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THE INFLUENCE OF SOIL MANAGEMENT ON SOIL PROPERTIES AND YIELD OF CROP ROTATION

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Summary

Climate changes require careful revision of traditional soil and plant management technologies. New tendency of land and soil management encourages to observe and to evaluate essential changes of soils and environment. The main goal of our study was to evaluate the changes in soil properties under different tillage and fertilisation management and to determine dominating factors which conditioned the changes of soil available phosphorus (P), potassium (K) and humus (as equivalent of soil organic carbon content in mineral soils).

With the aim of investigating the influence of different tillage (conventional – CT, reduced – RT and direct drilling – NT) in combination with three rates (none, moderate and enlarged) of mineral NPK fertiliser application on soil physical and chemical properties and crop grain yield, several field trials were set up on conditionally fertile and low fertility soils at the Lithuanian Institute of Agriculture (LIA) in 2000–2006. Four field satellite experiments were set up at the LIA in 2002. The goal of these field trials was to investigate the influence of CT, RT and NT and crop residues on soil physical properties and crop yield.

The experimental data revealed that conventional tillage produced the best soil physical properties (the least bulk density and the highest air permeability) either without or with post harvest crop residues. Worse soil physical properties were registered after direct drilling. Post harvest residues of preceding crop had a tendency to positively affect soil physical properties and especially air permeability. Air permeability was greater at the 5–20 cm soil depth on average by 47.3 %, as compared to when the post harvest residues had been removed from the field. NT caused greater soil moisture (SM) content after crop sowing in the upper 0–5 and 5–10 cm layers, while this index in deeper layers was essentially lower compared to CT and RT. Because of improving of SM regime in the upper 10 cm layer in NT, SM functional ability deteriorated in the 10-20 cm layer. The same tendency persisted during the whole growing season of all crops investigated. Plant residues in all soil layers determined significantly higher moisture content compared with the plots where residues had been removed. NT management resulted in the highest stratification of P and K in the soil. Subsoil texture had a determinant influence on the yield of metabolizable energy (ME) in the crop rotation. Prevailing sand particles in the 20–40 cm soil layer worsened water and nutrient content available to plants in top soil and caused lower yields of crops. The yield of ME of the crop rotation in the low fertility soil was on average by 27 % lower compared to ME yield in conditionally fertile soil. The effect of mineral fertilisers was very marked in all tillage systems. Moderate rates of fertilisers increased the yield of ME in conditionally fertile and low fertility soil by 31 and 29 %, respectively under CT, by 27 and 40 % under RT, and by 28 and 60 % under NT compared to unfertilised plots. Enlarged rates of fertilisers increased the yield of ME in the conditionally fertile and low fertility soil by 37 and 37 %, respectively under CT, by 29 and 49 % under RT, and by 39 and 77 % under NT compared to unfertilised plots.

Key words: soil management, physical properties, P, K, humus, yield, climate changes.

Introduction

Soil is a dynamic resource that supports plants. It has biological, chemical, and physical properties, some of which change in response to how the soil is managed. Protection of soil fertility is a necessary prerequisite for the economic and environmental integrity. Human activities break the balance between different properties in natural ecosystems, which may lead to soil physical and chemical degradation. A wide range of different factors indicate a soil that functions effectively today and will continue to do that in the future. Creating soils with favourable characteristics can be accomplished by utilizing management practices that optimize the processes found in native soils.

The growing season for agricultural plants in Lithuania (when the average air temperature in twenty four hours is not less than + 6 °C) lasts for about 180 days. An average annual rainfall in Lithuania is 624 mm. Only one crop per year of principal plants is harvested.

The main limiting factors for successful agricultural development in the country are fragic soils, soil acidification, erodibility, and excessive moisture conditions. Unfavourable conditions have an impact on agricultural plants' productivity, soil fertility and soil sustainability.

Humus content in most soils of Lithuania is low (0.6–2.0 %), about 1/3 of soils have moderate amount (2.1–2.4 %) and only 1/10 of soils have a high amount (4.1–6.0 %) of humus. Part of Lithuanian soils (20.3 %) contain a very low amount (up to 50 mg kg^{-1}) of available P_2O_5 in the humic horizon. 41.5 % of soils contain a small amount (51–100 mg kg^{-1}) and medium amount (101–150 mg kg^{-1}) is found in 23.3 % of soils, and only in few locations the soils (15.9 %) have sufficient amount (> 150 mg kg^{-1}) of P_2O_5. In Lithuania's the content of available K_2O is higher than that of available P_2O_5. Soils with very low amount of K_2O make up 7.6 %, with low amount 35.4 %, with medium amount 33.4 % and over 150 mg kg^{-1} (sufficient amount) account for 23.6 % of soils /Mažvila, Vaišvila, 1998/.

Climate changes require careful revision of traditional soil and plant management technologies. Forecast of the global climate change emphasises that the air temperature in Lithuania will increase. The amount of precipitation will increase marginally; the worst effect will be during the cold period of the year, while rainfall will continue to decrease in summer. An increase of aridity will be the highest in the June – September period. Consequently, soil and fertiliser nutrient assimilation level, tillage and sowing time and intensity may vary. Due to this a new approach and propagation of sustainable soil management technologies implementation in practical farming is vital.

Soil management trends in agriculture depend on many factors: national traditions, climate conditions, natural soil properties, and level of land sensitivity, machinery, and financial position.

The prevailing tillage system in Lithuania is mouldboard ploughing. Nonetheless, practical implementation of sustainable or conservation tillage systems is continually increasing. It comprises deep and shallow chisel ploughing, deep and shallow stubble cultivation with a tine cultivator and also direct seeding into stubble. Most favourable seed-bed depth has been structured in conventional tillage compared to reduced tillage or no tillage systems. Stubble cultivation in combination with pre-sowing rotary cultivation was in favour for the development of a “cultivation pan” at the 5-10 cm soil depth. It was observed that application of sustainable or conservation tillage systems is advisable on erosion-sensitive, undulating landscape and in karst region of Lithuania. Direct drilling has become increasingly popular in the more fertile soils of central Lithuania as well. NT is applied approximately only in 5 thousand ha area /Feiza et al., 2004/. However, our farmers underestimate the advantages and disadvantages of modern technologies under Lithuanian conditions.

Crop residues had been removed from the fields for many decades in Lithuania. Nowadays farmers chop up and broadcast straw and other residues on the soil surface. Consequently, the focus on the advantages and disadvantages of modern technologies is more important at this time.

The new trend of land and soil management encourages to observe and to evaluate essential changes of soils and environment. Global changes of climate and increase of anthropogenic influence on the environment showed, that advanced technologies of the 20 th century may mismatch the requirements of the 21st century.

The main goal of this study was to evaluate the changes in soil properties under different tillage and fertilisation and to determine the dominating factors which conditioned changes of soil available phosphorus (P), potassium (K) and humus (as equivalent of soil organic carbon content in mineral soils).

Materials and methods

The study site was located at the Lithuanian Institute of Agriculture (LIA) on a cultivated field of Central Lithuania ($55^0$23'50" N and $23^0$51'40" E). Two field trials were set up in 2000 and 2001. The soil was *Endocalcari - Epihypogleyic Cambisol,* with a texture of sandy clay loam. Soil texture was classified according to the USDA system of particle size distribution /Sheldric, Wang, 1993/. Four field satellite experiments were set up at the LIA in 2002. The goal of these field trials was to investigate the influence of CT, RT and NT and crop residues on soil physical properties and crop yield. The two-factor experiments consisted of three tillage treatments (CT, RT, and NT), arranged on two backgrounds of plant residues (1. Post harvest residues (straw) of preceding crop removed from the field; 2. Straw of preceding crop chopped and spread in the field). Tables 1–2 present general soil characteristics at the site.

Field experiments consisted of four replicates of a randomized split-plot design. Each replicate included 3 tillage treatments (Factor A) as main plots (CT – conventional tillage: deep ploughing (23–25 cm) + spring tine cultivation (4–5 cm); RT – reduced tillage: shallow ploughing (14–16 cm) + spring tine cultivation (4–5 cm); NT – no tillage + direct drilling), which were split into 3 subplots (Factor B) with different mineral fertiliser application rates (1 – not fertilised; 2 – moderate rates: NPK fertilisers according to soil properties and expected yield; 3 – enlarged rates: NPK fertilisers according to soil properties and for 30 % greater expected yield than in treatment 2). During crop rotation different rates of fertilisers were incorporated (Table 3).

Table 1. Soil characteristics at trial establishment (n=36)
1 lentelė. *Dirvožemio charakteristika įrengiant bandymus (n=36)*

Dotnuva, 2000

Trial No. *Bandymo Nr.*	Plough layer *Armuo* cm	Bulk density *Tankis* Mg m^{-3}	Clay content *Molio dalelių* %	Available P *Judrusis P* mg kg^{-1}	Available K *Judrusis K* mg kg^{-1}	Total N *Suminis N* %	Humus *Humusas* %	pH_{KCl}
I – soil of high fertility *Labai našus dirvožemis*	34	1.30	29	140	217	0.123	2.10	6.8
II – soil of moderate fertility / *Vidutiniškai našus dirvožemis*	30	1.40	18	47	131	0.108	1.60	6.2

Table 2. Soil texture characteristics at trial establishment
2 lentelė. *Dirvožemio granuliometrinė sudėtis įrengiant bandymus*

Dotnuva, 2000

Soil depth *Gylis* cm	Particle % / *Dalelių %*					
	I st trial / *I bandymas*			II nd trial / *II bandymas*		
	Sand / *Smėlis* (2.0–0.05 mm)	Silt / *Dumblas* (0.05–0.002 mm)	Clay / *Molis* (<0.002 mm)	Sand / *Smėlis* (2.0–0.05 mm)	Silt / *Dumblas* (0.05–0.002 mm)	Clay / *Molis* (<0.002 mm)
0–20	51.76	28.96	19.28	53.71	32.58	13.71
20–40	47.53	40.87	11.60	53.66	33.91	12.43

Before sowing, P (granular superphosphate, 20 % of P_2O_5) and K (potassium chloride, 60 % of K_2O) fertilisers were broadcast according to experimental design. Nitrogen was given as ammonium nitrate (35 % N). For winter wheat it was broadcast on the soil surface in spring just after the resumption of crop growth, and for spring crops it was broadcast on the soil surface before crop emergence.

Soil bulk density (BD) was determined according to Kachinsky method. Cone penetration resistance (PR) was determined under *in situ* conditions 1 week after sowing and periodically every 10 days till middle of June. Measurements were taken in increments of 5.0 cm, from the soil surface down to 20 cm depth, with a penetration velocity of about 1 m min^{-1}. PR was determined at one position, i.e. in the untrafficked interrow. Soil air permeability (AP) was determined according to Anderson method. Available P and K in the soil were determined by ammonium lactate (A-L) extraction /Egner et al., 1960/, humus by Tyurin. Analysis of variance was performed in a conventional way commonly used in crop science /Clewer, Scarisbrinck, 2001/. Means separation was done by using the least significant difference (LSD) at 0.05 probability level. Calculation of path analysis was performed also /Sokal, Rohlf, 2000/.

Table 3. Rates of mineral NPK fertilisers kg ha^{-1}
3 lentelė. *Mineralinių NPK trąšų normos kg ha^{-1}*
Dotnuva, 2000–2006

Rate *Norma*	Nutrients *Maisto medžiagos*	Crop rotation / *Sėjomainos rotacija*: Winter wheat *Žieminiai kviečiai* (*Triticum aestivum* L.)	Sugar beet *Cukriniai runkeliai (Beta vulgaris,* L.)	Spring wheat *Vasariniai kviečiai* (*Triticum aestivum* L.)	Spring barley *Vasariniai miežiai* (*Hordeum vulgare* L.)	Peas *Žirniai (Pisum sativum* L.)	Winter wheat *Žieminiai kviečiai* (*Triticum aestivum* L.)	Total amount of nutrients per rotation *Iš viso maisto medžiagų per rotaciją*
I[st] trial – soil of high fertility / *I bandymas – labai našus dirvožemis*								
Moderate *Vidutinė*	N	109	114	32	30	0	160	445
	P_2O_5	0	0	0	0	0	20	20
	K_2O	0	101	9	30	29	50	219
Enlarged *Padidinta*	N	190	205	114	120	30	205	864
	P_2O_5	0	0	0	0	0	30	36
	K_2O	0	136	24	44	56	74	36
II[nd] trial – soil of moderate fertility / *II bandymas – vidutiniškai našus dirvožemis*								
Moderate *Vidutinė*	N	104	150	90	91	0	187	622
	P_2O_5	93	30	36	7	69	149	384
	K_2O	47	137	54	25	52	96	411
Enlarged *Padidinta*	N	192	227	160	159	30	283	1051
	P_2O_5	183	75	40	14	221	268	801
	K_2O	65	166	60	41	90	170	592

Results and discussion

Soil physical properties. Individual years of the investigation had no significant influence on the general trends of soil physical properties. As a rule, RT and NT expressed less favourable soil physical properties year after year of investigation. Due to this the average data (2000–2006) will be presented in this paper. The reasons to reduce soil tillage intensity are very similar all over the world, i. e. to increase work capacity and output and maintain beneficial soil physical properties /Feiza et al., 2004/.

An important goal of tillage is conservation of *soil moisture (SM)*. SM is a relevant factor for favourable soil functioning, especially in the context of climate changes. It was found, that NT caused a higher SM content after crop sowing in the upper 0–5 and 5–10 cm layers, while this index in deeper layers was essentially lower compared to CT and RT (Fig. 1). This means that such distribution of SM in the plough layer could affect stratification of available P, K and humus. Because of improving of SM regime in the upper 10 cm layer in NT, SM functional ability deteriorated in the 10-20 cm layer. The same trend persisted throughout the growing season of all investigated crops. However, SM content of the upper soil layer at post harvesting period was higher than that at the crop sowing time because of rainy weather conditions at the end of summer season in Lithuania.

Plant residues in all soil layers determined significantly higher moisture content compared with the plots where residues had been removed.

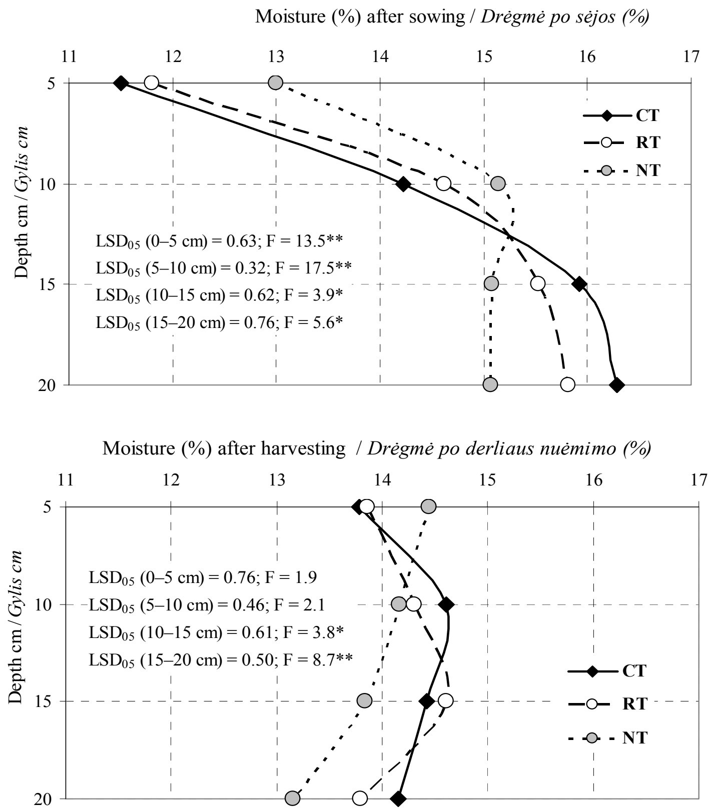


Figure 1. Soil moisture content in every 5 cm depth in the plough layer under different tillage CT – conventional tillage, RT – reduced tillage, NT – no tillage; LSD – least significant difference, F – variance ratio, * and ** – probability levels at., 0.05 and 0.01 respectively
1 paveikslas. *Armens dirvožemio drėgmė kiekviename 5 cm armens sluoksnyje skirtingose žemės dirbimo sistemose CT – tradicinis dirbimas, RT – supaprastintas dirbimas, NT – nedirbta, tiesioginė sėja; LSD – mažiausias esminis skirtumas, F – Fišerio kriterijus, * ir ** – tikimybės lygmuo atitinkamai 0,05 ir 0,01*
Dotnuva, 2000–2006

In summary, the results of six years of the investigation revealed, that the NT was more favourable for increasing and keeping up of SM in the top-soil layer unexceptionally. It was especially important during seed germination and early growth stages of crops. Therefore, our data agree with the scientific results of other researchers, who propose that no-tillage determines wetter soil conditions /Rasmussen, 1999; Riley et al., 2005; Licht, Al-Kaisi, 2005; Velykis, Satkus, 2005; De Vita et al., 2007/.

Our data are also in line with numerous experiments showing that *bulk density (BD) and penetration resistance (PR)* are greater in NT in the first 5–10 cm of soil, compared to CT /Lampurlanes, Cantero-Martinez, 2003; Taser, Metinoglu, 2005;

Schjønning, Rasmussen, 2000/, but they are contrary to the results, which suggest that no differences in BD were between tillage systems /Logsdon, Cambardella, 2000/ or BD even decreased under NT /Edwards, 1996/. Some authors indicate that BD is one of the most important indices of soil physical properties /Campbell, O'Sullivan, 1991/. Unfortunately, over time, bulk density, similarly to penetration resistance, tends to return to its original state in spite of a tillage method used /Ferreras et al., 2000/. Surface straw application in reduced tillage systems has not only positive, but also and some negative consequences. Some problems arise during seed sowing and even at later stage of crop development /Borresen, 1986/.

CT influenced lowest BD and PR in all experimental years. The data from 2000-2006 suggest that shortly after different crops sowing in both I[st] and in II[nd] trial the BD was 1.32±0.02 Mg m^{-3} under CT in 0–20 cm soil layer (Fig. 2).

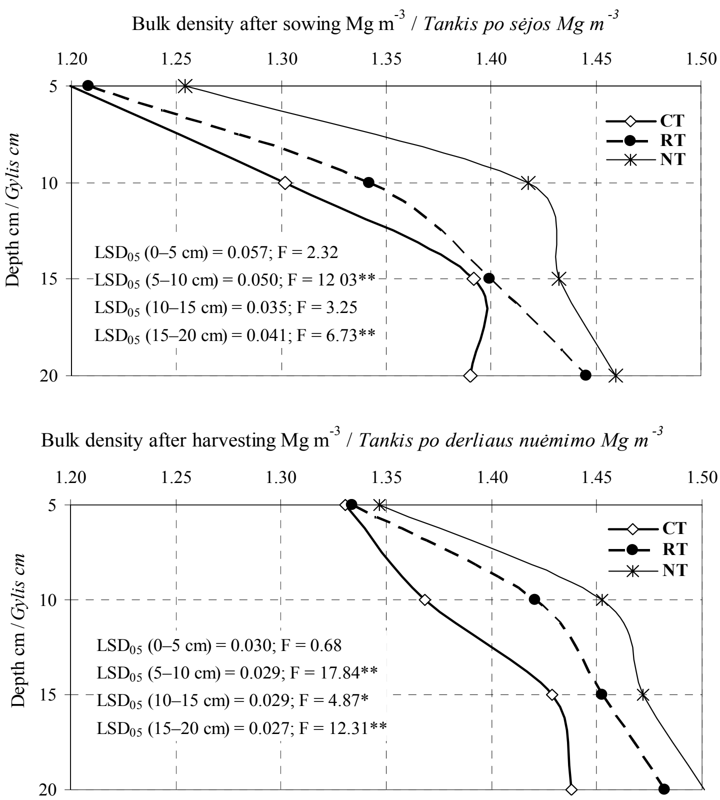


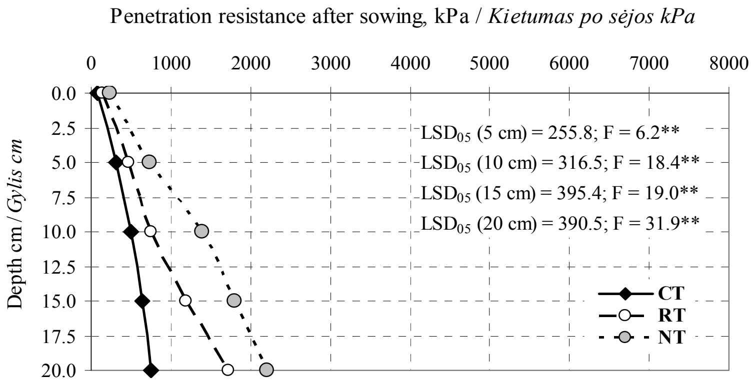
Figure 2. Soil bulk density in every 5 cm depth in the plough layer under different tillage CT – conventional tillage, RT – reduced tillage, NT – no tillage; LSD – least significant difference, F – variance ratio, * and ** – probability levels at 0.05 and 0.01 respectively

2 paveikslas. *Armens dirvožemio tankis kiekviename 5 cm armens sluoksnyje skirtingose žemės dirbimo sistemose CT – tradicinis dirbimas, RT – supaprastintas dirbimas, NT – nedirbta, tiesioginė sėja; LSD – mažiausias esminis skirtumas, F – Fišerio kriterijus, * ir ** – tikimybės lygmuo atitinkamai 0,05 ir 0,01*

Dotnuva, 2000–2006

RT conditioned significant increase in BD compared to CT. This index in NT plots was essentially higher, than in CT and RT plots. This consistent pattern was most evident in the 5–10, 10–15 and 15–20 cm soil layers. Admittedly, during crop rotation the soil BD returned to the initial values registered before sowing. Nevertheless, the same regularity of tillage effects continued during the whole growing period of all crops investigated. Post harvest residues of the preceding crop that have been chopped and left in the field had only a tendency to reduce bulk density.

PR can also be an indicator that may be used to evaluate tillage effects on soil sustainability. Tillage treatments showed significant differences in soil PR at all investigated soil depth during 7 weeks' period (Fig. 3).



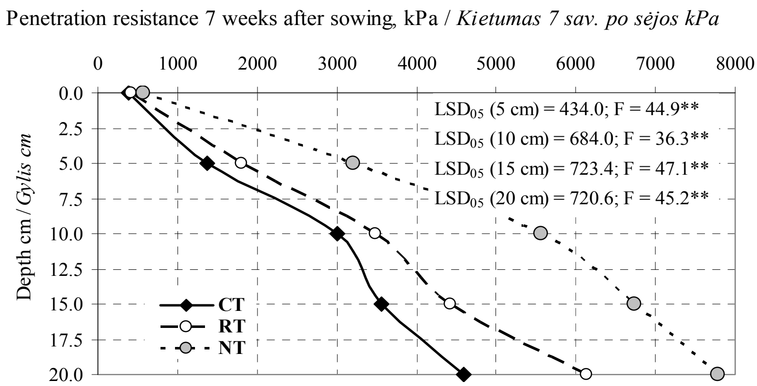


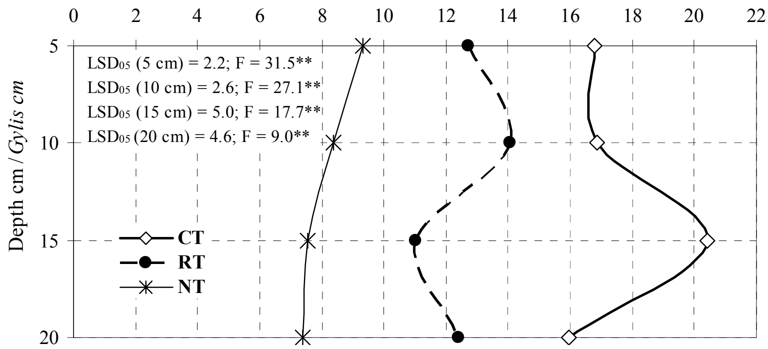
Figure 3. Soil penetration resistance in the plough layer under different tillage systems CT – conventional tillage, RT – reduced tillage, NT – no tillage; LSD – least significant difference, F – variance ratio, * and ** – probability levels at 0.05 and 0.01 respectively

3 paveikslas. *Armens dirvožemio kietumas skirtingose žemės dirbimo sistemose CT – tradicinis dirbimas, RT – supaprastintas dirbimas, NT – nedirbta, tiesioginė sėja; LSD – mažiausias esminis skirtumas, F – Fišerio kriterijus, * ir ** – tikimybės lygmuo atitinkamai 0,05 ir 0,01*

Dotnuva, 2000–2006

The variation of PR during different years of investigation was not significant. Soil PR value of 2000 kPa is defined as the upper limit for unrestricted root penetration /Taylor et al., 1996; Veiga et al., 2007/. The greatest PR after sowing was founded under NT. In both trials in the 20 cm layer PR amounted on average to 1280±200 kPa. CT and RT determined lover PR by 2.8 and 1.5 times, respectively compared to NT. Moreover, the greatest differences in PR among tillage systems were registered in the 5–20 cm soil layer. The deeper the soil layers the higher the differences among PR in unequal tillage plots were revealed. It was observed that PR increased noticeably during the May-June period, while differences among tillage treatments still persisted. Crop residues significantly decreased penetration resistance in the 5–10 cm soil layer only.

Air permeability after sowing l min^{-1} / *Oro laidumas po sėjos l min^{-1}*



Air permeability after harvesting l min^{-1} / *Oro laidumas po derliaus nuėmimo l min^{-1}*

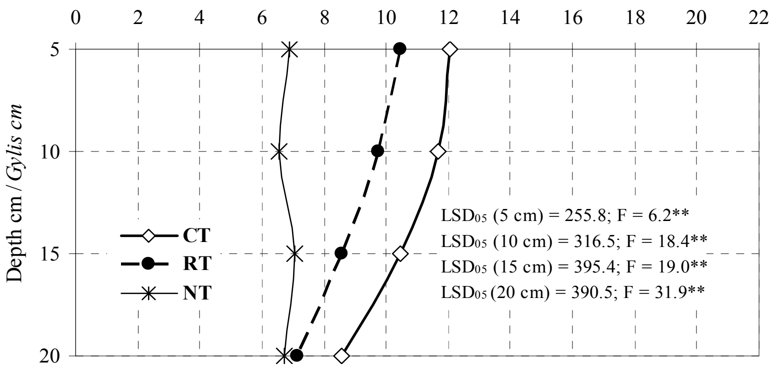


Figure 4. Soil air permeability in every 5 cm depth in the plough layer under different tillage. CT – conventional tillage, RT – reduced tillage, NT – no tillage; LSD – least significant difference, F – variance ratio, * and ** – probability levels at 0.05 and 0.01 respectively
4 paveikslas. *Armens dirvožemio oro laidumas kiekviename 5 cm armens sluoksnyje skirtingose žemės dirbimo sistemose CT – tradicinis dirbimas, RT – supaprastintas dirbimas, NT – nedirbta, tiesioginė sėja; LSD – mažiausias esminis skirtumas, F – Fišerio kriterijus, * ir ** – tikimybės lygmuo atitinkamai 0,05 ir 0,01*
Dotnuva, 2000–2006

Reduction of soil mixing causes not only an increase in soil BD and PR, but also reduces soil *air permeability (AP)* /Rasmussen, 1999; Schjønning, Rasmussen, 2000/. The best AP was registered after CT application (Fig. 4). Under NT the AP was by 50–68 % lower compared to AP under CT system. AP values (like other physical properties of soil) as influenced by the application of RT were considered to be intermediate between CT and NT.

Post harvest residues of preceding crop positively affected air permeability. Air permeability was greater at the 5–10 cm, 10–15 cm and 15–20 cm soil depths by 47.8 %, 34.4 % and 59.7 %, respectively as compared to that when post harvest crop residues had been removed from the field.

Therefore, long-term application of RT or NT systems conditioned deterioration of soil physical properties. In turn, due to less favourable soil physical environment, crop roots had found worse conditions for growing and yields decreased also.

Soil phosphorus and potassium. Tillage and fertilisation created different soil conditions which in turn, influenced soil P, K, humus content and its changes. For a long time in Lithuania an attitude concerning safe fertilisation requirement has been widely spread. It was commonly recognized that the application of mineral PK fertilisers is necessary only if soil fertility is below 150 mg kg^{-1} P_2O_5 and K_2O. Nowadays fertilisation trend suggests using fertiliser rates according to the expected yield, paying attention to nutrient uptake by plants and soil properties. Manure is an important source for soil amendment, while amount of manure received per one ha of conventional farms in Lithuania is only 6.09 t ha^{-1}. Mineral fertilisers are prevailing in intensive cropping systems in Lithuania. Different fertilisation level requires different attitudes to the consequence of different tillage systems.

More evident changes in NT management related to a different distribution of P and K in the top soil. It usually leads to P and K stratification in the soils. Both nutrients accumulate in the soil surface as a result of minimal mixing – applied fertilizers and crop residues within top soil, limited vertical movement of P and K in most soils, and cycling of nutrients from deep soil layers to shallow layers through nutrient uptake by roots. Furthermore, P sorption and K retention by soil constituents in surface layers of no-till soils often are reduced compared with conventionally tilled soils /Holanda et al., 1998; Howard et al., 1999; Yin, Vyn, 2004; Feizienė et al., 2006/. Our data confirm that NT caused soil P and K stratification, while, the management of unequal soils revealed different results.

Soil available P content at the Ist trial establishment in the 0-20 cm layer varied from 122 to 142 mg kg^{-1}. During a 6-year course crop rotation this index decreased on average by 23 % in CT, 16 % in RT and 19 % in NT systems. At the IInd trial establishment P content varied from 53 to 77 mg kg^{-1}. The changes of this index in the 0-20 cm layer were opposite to the results of the Ist trial. During rotation P content increased on average by 24 % in CT, 34 % in RT and 26 % in NT systems. Experimental results showed different changes of ratio *"P content at 0–10 cm layer / P content at 10–20 cm layer"* (Table 4). This ratio did not essentially move on during the 6 years period in the Ist trial in CT and RT systems; however in NT system it increased by 9 %. In the IInd trial the above-mentioned ratio increased in all tillage systems, but reduction of tillage depth caused a demonstrably greater rise of this ratio. In CT the increase amounted to 7, in RT 15, and in NT 53 %.

***Table* 4**. Soil P, K and humus stratification under different tillage with unequal fertilisation
4 lentelė. *Dirvožemio P, K ir humuso stratifikacija skirtingose žemės dirbimo-tręšimo sistemose*

Dotnuva, 2000–2006

Trial No. *Bandymo Nr.*	Year *Metai*	CT-1	CT-2	CT-3	RT-1	RT-2	RT-3	NT-1	NT-2	NT-3
Ratio "*P content at 0–10 cm layer / P content at 10–20 cm layer*" *Santykis „P kiekis 0–10 cm sluoksnyje / P kiekis 10–20 cm sluoksnyje"*										
I trial – soil of high fertility *I bandymas – labai našus dirvožemis*	2000	1.02	1.01	0.97	0.96	0.97	0.93	1.07	0.94	1.02
	2005	1.04	0.92	1.03	1.03	0.89	1.00	1.07	1.17	1.05
	Ratio change (%) *Santykio pokytis (%)*	2	-8	7	8	-9	7	0	24	3
II trial – soil of moderate fertility *II bandymas – vidutiniškai našus dirvožemis*	2001	0.90	1.24	1.47	0.95	1.04	1.34	0.85	1.19	1.34
	2006	1.10	1.45	1.21	1.08	1.43	1.22	1.28	1.64	2.29
	Ratio change (%) *Santykio pokytis (%)*	22	17	-18	14	38	-9	51	38	71
Ratio "*K content at 0–10 cm layer / K content at 10–20 cm layer*" *Santykis „K kiekis 0–10 cm sluoksnyje / K kiekis 10–20 cm sluoksnyje"*										
I trial – soil of high fertility *I bandymas – labai našus dirvožemis*	2001	0.94	0.98	1.14	0.95	0.82	0.87	0.89	0.91	1.01
	2005	1.06	0.96	1.14	1.06	1.14	1.16	1.29	1.55	1.57
	Ratio change (%) *Santykio pokytis (%)*	12	-2	0	11	40	32	45	71	56
II trial – soil of moderate fertility *II bandymas – vidutiniškai našus dirvožemis*	2002	1.09	1.10	1.22	1.00	1.07	1.14	1.04	1.24	1.13
	2006	1.20	1.20	1.18	1.15	1.20	1.28	1.54	1.69	1.58
	Ratio change (%) *Santykio pokytis (%)*	11	9	-3	16	12	12	48	37	40
Ratio "*Humus content at 0–10 cm layer / Humus content at 10–20 cm layer*" *Santykis „Humuso kiekis 0–10 cm sluoksnyje / Humuso kiekis 10–20 cm sluoksnyje"*										
I trial – soil of high fertility *I bandymas – labai našus dirvožemis*	2000	1.10	0.99	1.05	1.03	1.03	1.02	1.02	1.03	1.04
	2005	0.98	0.99	1.01	1.01	0.97	0.98	1.08	1.13	1.12
	Ratio change (%) *Santykio pokytis (%)*	-11	-1	-3	-2	-6	-4	6	10	7
II trial – soil of moderate fertility *II bandymas – vidutiniškai našus dirvožemis*	2001	0.99	1.00	0.97	0.94	1.00	1.05	0.94	0.98	0.99
	2006	0.99	0.96	0.95	0.99	0.99	1.02	1.09	1.13	1.15
	Ratio change (%) *Santykio pokytis (%)*	0	-4	-2	6	-2	-3	16	15	16

Note / *Pastaba*. CT – conventional tillage / *tradicinis dirbimas*, RT – reduced tillage / *supaprastintas dirbimas*, NT – no tillage / *nedirbta, tiesioginė sėja*; 1 – no fertilised / *netręšta*, 2 – moderate rates of fertilisers / *vidutinės trąšų normos*, 3 – enlarged rates of fertilisers / *padidintos trąšų normos*

Soil available K content at the Ist trial establishment in the 0–20 cm layer varied from 189 to 225 mg kg^{-1}. During the crop rotation this index decreased on average by 25 % in CT, 26 % in RT and 18 % in NT systems. At the IInd trial establishment K content varied from 109 to 121 mg kg^{-1}. The changes of this index in 0–20 cm layer were significant: in CT it increased on average by 19 %, in RT by 20 %, and in NT by 30 %. The ratio *"K content at 0–10 cm layer / K content at 10–20 cm layer"* in the Ist trial did not essentially change in CT, while it increased in RT and NT by 28 and 57 % respectively. In the IInd trial the increase of this ratio in CT was not essential, but the use of RT and NT caused the increase of this ratio by 13 and 42 % respectively.

Soil humus. The variation of total *soil humus* content within 0–20 cm layer during the crop rotation was not essential. Nevertheless, renouncement of deep soil mixing and use of NT tended to increase the ratio *"Humus content at 0–10 cm layer / Humus content at 10–20 cm layer"* in both Ist and IInd trials on average by 12 %. So, our findings agree with those obtained by other researchers concerning organic matter accumulation near the soil surface after ploughless tillage /Rasmussen, 1999; Tebrügge, Düring, 1999; Šlepetienė, Šlepetys, 2005/.

Interaction of soil physical and agrochemical properties. Primary tillage depth had dominating effect on stratification of P, K and humus, while this was indirect effect. It necessitated soil physical properties (BD, PR, AP and moisture content) pre-eminently. Very high paired correlation between tillage and BD, PR or AP (respectively r = -0.90**; -0.94**; 0.98**) tells about the considerable influence of deep tillage on soil physical indices. PR exerted direct effect on stratification of P, K and humus, however, BD and AP acted indirectly through reciprocity with other soil properties. After-effects of soil moisture, BD, and AP were revealed through PR and tillage depth. So, the deeper the tillage the higher PR had influence on stratification of P, K and humus. The higher PR the lower AP was determined. The higher PR the higher BD was noticed.

The effect of mineral fertilisers on stratification of P, K and humus was direct and dominating, while, usual regression analysis could not reveal statistically clear relationship between indices. *Path analysis* made clearer causality of this effect only. It showed that PR reduced action of fertilisers – consequently, summarised degree of influence of all factors (correlation coefficient) investigated on soil P and K stratification was very low (r = -0.16; r = -0.03, respectively). The effect of mineral fertilisers on the stratification of soil humus was weak (r = 0.35). Of course, it is not to be expected during 6 years' crop rotation.

Initial status of soil P, K and humus had indirect and not dominating influence on P, K and humus stratification. However, rising PR and declining AP reduced this influence. Correlation coefficient (total sum of effects) showed that the strength of influence of soil P and K initial status was weak (r = 0.40 and r = -0.28, respectively). After-effect of soil humus on humus stratification was revealed through tillage depth, soil PR, moisture and AP. Reciprocity of different factors was very strong. Because of after-effect of soil humus initial content on humus stratification was very high, the degree of influence of all factors (correlation coefficient) investigated on above-mentioned index was very strong as well (r = 0.82**).

Crop yields. All soil management systems are targeted at growing high yields and producing healthy food and forage. However, every system has its advantages and disadvantages. Some researchers indicate that NT increased yield of spring cereals mainly if the early summer had been dry /Aura, 1999; Baker, Saxton, 2006/, others report that because of the deterioration of soil physical properties and increasing weediness and plant diseases under NT, crops produce lower yields compared to CT /Feiza, Cesevičius, 2006; Baigys et al., 2006/.

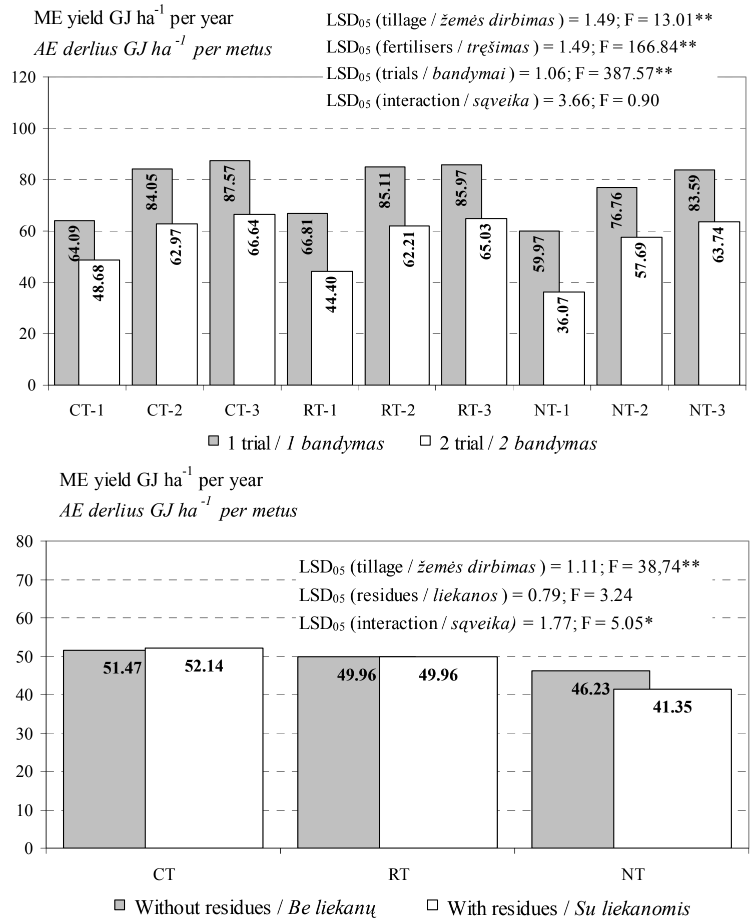


Figure 5. Average annual yield of metabolizable energy in the crop rotation under different soil management systems CT – conventional tillage, RT – reduced tillage, NT – no tillage; 1 – no fertilised, 2 – moderate rate of fertilisers, 3 – enlarged rates of fertilisers; LSD – least significant difference, F – variance ratio, * and ** – probability levels at 0.05 and 0.01 respectively

5 paveikslas. *Vidutinis metinis apykaitinės energijos derlius skirtingose žemės dirbimo-tręšimo sistemose CT – tradicinis dirbimas, RT – supaprastintas dirbimas, NT – nedirbta, tiesioginė sėja; 1 – netręšta, 2 – vidutinė trąšų norma, 3 – padidinta trąšų norma; LSD – mažiausias esminis skirtumas, F – Fišerio kriterijus, * ir ** – tikimybės lygmuo atitinkamai 0,05 ir 0,01*

Despite similar effect of tillage on soil physical properties and fertilisation according to soil properties and expected yield, the productivity of crop rotation markedly differed in the Ist and in the IInd trial (Fig. 5).

The yield of metabolizable energy (ME) of the crop rotation in the Ist trial was on average by 27 % higher compared to ME yield in the IInd one. Presumable reason of this is differences in subsoil texture. Prevailing sand particles in the 20–40 cm soil layer worsened water and nutrient regime and caused lower yields of crops in the IInd trial.

Tillage significantly influenced the overall ME yield of the rotation. The highest yield (78.6 and 59.4 GJ ha^{-1} in Ist and IInd trial, respectively) was obtained under CT. ME yield under RT did not differ from yield in CT. NT caused lower ME yield by 7–12 % compared to CT.

The effect of mineral fertilisers was very considerable in all tillage systems. Moderate rates of fertilisers increased the yield of ME in the Ist and in the IInd trials by 31 and 29 %, respectively under CT, by 27 and 40 % under RT, and by 28 and 60 % under NT compared to unfertilised plots. Enlarged rates of fertilisers increased yield of ME in the Ist and in the IInd trials by 37 and 37 %, respectively under CT, by 29 and 49 % under RT, and by 39 and 77 % under NT compared to unfertilised plots.

Crop residues did not affect the yield of ME in CT and RT systems, while their application caused lower yield of ME on average by 11 % compared to CT.

Conclusions

1. Conventional tillage produced the best soil physical properties (the lowest bulk density, cone penetration resistance, and the highest air permeability). Significantly worse soil physical properties were registered after no-tillage. Post harvest residues of preceding crop had only a tendency to reduce bulk density, while they significantly decreased penetration resistance in the 5–10 cm soil layer and positively affected air permeability. Soil cone penetration resistance could be used for expression as a basic index for assessment of physical state of soil conditions.

2. No-tillage caused greater soil moisture content after crop sowing in the upper 0–5 and 5–10 cm layers, while this index in deeper layers was essentially lower compared to both conventional and reduced tillage. Because of improving of soil moisture regime in the upper 10 cm layer under no-tillage, its functional ability deteriorated in the 10–20 cm layer. The same tendency persisted during the whole growing period of all crops investigated. Plant residues in all soil layers determined significantly higher moisture content compared with the plots where residues had been removed.

3. No-tillage management resulted in the highest stratification of P, K and humus in the soil.

4. Site and subsoil texture had a determinant influence on the yield of metabolizable energy of crop rotation. In our experiments prevailing sand particles in soil 20–40 cm layer worsened available water and nutrient content to plants in top soil and caused lower crop yields. The yield of metabolizable energy of the crop rotation in the trial with soil of high fertility was on average by 27 % higher compared to that in the trial with soil of moderate fertility.

5. The effect of mineral fertilisers was considerable in all tillage systems. Moderate rates of fertilisers increased the yield of metabolizable energy in the trial with

soil of high fertility and in the trial with soil of moderate fertility by 31 and 29 %, respectively under conventional tillage, by 27 and 40 % under reduced tillage, and by 28 and 60 % under no-tillage compared to unfertilised plots. Enlarged rates of fertilisers increased the yield of metabolizable energy in the trial with soil of high fertility and in the trial with soil of moderate fertility by 37 and 37 %, respectively under conventional tillage, by 29 and 49 % under reduced tillage, and by 39 and 77 % under no-tillage compared to unfertilised plots.

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ŽEMĖS DIRBIMO ĮTAKA DIRVOŽEMIO SAVYBĖMS IR AUGALŲ DERLINGUMUI SĖJOMAINOJE

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Santrauka

Klimato pokyčiai verčia iš esmės peržiūrėti tradicines žemdirbystės sistemas. Naujos tendencijos žemdirbystėje skatina stebėti ir vertinti pagrindinius pokyčius, vykstančius dirvožemyje ir aplinkoje. Tyrimų pagrindinis tikslas – įvertinti dirvožemio savybių pokyčius skirtingai dirbant ir tręšiant dirvožemį bei nustatyti vyraujančius veiksnius, turinčius įtakos augalams prieinamo fosforo, kalio bei humuso, kaip organinės anglies ekvivalento, pokyčiams mineraliniame dirvožemyje.

Trijų žemės dirbimo (tradicinis-ariminis-CT, supaprastintas-ariminis-RT bei neariminis-tiesioginė sėja-NT) būdų bei trijų tręšimo lygių (netręšta, vidutinis ir padidintas) įtaka dirvožemio fizikinėms ir agrocheminėms savybėms bei augalų derlingumui tirta sąlyginai turtingame ir sąlyginai neturtingame dirvožemiuose Lietuvos žemdirbystės institute 2000–2006 metais. Keturi palyginamieji lauko bandymai buvo dar papildomai daryti 2002 m. Tyrimų tikslas – įvertinti skirtingų žemės dirbimo būdų įtaką dirvožemio fizikinėms savybėms ir augalų derlingumui.

Nustatyta, kad, žemę dirbant įprastai, dirvožemio fizikinės savybės buvo geriausios (mažiausias tankis, didžiausias laidumas orui) arba paliekant augalų liekanas ant dirvos paviršiaus, arba jas pašalinant iš lauko. Blogiausios fizikinės dirvožemio savybės buvo dirvų neariant, sėjant augalus tiesiai į nepurentą dirvą. Augalų liekanos, įterptos į dirvožemį, turėjo tendenciją gerinti fizikines dirvožemio savybes. Įterpus į dirvožemį augalų liekanų, dirvožemio laidumas orui 5–20 cm dirvožemio sluoksnyje buvo didesnis vidutiniškai 47,3 %, palyginti su oro laidumu dirvožemyje, kur augalų liekanos buvo pašalintos iš lauko. Dirvų neariant, didėjo drėgmės kiekis 0–5 ir 5–10 cm dirvožemio sluoksniuose, bet mažėjo gilesniuose sluoksniuose, palyginti su tradiciniu bei su supaprastintu žemės dirbimu. Šis drėgmės kiekio pasiskirstymas dirvožemyje išliko per visą augalų vegetaciją. Augalų liekanos didino drėgmės kiekį visuose armens sluoksniuose. Nearimis žemės dirbimas sąlygojo P ir K sluoksniavimąsi (stratifikaciją) skirtinguose dirvožemio gyliuose. Podirvio granuliometrinė sudėtis turėjo esminę įtaką augalų sukauptos apykaitinės energijos kiekiui (ME) per sėjomainą. Vyraujančios smėlio dalelės 20–40 cm dirvožemio sluoksnyje mažino drėgmės kiekį viršutiniame dirvožemio sluoksnyje bei mažino augalų derlingumą. Sąlyginai neturtingame maisto medžiagų dirvožemyje augalų sukauptas ME kiekis buvo vidutiniškai 27 % mažesnis, palyginti su sąlyginai turtingu dirvožemiu. Mineralinės trąšos efektyviai didino augalų derlingumą skirtingai dirbant žemę. Vidutinis tręšimo lygis didino ME kiekį sąlyginai turtingame ir neturtingame augalų maisto medžiagų dirvožemyje tradiciškai dirbant žemę – atitinkamai iki 31 ir 29 %, dirbant žemę supaprastintu būdu – iki 27 ir 40 % bei iki 28 ir 60 % – taikant nearimį žemės dirbimą, palyginti su augalų derlingumu tose pačiose žemės dirbimo sistemose, tik jų netręšiant. Padidintas tręšimo lygis didino ME kiekį sąlyginai turtingame ir neturtingame augalų maisto medžiagų dirvožemyje tradiciškai dirbant žemę – atitinkamai iki 37 ir 37 %, dirbant žemę supaprastintu būdu – iki 29 ir 49 % bei iki 39 ir 77 % – taikant nearimį žemės dirbimą, palyginti su augalų derlingumu tose pačiose žemės dirbimo sistemose, tik jų netręšiant.

Reikšminiai žodžiai: žemės dirbimas, fizikinės dirvožemio savybės, fosforas, kalis, humusas, derlingumas, klimatas.