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Response of soil physical properties and dehydrogenase activity to contrasting tillage systems

Edvin NUGIS, Liina EDESI, Kalvi TAMM, Jüri KADAJA, Elina AKK,
Peeter VIIL, Ene ILUMÄE

Estonian Crop Research Institute
J. Aamisepa 1, 48309, Jõgeva, Estonia
E-mail: edvin.nugis@etki.ee

Abstract

The aim of this study was to compare the influence of conventional tillage (CT) and no tillage (NT) on sandy loam and loamy sand soils in three sites of Estonia: 1) Viljandi county (*Gleic Albeluvisol*), 2) Valga county (*Fragi-Stagnic Albeluvisol*) and 3) Pärnu county (*Mollic Gleysol*). The dry bulk density, gravimetric water content and dehydrogenase activity of the soils were determined in the spring of 2013 and 2014. In addition, a soil density index based on soil dry bulk density differences was introduced. Soil samples were collected from 0–10 and 10–20 cm layers in spring.

The no tillage treatment had higher soil dry bulk density than the conventional tillage in *Gleic Albeluvisol* and *Mollic Gleysol*, where the no tillage fields had not been ploughed for 10 and 2 years, correspondingly. The index of soil density varied between 0.289–0.511, when compared the no tillage and conventional tillage treatments the lowest values were obtained in *Gleic Albeluvisol* and *Mollic Gleysol*. Gravimetric water content was significantly lower 2–5% ($p < 0.05$) in the conventional than in no tillage treatments. No tillage fields showed higher soil dehydrogenase activity in the upper 0–10 cm layer, conventional tillage treatments had no significant differences between the layers. Soil dehydrogenase activity had significant positive correlation ($p < 0.01$) with soil gravimetric water content and organic carbon, and negative correlation ($p < 0.05$) with soil dry bulk density and soil density index.

Key words: conventional tillage, dry bulk density, gravimetric water content, no tillage, soil density index, soil microbial activity.

Introduction

In order to facilitate plant growth, it is important to create favourable conditions in the soil for root development. The major factor influencing soil structure and thereby soil air-water content, as well as the movement and availability of plant nutrients, is soil tillage. The adoption of no tillage farming systems has globally an increasing trend (Derpsch et al., 2010) because they require less energy and machinery inputs (Triplett, Dick, 2008) and reduce wind and water erosion (Verhulst et al., 2010). In addition, no tillage has been found to improve soil quality by improving soil structure, water holding capacity and water infiltration due to lesser physical disruption of soil aggregates (Verhulst et al., 2010). In contrast to no tillage management, conventional tillage, with ploughing, may result in increasing soil erosion and loss of soil structure (Kassam et al., 2009). Also, the no tillage may have some disadvantages. In northern Europe, due to the higher soil water content, the soils under no tillage tend to warm slowly (Mikkola et al., 2005). Higher bulk density in no tillage than in conventional tillage was found on a sandy loam soil in Denmark by Munkholm et al. (2003) already in the first year after conversion. However, Vogeler et al. (2009) suggest that 6 years after conversion to no tillage, the differences equalize or bulk density of no tillage is even less than that after ploughing.

Also, different soil tillage practices influence the soil processes which are carried out by microorganisms through the changes of plant residue distribution and soil physical properties (Bogužas et al., 2010; Janušauskaitė et al., 2013). Soil enzymatic activity is a sensitive indicator of tillage management induced changes in soil microorganisms (Watts et al., 2010). Dehydrogenase is an enzyme that occurs in all viable microbial cells and therefore soil dehydrogenase activity is the most adequate and widely used bioindicator (Wolinska, Stepniewska, 2012).

The aim of this study was to evaluate the effect of conventional and no tillage practices on soil bulk density, gravimetric water content, soil density index and microbial activity in sandy loam and loamy sand soils in three Estonian regions.

Materials and methods

Experimental sites. The field experiment was carried out in 2012–2014 in the commercial fields in Estonia. The trial plots were located on three different farmers' fields. Site 1 was located in Abja-Paluoja, South part of Viljandi county (58°7′39″ N, 25°15′32″ E), site 2 – in Õru,Valga county (57°56′31″ N, 26°9′17″ E) and site 3 – in Halinga, Pärnu county (58°38′18″ N, 24°21′17″ E). The soils were classified according to the WRB (2014). The fields were selected on the principle that in all three sites the comparison pairs of conventional (CT) and no tillage (NT) fields locate closely (under similar weather conditions) and have similar soil characteristics (Table 1).

Table 1. Classification and characteristics of the experimental soils

Location	Soil classification (WRB)	Depth cm	Notillage					Conventional tillage				
			C_{org}	soil fraction %			Soil texture (FAO)	C_{org}	soil fraction %			Soil texture (FAO)
				sand >0.063	silt 0.002–0.063	clay <0.002			sand >0.063	silt 0.002–0.063	clay <0.002	
Site 1	*Gleic Albeluvisol*	0–10	1.6	59.5	31.5	9.0	sandy loam	1.5	66.4	27.1	6.5	sandy loam
		10–20	1.4	59.6	32.7	7.7	sandy loam	1.4	77.3	19.1	3.6	loamy sand
Site 2	*Fragi-Stagnic Albeluvisol*	0–10	1.4	69.3	22.5	8.3	sandy loam	1.5	83.5	12.5	4.0	loamy sand
		10–20	1.6	66.1	27.2	6.8	sandy loam	1.5	74.7	19.7	5.6	sandy loam
Site 3	*Mollic Gleysol*	0–10	4.0	66.6	23.4	10.0	sandy loam	3.1	68.5	22.5	9.0	sandy loam
		10–20	3.1	71.0	19.7	9.3	sandy loam	2.8	71.3	20.6	8.1	sandy loam

Notes. Organic carbon (C_{org}) content in soils was measured by NIRS method. For soil texture determination the sieving method was used.

Crops grown in the years of observation are presented in Table 2. Unfortunately, in *Fragi-Stagnic Albeluvisol* the farmers continued the crop rotation differently in 2014.

Table 2. Cultivated crops in no tillage (NT) and conventional tillage (CT) fields in 2013–2014

Soil	Treatment	2013	2014
Gleic Albeluvisol	NT	winter wheat	spring barley
	CT	winter wheat	spring barley
Fragi-Stagnic Albeluvisol	NT	oats	winter wheat
	CT	oats	spring rape
Mollic Gleysol	NT	spring barley	spring rape
	CT	spring barley	spring rape

Experimental design. Tillage systems in the CT fields were mouldboard ploughing with a depth of 20 cm. The NT fields in *Gleic Albeluvisol* and *Fragi-Stagnic Albeluvisol* had not been ploughed for ten years and in *Mollic Gleysol* for the last two years. From each observed field a represntive study area with size 1 ha was selected and the soil physical parameters were measured at three fixed points, in total six measurements per two years. Each measurement point was established by GPS equipment.

Soil dry bulk density (DBD) and gravimetric water content (GWC). In the spring of 2013 and 2014 the soil dry bulk density (Mg m^{-3}) and soil gravimetric water content (kg kg^{-1}) were measured in the depths of 3–8 and 13–18 cm to give evaluation for layers 0–10 and 10–20 cm. The DBD was determined by Eijekelkmp's cylinder (100 ± 0.14 cm^3 with 50.0 mm internal diameter and 50.8 mm height). The soil samples were oven-dried at 105°C for 24 h and re-weighed for determination of GWC.

Soil density index (SDI). Range of soil dry bulk density interval is different for different soils. The same DBD value may affect crop growth variously in different soils. Therefore, to compare density of different soils, introducing an index considering available limits of density range is rational. The same approuch has been also used by several authors (Mouazen, Ramon, 2009; Mueller et al., 2009). The main principle of assessment of such kind limited system is to calculate the relation between the difference of the most loosened and particular intermediate states, and the difference of the most loosened and compacted states. Resulting from this principle the SDI can be presented on the basis of void ratio values.

$$SDI = \frac{\varepsilon_o - \varepsilon_i}{\varepsilon_o - \varepsilon_{\min}} \quad (1),$$

where ε_o and ε_{min} are void ratios of soil in the most loosened and compacted states, respectively; ε_i is void ratio of particularly observed ploughed or no tillage soil.

In our research the determined parameter is dry bulk desity. Therefore, using the definition of void ratio:

$$\varepsilon = \frac{\delta - \gamma}{\gamma} \quad (2),$$

where δ is specific density (density of dry solid material) and γ is dry bulk density of soil, we substituted (2) to the eq. 1 and after transformation the SDI is calculable as:

$$SDI = \left(1 - \frac{\gamma_o}{\gamma_i}\right) \Bigg/ \left(1 - \frac{\gamma_o}{\gamma_{\max}}\right) \quad (3),$$

where γ_o is dry bulk density of soil in its most loosened state, γ_i – current value of observed soil dry bulk density in ploughed or no-tillage treatment, γ_{max} – limit of dry bulk density of soil in the state of maximum compaction, at which plants are not able to grow any more.

Soil dehydrogenase activity (DHA). Soil samples were taken in the spring of 2013 and 2014, before cultivation, from each treatment in six replications (three in each year) by a random method from the 0–10 and 10–20 cm soil layers with a 1 cm diameter auger. Each soil sample was composite of 20 subsamples. Samples were sieved (2 mm) and kept at 4°C until analysis. DHA was measured in 5 g soil samples 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.

Statistical analysis. All results were based on six soil sample replicates. The data were analyzed by *ANOVA*. The Tukey-Kramer honest significant sifference (HSD) test and correlation matrix were used via the software *JMP 5.0.1.2* (SAS, 2002).

Results and discussion

Soil physical properties. The soil DBD is usually the most important parameter to describe the soil physical status. The moderate DBD (1.3–1.5 Mg m^{-3}) enhances root growth and thus increases the crop yield (Tracy et al., 2012). At the same time for crop growth, the optimal and critical limits of DBD depend on soil texture, particle shape, and the content of organic matter, which affect soil structure and, thus mechanical resistance of the soil (Guimarães et al., 2002). In this study the average for all years, sites and depths were similar for the both tillage systems: NT – 1.48 and CT – 1.47 Mg m^{-3} (Table 3). As well, within one treatment significant differences between DBD in 0–10 and 10–20 cm soil layers did not occur. The highest DBD in both investigated soil layers was measured in *Fragi-Stagnic Albeluvisol* with the high sand and low silt and clay content (Table 1) being higher in the CT treatment: 0–10 cm –1.69 and 10–20 cm – 1.70 Mg m^{-3} (Table 3).

Dexter (2004) indicated that the critical bulk density in sandy loam was 1.7 Mg m^{-3} and therefore according to this value in the *Fragi-Stagnic Albeluvisol* in CT treatment the critical value of DBD was almost reached. The tendency of higher bulk density in NT than CT treatment was observed in *Gleic Albeluvisol* and *Mollic Gleysol*, where the NT treatment fields had not been ploughed for ten and two years, accordingly. Higher soil DBD in sandy loam in no till than ploughed soil was found by Munkholm et al. (2003) too, already within the first year after conversion to NT.

Table 3. Mean values of soil dry bulk density (DBD), gravimetric water content (GWC), soil density index (SDI) and soil dehydrogenase activity (DHA) in no tillage (NT) and conventional tillage (CT) fields during 2013–2014

Soil	Depth cm	DBD Mg m^{-3}		GWC kg kg^{-1}		SDI		DHA TPF µg^{-1} g^{-1} h^{-1}	
		NT	CT	NT	CT	NT	CT	NT	CT
Gleic Albeluvisol	0–10	1.45 bc	1.35 cd	0.249 bc	0.217 b	0.395 cd	0.312 d	4.21 c	2.79 d
	10–20	1.46 bc	1.36 cd	0.226 bcd	0.213 b	0.400 cd	0.332 d	1.81 e	2.27 de
Fragi-Stagnic Albeluvisol	0–10	1.60 ab	1.69 a	0.210 de	0.156 fg	0.467 bc	0.509 ab	3.89 cd	2.50 d
	10–20	1.59 ab	1.70 a	0.195 ef	0.149 g	0.462 bc	0.511 a	2.63 d	2.26 de
Mollic Gleysol	0–10	1.35 cd	1.29 d	0.280 a	0.259 b	0.329 d	0.289 d	12.05 a	11.19 ab
	10–20	1.44 bcd	1.40 cd	0.282 a	0.263 b	0.388 cd	0.359 d	9.68 b	10.61 ab
$p > F$		<0.001		<0.001		<0.001		<0.001	

Notes. Different letters after the mean values indicate significant differences ($p < 0.05$) in a category. 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. The red-tinted product triphenylformazan (TPF) was used as DHA indicator.

During 2013–2014 the average soil GWC for all treatments, depths and years was 0.249 kg kg^{-1} (Table 3). Considerably lower GWC, averaged over different sites, was measured in CT treatments compared to NT fields, where the average GWC was 2.0–5.0% higher in 0–20 cm soil layer. Higher soil moisture content in NT treatments was probably due to the fact that in spring the soil surface was covered with plant residue, which reduced access of solar radiation and hindered the soil evaporation. In turn, this effect may cause serious delay in the drilling of spring-sown crops (Soane et al., 2012). This is a common problem in northern Europe (Van den Putte et al., 2010). Drilling may be delayed there up to a week compared to drilling into ploughed soils, and therefore, may decrease the yield (Mikkola et al., 2005), although in semi-arid areas, as south-western Europe, the residues in soil surface have been found to conserve the soil and water as well as increase the yield (Van den Putte et al., 2010).

In addition, our results indicate, that GWC was the highest (0.280–0.282 kg kg^{-1}) in *Mollic Gleysol* in NT field (Table 3), where the organic carbon content was the highest (3.1–4.0%) (Table 1). The strong positive relationship between soil moisture and organic carbon has been also documented by Manns and Berg (2014).

The SDI varied between 0.289–0.511 (Table 3). The favourable level of SDI is below 0.33 (Materechera, 2009; Agbede, 2010; Mellek et al, 2010). In our investigations this condition was met in CT fields of *Gleic Albeluvisol* and *Mollic Gleysol* (Table 3). Similary to DBD, the highest SDI values were found in the fields of *Fragi-Stagnic Albeluvisol* being in both treatments higher than favourable, and indicating unfavorable soil physical condition for plant growth there (Table 3). Also, SDI was considerably higher in CT than NT treatment in this site. The contrast in DBD and SDI results between *Fragi-Stagnic Albeluvisol* and *Gleic Albeluvisol* and *Mollic Gleysol* is mostly associated with the different crops. In *Fragi-Stagnic Albeluvisol* in the second experimental year, the winter wheat was grown in NT treatment, but the spring rape in CT field (Table 2). Suppousedly, a reason here is different soil texture in different experimental sites, too: high soil sand content in *Fragi-Stagnic Albeluvisol*.

Soil dehydrogenase activity (DHA). The study results in NT systems showed the higher DHA in the upper 0–10 cm soil layer than in 10–20 cm layer (Table 3), similar results were found by Gajda et al. (2013). The higher microbial activity in upper layer of no till soils is associated with higher organic carbon in this layer. In CT treatments, no significant difference in DHA between soil layers was observed. Similar results were found by Janušauskaitė et al. (2013). Higher upper layer DHA in NT than CT fields in *Gleic Albeluvisol* and *Mollic Gleysol* was probably related to significantly higher soil GWC, and in addition for *Fragi-Stagnic Albeluvisol* to the lower sand content compared to CT treatment (Tables 1–3). The strong positive relationship between DHA and GWC is also demonstrated by the correlation ($P < 0.01$, $r = 0.71$) (Table 4) and has been obtained by other researchers as well (Zhang et al., 2015). The negative relationship between sand content and soil microorganisms was also observed by Najmadeen et al. (2010).

Table 4. Correlation coefficents (*r*) of soil dehydrogenase activity (DHA) with soils physical properties and organic carbon (C_{org}) in all investigated fields at a soil depth of 0–20 cm (n = 72)

	GWC g kg^{-1}	DBD Mg m^{-3}	SDI	C_{org}
DHA (TPF µg^{-1} g^{-1} h^{-1})	0.71**	−0.47*	−0.42*	0.94**

Note. The red-tinted product triphenylformazan (TPF) was used as DHA indicator; GWC – gravimetric water content, DBD – dry bulk density, SDI – soil density index; * – $P < 0.05$ and ** $P < 0.01$.

No significant difference in soil dehydrogenase activity was found between NT and CT treatments in *Mollic Gleysol*, which may be due to implementation of no till technology for a short period (Table 3). Although the sand content of soil was high in *Mollic Gleysol*, compared to other test areas, the organic carbon content of these soils was higher (Table 1). Most microorganisms are chemoorganotrophic, because they use organic carbon as a source of carbon and energy. Therefore, the higher organic carbon levels have been found to support greater enzyme activities in soils (Niemeyer et al., 2012; Gajda et al., 2013). Also, in this study the correlation between the content of organic carbon and soil DHA was strong ($P < 0.01$, $r = 0.94$) (Table 4). An increase in the DBD and SDI had a negative influence on soil DHA ($P < 0.05$, $r = -0.47$ and $r = -0.42$) (Table 4). Gispert et al. (2013) also found the most abundant soil microbial populations in the low bulk density treatments, presumably due to the favourable soil physical conditions.

Conclusions

1. The no tillage system raised soil water content, but at the same time increased the soil dry bulk density.
2. The soil density index suggests a better soil physical condition in conventionally tilled fields.
3. Study results in no tillage systems showed the higher soil dehydrogenase activity in the upper 0–10 cm soil layer than in the 10–20 cm layer. In conventional tillage treatments, no significant difference in soil dehydrogenase activity between both soil layers was observed.
4. The positive correlations of soil dehydrogenase activity with soil gravimetric water content and organic carbon, and negative correlation with soil dry bulk density and soil density index confirmed its strong dependence on the cultivation methods, which in turn influenced the soil physical parameters.

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Dirvožemio fizikinės savybės ir dehidrogenazės aktyvumas taikant įvairias žemės dirbimo sistemas

E. Nugis, L. Edesi, K. Tamm, J. Kadaja, E. Akk, P. Viil, E. Ilumäe

Estijos augalininkystės tyrimų institutas

Santrauka

Tyrimo tikslas – palyginti tradicinį ir neariminį žemės dirbimą smėlingo priemolio bei rišlaus smėlio dirvožemiuose trijose Estijos vietovėse: 1) Viljandėje (*Gleic Albeluvisol*), 2) Valgoje (*Fragi-Stagnic Albeluvisol*) ir 3) Pernu (*Mollic Gleysol*) apylinkėse. Dirvožemio tankis, gravimetrinė drėgmė ir dehidrogenazės aktyvumas buvo nustatyti 2013 ir 2014 m. pavasarį. Be to, buvo įvestas dirvožemio tankio indeksas, paremtas skirtumais tarp dirvožemio tankių. Ėminiai buvo paimti pavasarį iš dirvožemio 0–10 ir 10–20 cm sluoksnių.

Neariminio žemės dirbimo variante buvo nustatytas didesnis dirvožemio tankis, palyginus su tradiciniu dirbimu *Gleic Albeluvisol* ir *Mollic Gleysol*, kur neariminio varianto laukai nebuvo arti atitinkamai 10 ir 2 metus. Dirvožemio tankio indeksas įvairavo nuo 0,289 iki 0,511, palyginus neariminio ir tradicinio žemės dirbimo variantais, mažiausios vertės buvo nustatytos ariamų variantų *Gleic Albeluvisol* ir *Mollic Gleysol* tyrimų vietovėse. Gravimetrinės drėgmės kiekis buvo žymiai mažesnis (2–5 %, $p < 0.05$) žemę dirbant tradiciškai nei neariminio žemės dirbimo variantuose. Neariminio žemės dirbimo variantuose didesnis dehidrogenazės aktyvumas buvo nustatytas dirvožemio viršutiniame 0–10 cm sluoksnyje, o tradicinio žemės dirbimo variantuose esminių skirtumų tarp sluoksnių nebuvo nustatyta. Dirvožemio dehidrogenazės aktyvumas esmingai teigiamai ($p < 0,01$) koreliavo su dirvožemio gravitacinės drėgmės ir organinės anglies kiekiu ir neigiamai ($p < 0,05$) – su dirvožemio tankiu ir tankio indeksu.

Reikšminiai žodžiai: dirvožemio mikrobų aktyvumas, dirvožemio tankis, dirvožemio tankio indeksas, gravimetrinės drėgmės kiekis, neariminis žemės dirbimas, tradicinis žemės dirbimas.

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