ARABLE LAYER AGRO-PHYSICAL PROPERTIES INDEXING IN A LONG-TERM SOIL MANAGEMENT SYSTEMS IN LITHUANIA

V. FEIZA[1], Dalia FEIZIENE[1],
Grazina KADZIENE[1], Danute SIMANSKAITE[1],
Birute RAMANAUSKIENE[1]

[1] Lithuanian Institute of Agriculture, Akademija,
e-mail: virgis@lzi.lt; telephone number:+370-347-37275

The goals of this paper – to investigate changes of physical soil properties within arable layer of the Endocalcari Epihypogleyic Cambisol under different soil management systems and to evaluate the agro-physical soil quality according to Amacher, O'Neill ir Perry scheme.

Traditional, reduced and no-tillage (direct drilling) systems have been investigated for 9 successive years. It was revealed that the best (highest) agro-physical Soil Quality Index ($SQI_{physical}$) within 0-20 cm soil layer was determined to be by managing conventional tillage system.

Key words: *Tillage, Agro-physical Soil Quality Index.*

The concept of soil quality emerged in the literature in the early 1990s [3, 11], and the first official application of the term was approved by the Soil Science Society of America Ad Hoc Committee on Soil Quality (S-581) and discussed by Karlen et al., [8]. Soil quality was been defined as ''the capacity of a reference soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation". Subsequently the two terms are used interchangeably [6] although it is important to distinguish that, soil quality is related to soil function [7,9], whereas soil health presents the soil as a finite non-renewable and dynamic living resource [4].

Soil physical properties are estimated from the soil's texture, bulk density (a measure of compaction), porosity, water-holding capacity. The presence or absence of hard pans usually presents barriers to rooting depth. These properties are all improved through additions of organic matter to soils. Therefore, the suitability of soil for **s**ustaining plant growth and biological activity is a function of its physical properties (porosity, water holding capacity, structure, and tilth).

Goals of the research were: 1) to investigate selected soil physical properties changes on *Endocalcari-Epihypogleyic Cambisol* of Lithuania by applying long-term different soil management systems and 2) to evaluate the agro-physical soil quality according to Amacher, O'Neill ir Perry scheme [1].

MATERIAL AND METHOD

Indexing. The interpretations and indexing the properties of mineral soils and threshold levels are listed in *table 1*.

Table 1

Classification of some soil physical parameters and indexing according to Amacher, O'Neill and Perry scheme [1]

Parameter	Range	Interpretation	Index
Soil bulk density ($Mg\ m^{-3}$)	>1.5	critical, plant root growth restricted	0
	1.3-1.5	satisfactory, plant root growth still not restricted	1
	<1.3	suitable, plant root growth not restricted	2
Penetration resistance (MPa)	<0.3	very low, plant root growth not restricted	2
	0.3-1.0	low, plant root growth not restricted	1
	1.0-1.5	suitable, plant root growth not restricted	0
	>1.5	critical, plant root growth restricted	-1
Air-permeability ($l\ min^{-1}$)	<10	critical, plant root growth restricted	0
	10-20	satisfactory, plant root growth still not restricted	1
	>20	suitable, plant root growth not restricted	2
Total porosity (%)	<40	critical for plant root growing	1
	40-60	suitable for plant root growing	2
	>60	Weak contact of soil and plant roots	1
Soil moisture content (%)	<10	critical, plant root growth restricted	-1
	10-13	satisfactory, plant root growth somewhat restricted	1
	13-18	optimal for crop growing	2
	>18	satisfactory, plant root growth may be restricted due to oxygen shortage	1
Air-filled porosity (%)	<10	critical for plant root growing	0
	10-20	suitable for plant root growing	1
	>20	optimal for plant root growing	2
Soil structure coefficient	<1.0	critical for plant root growing	0
	1.0-1.5	suitable for plant root growing	1
	>1.5	optimal for plant root growing	2

All physical properties indexes measured on mineral soils are summed up due to give a total physical soil quality index ($SQI_{physical}$):

$$SQI_{physical} = \Sigma \text{ individual soil physical property index}$$

We have investigated 7 soil physical properties, thus the maximum value of the $SQI_{physical}$ would be 14.

The essence of $SQI_{physical}$ consists of relationship between individual soil physical properties. Each property, according to its parameters, receives different evaluation – so called Index.

Field trial conditions. The experiment was carried out at the Lithuanian Institute of Agriculture on *Endocalcari-Epihypogleyic Cambisols* during 1999-2007. Two field trials were set up on soils having different fertility level. The first of them was established on soil rich in macronutrients (PK) and moderately rich in humus (the I[st] trial) and the second on moderately rich in macronutrients (PK) and having low amount of humus (the II[nd] trial) soil. According to FAO classification system the soil in the I[st] trial is clay loam and in the II[nd] trial – sandy clay loam.

Experimental design. Two factorial field trials were carried out in 4 replications. Each one replication consisted of 3 tillage systems and every tillage system consisted of 3 different fertilisation levels. The control treatment of the trials was conventional tillage treatment CT-1 (i.e. deep ploughing + presowing shallow cultivation, not fertilised) (*tab. 2*).

Table 2

Field trial design

Tillage (factor A)		
Abbreviation	Primary	Presowing
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-direct drilling	No-tillage	Direct drilling
Fertilisation (factor B)		
1	Not fertilised	
2	Moderate rates: NPK fertilisers according to soil properties and expected yield	
3	High rates: NPK fertilisers according to soil properties and expected yield	

Sowing and fertilisation. The last crop in the crop rotation was spring oil-seed rape var. *"Maskot"*. The rates of mineral NPK fertilisers were calculated according to PC programme "*Tresimas"* ("Fertilisation") [10].

Methods of analysis. Bulk density **(**Mg m^{-3}) was determined according to A. Kachinskij method [12]; penetration resistance (MPa) – with hand-held penetrometer „Eijkelkamp"; air-permeability (L min^{-1}) – with A. Andersson apparatus; total porosity (%) – calculated [5]; soil texture – by pipette method [2].

RESULTS AND DISCUSSIONS

Bulk density (BD). The highest BD soon after spring oil-seed rape sowing was determined in the NT system (*fig. 1, tab. 3*).

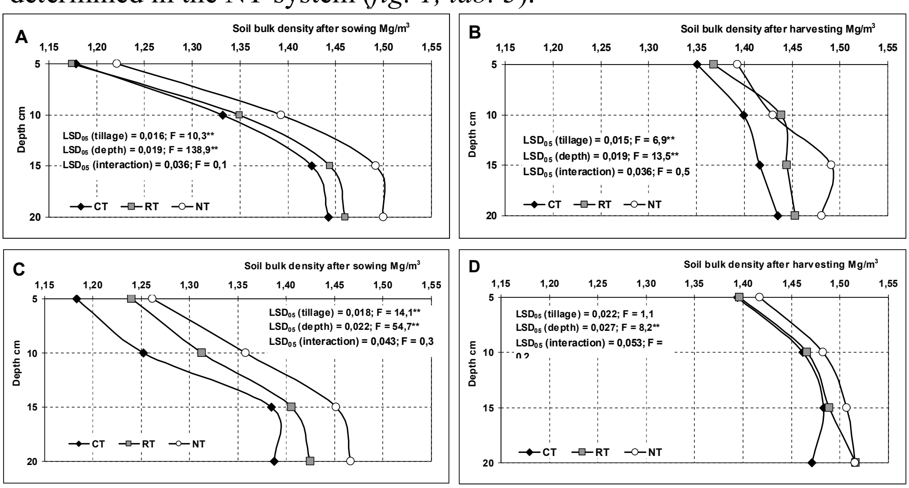

Figure 1 **Soil bulk density in the field trials in 2007. A - in the I[st] (after sowing), B - in the I[st] (after harvesting), C – in the II[nd] (after sowing), D – in the II[nd] (after harvesting)**

However, in the 0-10 cm soil layer it did not exceed 1.30-1.31 Mg m^{-3}, thus it was suitable for the crop sprouting and roots development. BD differences in the 0-10 cm layer under CT and RT tillage systems were insignificant in the I[st] trial. In the II[nd] trial this index was by 5 % lower under CT compared to RT. BD in the 10-20 cm soil layer did not differ significantly in CT and RT systems. The deeper soil layer the higher BD was registered in spite of tillage system managed.

Table 3

Variance analysis of soil bulk density

Factor	I[st] trial				II[nd] trial			
	After sowing		After harvesting		After sowing		After harvesting	
	$F_{act.}$	LSD_{05}	$F_{act.}$	LSD_{05}	$F_{act.}$	LSD_{05}	$F_{act.}$	LSD_{05}
Tillage (A)	10.28**	0.016	6.88**	0.015	14.12**	0.018	1.08	0.022
Soil layer (B)	138.98**	0.019	13.54**	0.019	54.67**	0.022	8.21**	0.027
Interaction (AxB)	0.11	0.036	0.48	0.036	0.25	0.043	0.15	0.053

BD during crop vegetation period changed. In spite of tillage intensity, the tilled soil tended to return to its original stage which was registered at the sowing time in spring. It is worth though to notice, that by applying different tillage systems for 9 years the BD in each of them has reached its own stability-equilibrium. After crop harvesting BD have remained significantly different and still persisted in different tillage systems. The least BD was registered in the CT, while the highest in the NT.

It might be concluded that the optimal BD within plough soil layer was ensured only by applying CT (*tab. 4*). This engaged successful crop establishment, rooting and uniformity of crop development at early growing stages. The appropriate BD under NT application was determined within 0-10 cm soil layer only. In the 10-20 cm soil layer BD was rather high and very close to the relevant crop growing limit.

Table 4

Soil quality indexing according to data of actual soil physical properties

Soil properties	Depth (cm)	I[st] trial						II[nd] trial					
		CT		RT		NT		CT		RT		NT	
		After sowing	After harvesting	After sowing	After harvesting	After sowing	After harvesting	After sowing	After harvesting	After sowing	After harvesting	After sowing	After harvesting
Bulk density	0-10	2	1	2	1	2	1	2	1	2	1	1	1
	10-20	1	1	1	1	0	1	1	1	1	0	1	0
Penetration resistance	0-10	1	1	1	1	1	1	0	0	0	0	0	-1
	10-20	1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1
Air-permeability	0-10	1	0	1	0	0	0	1	0	1	0	0	0
	10-20	1	1	0	0	0	0	0	1	0	0	0	0
Total porosity	0-10	2	2	2	2	2	2	2	2	2	2	2	2
	10-20	2	2	2	2	2	2	2	2	2	2	2	2
Moisture	0-10	2	1	2	2	1	1	2	2	1	2	1	2
	10-20	1	2	2	2	2	2	2	1	2	1	1	1
Air-filled porosity	0-10	2	1	2	1	2	1	2	1	2	1	2	1
	10-20	1	1	1	1	1	1	1	2	1	1	2	2
Soil structure coefficient	0-10	2	2	2	2	2	2	1	1	1	2	1	1
	10-20	1	2	1	2	2	2	0	1	1	1	1	2

Penetration resistance (PR). PR in the 0-10 cm soil layer after crop sowing at both trials under CT and RT systems did not differ significantly, while in the NT system it was on average by 49-54 % higher compared to the CT and RT (*fig 2, tab. 5*). PR in the 10-20 cm soil layer under RT was by 12-15 % higher, under NT by 92-108 % higher than under CT.

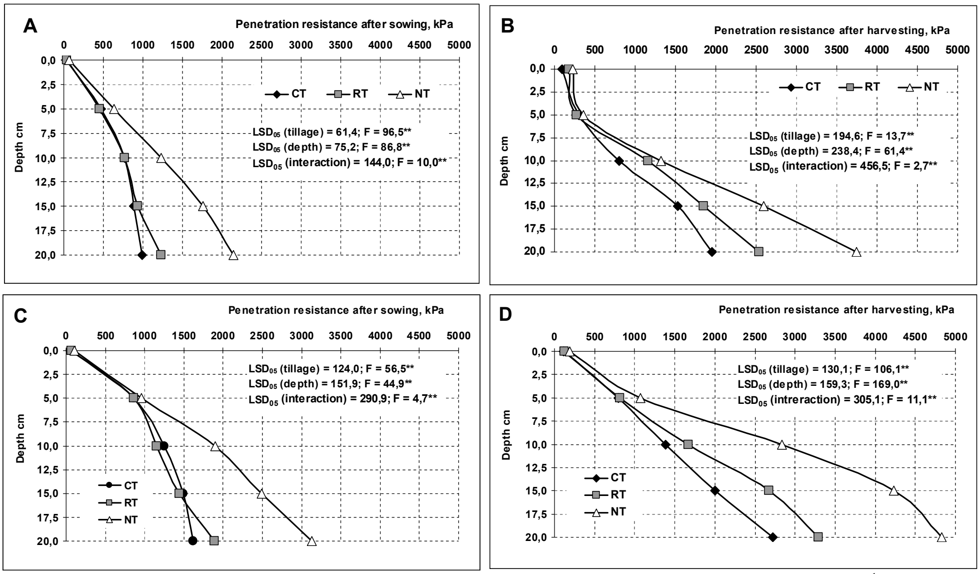

Figure 2 **Soil penetration resistance in the field trials in 2007. A - in the Ist (after sowing), B - in the Ist (after harvesting), C – in the IInd (after sowing), D – in the IInd (after harvesting)**

Table 5

Variance analysis of soil penetration resistance

Factor	Ist trial				IInd trial			
	After sowing		After harvesting		After sowing		After harvesting	
	$F_{act.}$	LSD_{05}	$F_{act.}$	LSD_{05}	$F_{act.}$	LSD_{05}	$F_{act.}$	LSD_{05}
Tillage (A)	96.53**	61.4	13.71**	194.6	56.47**	124	106.13**	130.1
Soil layer (B)	86.85**	75.2	61.38**	238.4	44.87**	151.9	168.95**	159.3
Interaction (AxB)	9.95**	144.0	2.73*	456.5	4.7**	290.9	11.14**	305.1

After harvesting the PR differences among tillage systems were evidence. PR in the 0-10 cm soil layer under RT was by 12-30 % higher, under NT by 52-71 % higher than under CT. PR in the 10-20 cm soil layer under RT was by 12-26 % higher, under NT by 82-91 % higher compared to the CT system.

The data revealed that all tillage systems were not able to ensure optimal PR till termination of the crop vegetation period. Due to this reason the soil quality index provided for PR after crop sowing was rather low and it after harvesting was even negative (*tab. 4*).

Air-permeability (AP). The best AP was registered under CT system application (*fig. 3, tab. 6*).

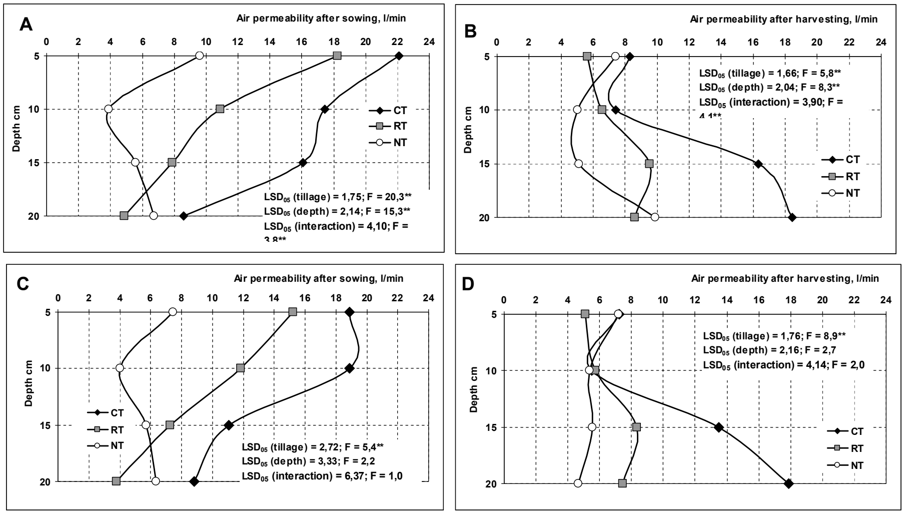

Figure 3 **Soil air-permeability in the field trials in 2007. A - in the Ist (after sowing), B - in the Ist (after harvesting), C – in the IInd (after sowing), D – in the IInd (after harvesting)**

In spring in the 0-10 cm soil layer under RT the AP was by 10-26 % lower, under NT by 54-68 % lower compared to the CT system. In the 10-20 cm layer differences were 0-67 % and 32-47 %, respectively. After harvesting the situation has somewhat changed. In the Ist trial under RT and NT systems application in the 0-10 cm soil layer the AP was by 24-35 % higher compared to the CT, while in the IInd trial under RT and NT systems it was by 24-34 % lower compared to the CT. In the 10-20 cm layer in both trials the AP differences remained similar to that of 0-10 cm. Under RT system application the AP was by 42-51 % lower, under NT system by 60-65 % lower compared to the CT system.

Table 6

Variance analysis of soil air-permeability

Factor	Ist trial				IInd trial			
	After sowing		After harvesting		After sowing		After harvesting	
	$F_{act.}$	LSD_{05}	$F_{act.}$	LSD_{05}	$F_{act.}$	LSD_{05}	$F_{act.}$	LSD_{05}
Tillage (A)	36.35**	1.320	13.15**	1.420	20.98**	1.54	15.67**	1.180
Soil layer (B)	20.15**	1.610	7.76**	1.740	9.96**	1.88	6.54**	1.440
Interaction (AxB)	3.62**	3.080	2.72*	3.340	2.87*	3.61	5.51**	2.770

At the end of crop vegetation period the suitable air-permeability conditions were registered under CT within 10-20 cm soil layer in both Ist and IInd field trials (*tab. 4*). RT and NT system application did not ensure suitable soil air-permeability at the final stage of the crop growing.

Total soil porosity (TP). TP of mineral soils can vary from 20 to 70 %. It is influenced by bulk density, soil structure, climatic conditions as well soil management. The soils in both field trials have followed the best value of this parameter (*fig.4, tab.7*).

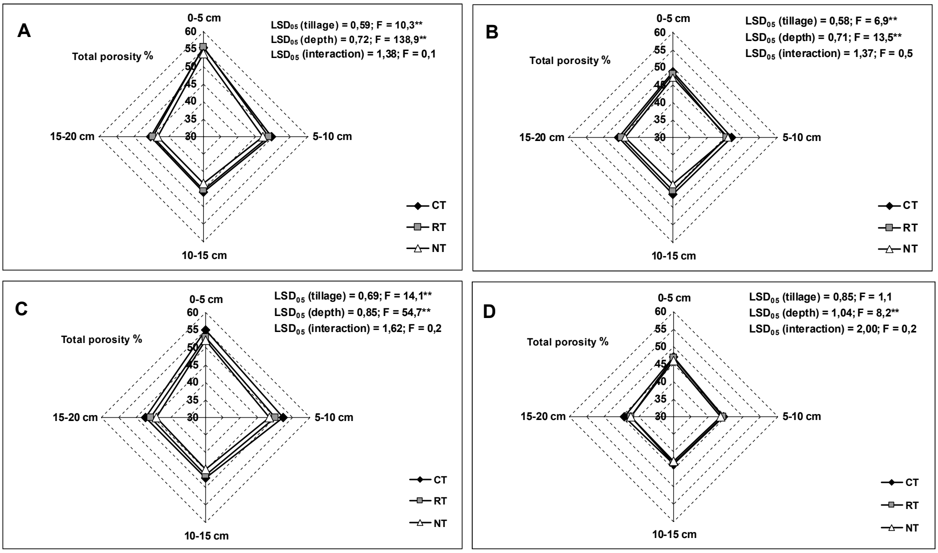

Figure 4 **Total soil porosity in the field trials in 2007. A - in the Ist (after sowing), B - in the Ist (after harvesting), C – in the IInd (after sowing), D – in the IInd (after harvesting)**

Differences in TP were not high in all tillage systems, while under NT system (in spring and autumn) in both 0-10 cm and 10-20 cm layers TP was significantly lower compared to the CT system.

Table 7

Variance analysis of total soil porosity

Factor	Ist trial				IInd trial			
	after sowing		after harvesting		after sowing		after harvesting	
	$F_{act.}$	LSD_{05}	$F_{act.}$	LSD_{05}	$F_{act.}$	LSD_{05}	$F_{act.}$	LSD_{05}
Tillage (A)	10.28**	0.590	6.88**	0.582	14.12**	0.693	1.08	0.853
Soil layer (B)	138.98**	0.723	13.54**	0.713	54.67**	0.849	8.21**	1.045
Interaction (AxB)	0.11	1.384	0.48	1.366	0.25	1.625	0.15	2.001

Soil moisture content (SM). It is important to mention that in 0-5 cm soil layer the SM was 2.1 fold higher under NT system application compared to that in the CT. During spring oil-seed rape vegetation period the SM reduced in all tillage systems. Unfortunately, after crop harvesting within 10-20 cm soil layer the SM under NT was by 9-11 % lower compared to SM in the CT. Due to this it might be concluded that under global warming conditions the application of NT system may be the right measure to preserve soil moisture at early stage of crop development.

Air-filled soil porosity (AFP). Differences in AFP were not high in all tillage systems, while under NT system (in spring and autumn) either in the 0-10 cm or in the 10-20 cm soil layers the AFP was significantly lower compared to the CT system.

Soil structure coefficient (ST). In both field trials the best soil structure coefficients were determined under NT. In addition, soil structure coefficient in the Ist trial (clay loam) was on average by 44 % higher than in the IInd one (sandy clay loam).

Agro physical soil quality. Sum of Indexes of different soil physical properties revealed the influence of long-term application of contrasting tillage systems on total agro physical soil quality (*fig. 5*).

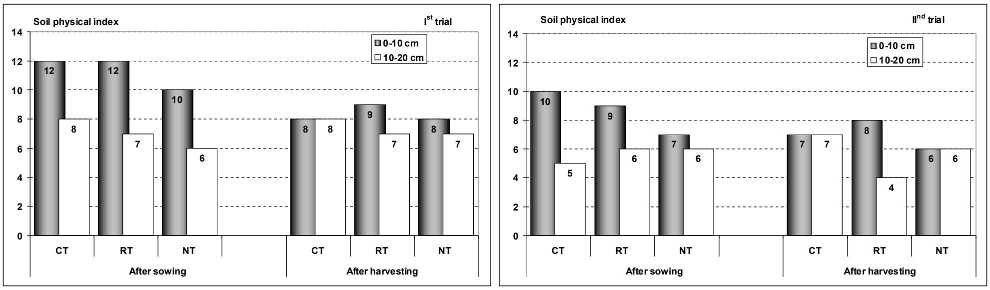

Figure 5 **The $SQI_{physical}$ under different tillage systems, 2007**

The highest possible agro-physical Soil Quality Index ($SQI_{physical}$) in the field trials was 14. The $SQI_{physical}$ of the Ist trial in the 0-20 cm layer has been evaluated by 10, while $SQI_{physical}$ of the IInd trial of the same layer was only 7. This means that in general, soil quality of plough layer is not very high and it could be improved.

The $SQI_{physical}$ after crop sowing in the Ist trial revealed that within 0-10 cm layer the application of NT system conditioned lower soil physical quality (Index 10) compared to the CT and RT (Index, on average, 12). The $SQI_{physical}$ within 0-10 cm layer after crop sowing in the IInd trial was also registered lower under NT (Index 7) compared to the CT (Index 10) and RT (Index 9). Within 10-20 cm layer of the Ist trial the $SQI_{physical}$ was higher under CT (Index 8) compared to the RT (Index 7) and NT (Index 6). In the IInd trial the $SQI_{physical}$ within 10-20 cm layer was similar in different tillage systems and varied from 5 to 6.

After crop harvesting in both field trials the $SQI_{physical}$ within 10-20 cm soil layer did not change, but within 0-10 cm layer it reduced under CT and RT application.

CONCLUSIONS

1. The optimal bulk density within plough soil layer was ensured by applying conventional tillage system. The appropriate bulk density under direct drilling was determined within 0-10 cm layer only. In the 10-20 cm layer bulk density was rather high and very close to the relevant crop growing limit.
2. Penetration resistance in the 0-10 cm soil layer after crop sowing under conventional tillage and reduced tillage systems did not differ significantly, while after applying direct drilling it was by 49-54 % higher compared to conventional and reduced tillage systems. After harvesting the changes in penetration resistance were the least by applying conventional tillage system.

3. The best air-permeability was registered under conventional tillage system application. Reduced tillage and direct drilling application did not ensure suitable soil air-permeability at the final stage of the crop growing.
4. Under direct drilling (in spring and autumn) in both 0-10 cm and 10-20 cm soil layers total porosity was significantly lower compared to the conventional tillage.
5. The best soil structure coefficients were determined to be under no-tillage application.
6. Over the 9 years of different tillage systems application the best agro-physical Soil Quality Index ($SQI_{physical}$) within 0-20 cm soil layer was determined by managing the conventional tillage system.

Acknowledgement. The study has been supported by the Lithuanian State Science and Studies Foundation.

BIBLIOGRAPHY

1. Amacher, M.C., O'Neill, K.P., Perry, C. H., 2007 - *Soil vital signs: a new soil quality index (SQI) for assessing forest soil health.* Research paper of USD of Agriculture, Forest service, Rocky Mountain research station, p. 2-12.
2. Day, P.R., 1965 - *Particle fractionation and particle-size analysis,* in Black, C.A., ed., Methods of soil analysis, Part 1: American Society of Agronomy, Inc., Madison, Wisconsin, p. 545-567.
3. Doran, J.W. and Safley, M., 1997 - *Defining and assessing soil health and sustainable productivity*. In: Pankhurst, C. et al. (eds.). Biological indicators of soil health. Wallingford, UK: CAB International. p. 1–28.
4. Doran, J.W., Zeiss, M.R., 2000 - *Soil health and sustainability: managing the biotic component of soil quality*. Applied Soil Ecology 15, p. 3–11.
5. Hillel, D., 1982 - *Introduction to soil physics*. Academic Press, San Diego, CA. 9, p.13-27.
6. Karlen, D. L., Andrews, S. S., Doran, J. W., 2001 - *Soil quality: Current concepts and applications*. Advances in Agronomy, vol. 74, p. 1-40.
7. Karlen, D. L., Doran, J. W., Weinhold, B. J., Andrews, S. S., 2003 - *Soil quality: Humankind's foundation for survival*. Journal of Soil and Water Conservation, vol. 58, p. 4- 11.
8. Karlen, D. L., Mausbach, M. J., Doran, J. W., Cline, R. G., Harris, R. F., Schuman, G. E., 1997 - *Soil quality: a concept, definition, and framework for evaluation*. Soil Science Society of America Journal, vol. 61, p. 4-10.
9. Letey, J., Sojka, R. E., Upchurch, D. R., Cassel, D. K., Olson, K. R., Payne, W. A., Petrie, S. E., Price, G. H., Reginato, R. J., Scott, H. D., Smethurst, P. J., Triplett, G. B., 2003 - *Deficiencies in the soil quality concept and its application*. Journal of Soil and Water Conservation, vol. 58, p. 180 - 187.
10. Svedas, A., Tarakanovas, P., 2000 - *Tresimo planavimas*. Kompiuterine versija Tresimas. - Akademija, p. 34 (In Lithuanian).
11. Wienhold, B. J., Andrews, S. S., Karlen, D. L., 2004 - *Soil quality:* A review of the science and experiences in the USA. Environ. Geochem. Hlth., vol. 26, p. 89-95.
12. Нерпин, С., Чудновский, А., 1967 - *Физика почвы*. Москва. Наука. с. 13-18 (In Russian).