.65^{ab}	$0.228^{a–e}$	$0.215^{c–g}$				
Prob > F		< 0.0001		< 0.0001		0.012		< 0.0001	

Note. Different letters behind the mean values indicate significant differences ($p < 0.05$). Significances of model effects ($p > F$) are indicated. In the case of significant model effects, a Tukey-Kramer HSD test was performed in order to compare mean values.

Soil structure is based on soil aggregate dynamics. Soil agregates play an essential role in water availability, movement in soil and thus they are very important in crop production (Bronick & Lal, 2005). Results showed a best soil structure K_{str} in Põlvamaa no-till field (0.86), the lowest value (0.16) was found in Valgama no-till field. Significant differences between tilled and no-till fields soil structure K_{str} was not found.

The more soil consists particles resistant to precipitations, the bigger is ratio of water stable soil aggregates W_r (%). In South-Viljandimaa and Pärnumaa the ratio of water stable soil aggregates W_r (%) was significantly bigger in tilled than in no-tilled soils. However, according to Bogužas et al. (2010) no-till increases the amount of water stable soil aggregates because tillage influences changes in the natural soil features and the organic matter decomposition is enhanced.

Weed seed bank in the soil

In average the abundance of weeds seeds was higher on the test fields with no-till, compared to tillage – accordingly 60,975 and 29,250 weed seeds m^{-2} in 25 cm soil layer ($p < 0.003$) which is in accordance to Carter and Ivany (2006), Chauhan et al. (2006), Auškalnienė & Auškalnis (2009). Our research also supported findings by Tørresen et al. (2003) who found that weed seed densities in the upper soil surface in no-till soils were higher than in ploughed soils. On the fields with tillage the soil in the tillage depth is moved over whole field area, thus the weed seeds were distributed more evenly in the tillage depth. Soil weed seed bank consisted largely of annual weed seeds. *Chenopodium album* was the most abundant weed species in both tillage systems. A lesser extent of the seeds of *Viola arvensis, Thlaspi arvense, Polygonum convolvulus* and *Galium aparine* were present. The highest number of weed species were found from the South-Viljandi no-till field (weed seeds from 15 different species) and smallest number from North-Viljandi no-till field (8 species). Also, Murphy et al. (2006) found that no-till promoted higher weed species diversity compared to the ploughed fields. Tørresen et al. (2003) observed an increase in annual grasses and perennial weeds species under no-till. Only in South-Viljandi no-till field we found that number of perennial weeds species were higher than in ploughed field.

***S*oil dehydrogenase activity (DHA)**

Results showed that no-till fields had higher soil DHA in the 0–10 cm layer compared to 10–20 cm layer (Table 4). In tillage occurred no significant difference between soil layers DHA. Similar results were found by Gajda et al. (2013) and Janušauskaite et al. (2013). This could be caused by the fact that in the no-tilled soils the content of organic carbon (C_{org}) (Table 1) in the upper layer was higher than in lower layer, but in tilled soils the C_{org} content in both layers was similar between each other or opposite to no-till. The positive relationship between soil C_{org} content and DHA was observed in North-Viljandimaa and Põlvamaa where the soil DHA was remarkably higher in the comparison pair soil with higher content of C_{org} (Table 1, Table 4).

Table 4. Impact of different tillage systems on soil DHA (μg TPF g^{-1} soil h^{-1}) in 2012–2014 (North-Viljandimaa, Põlvamaa, Tartumaa n = 6; Valgamaa and South-Viljandimaa n = 9)

	No-till		Tillage	
Location	0–10 cm	10–20 cm	0–10 cm	10–20 cm
North-Viljandimaa	7.9^{b}	4.8^{d}	9.8^{a}	8.5^{ab}
South-Viljandimaa	3.7^{ef}	1.7^{i}	2.8^{fgh}	2.2^{ghi}
Valgamaa	3.7^{ef}	2.3^{fghi}	$2,2^{ghi}$	1.8^{hi}
Põlvamaa	4.6^{de}	2.4^{ghi}	3.1^{fg}	2.9^{fgh}
Tartumaa	10.2^{a}	5.6^{cd}	6.0^{c}	6.0^{c}
Prob > F	< 0.0001			

Note. Different letters behind the mean values indicate significant differences ($p < 0.05$). Significances of model effects ($p > F$) are indicated. In the case of significant model effects, a Tukey-Kramer HSD test was performed in order to compare mean values.

Compared to tillage, the 0–10 cm layer DHA activity was higher in no-till in Valgamaa (Table 4). The main reason could be that the content of sand (75–84%, Table 1) in the tilled field was higher than in no-till (66–69%). The negative relationship between soil microorganisms and sand contents was also noticed by Najmadeen et al. (2010).

The soil microorganisms are directly affected by fertilization. The application of organic fertilizers, due to supply of organic compounds to the carbon-limited microbial communities generally results in increased microbial activity (Knapp et al., 2010).

Therefore, the liquid manure at the rate 30 t ha^{-1} used in Tartumaa no-till field in 2013 could be the main reason why soil DHA in 0–10 cm soil layer was higher than in tillage.

CONCLUSIONS

The trial period 2012–2014 is too short to make general conclusions about response of soil bulk density and gravimetric moisture content to contrasting tillage methods. However, soil bulk density differences between layers occurred in South-Viljandimaa and Pärnumaa tilled soils, in which plough pan in layer 20–30 cm was noticeable.

Smaller numbers of weed seeds in tilled soils shows that tillage encourages weed seeds to germinate which is resulting with termination of weed seeds and plants after treatments. No-till preserves weed seeds better in soil compared to tillage. Thus, any soil movement on no-tilled field may lead to much larger number of emerging weeds compared to tilled soils.

Soil dehydrogenase activity is higher in the upper 0–10 cm and lower in the 10–20 cm layer in no-till systems. In tillage, no significant difference occurred between dehydrogenase activity of soil layers.

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