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Agro-physical properties of *Endocalcari-Epihypogleyic Cambisol* arable layer in long-term soil management systems

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The aim of this work was to determine the differences and changes of agro-physical properties in the arable layer of the *Endocalcari-Epihypogleyic Cambisol* (clay loam and sandy clay loam) under different soil management systems and to determine the agro-physical soil quality according to the Amacher, O'Neill and Perry scheme. It was revealed that the optimal bulk density within the ploughed soil layer was ensured by applying a conventional tillage system. The appropriate bulk density under direct drilling was determined in the 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. 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, changes in penetration resistance were the least under the conventional tillage system. The best air-permeability was registered also under the conventional tillage system. Reduced tillage and direct drilling did not ensure suitable soil air-permeability at the final stage of crop growing. Under global warming conditions, the application of the direct drilling system could be the right measure to preserve soil moisture at early stages of crop development.

Under direct drilling (in spring and autumn), in both 0–10 cm and 10–20 cm soil layers, the total and air-filled porosity were significantly lower as compared to the conventional tillage. Ploughless tillage has a positive influence on soil structure. The best soil structure coefficients were determined under direct drilling. Over 8 years of applying different tillage systems, the best agro-physical soil quality index ($SQI_{physical}$) in the 0–20 cm soil layer was determined under the conventional tillage system.

Key words: agro-physical soil properties, tillage, agro-physical soil quality index

INTRODUCTION

Soil physical quality for crops was percepted from the conceptual point of view and from strategies used for its assessment. Researchers have highlighted the importance of the soil physical environment for plant growth and for the chemical (Drury et al., 2003) and biological (Allmaras et al., 2002) soil conditions. Different soil physical properties have been used to assess soil physical quality (Silva, Kay, 2004).

Soil health is defined as its continued capacity to function as a vital living system, by recognizing that it contains biological elements that are key to the ecosystem's functioning within land-use boundaries (Doran, Zeiss, 2000; Karlen et al., 2001). These functions are able to sustain the biological productivity of soil, maintain the quality of the surrounding air and water environments, as well as promote plant, animal, and human health (Doran et al., 1996).

The concept of soil quality emerged in the literature in the early 1990s (Doran, Safley, 1997; Wienhold et al., 2004), 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. (1997). Soil quality was 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 (Karlen et al., 2001) although it is important to distinguish that soil quality is related to soil function (Karlen et al., 2003; Letey et al., 2003), whereas soil health presents the soil as a finite non-renewable and dynamic living resource (Doran, Zeiss, 2000).

Protection of soil quality under intensive land use and fast economic development is a major challenge for sustainable resource use in the developing world (Doran et al., 1996). The basic assessment of soil health and soil quality is necessary to evaluate the degradation status and changing trends following

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different land use and smallholder management interventions (Lal, Stewart, 1995).

Soil physical properties are estimated from its texture, bulk density (the measure of compaction), porosity, water-holding capacity (Hillel, 1982). The presence or absence of hard pans usually presents barriers to rooting depth. These properties are all improved by adding 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).

The aim of the research was to investigate soil quality changes on *Endocalcari-Epihypogleyic Cambisols* in the middle lowland of Lithuania with applying long-term different soil management systems.

The goals of this paper are: 1) presentation of research data on selected soil physical properties changing under long-term application of different intensity soil management systems; 2) evaluation-indexing of soil agro-physical properties according to the Amacher, O'Neill and Perry scheme (Amacher et al., 2007).

MATERIALS AND METHODS

Indexing. Mineral soil property threshold levels, interpretations and indexing are listed in Table 1. All indexes of physical properties measured on mineral soils are summed up to give a total physical soil quality index ($SQI_{physical}$):

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

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

The essence of $SQI_{physical}$ consists in a relationship among individual soil physical properties. Each property, according to its parameters, receives different evaluation (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 with different fertility. The first of them was established on soil rich in macronutrients (PK) and moderately rich in humus (1st trial) and the second on soil moderately rich in macronutrients (PK) with a low amount of humus (2nd trial). Soil texture is presented in Table 2. According to the FAO classification system, the soil in the 1st trial was clay loam and in the 2nd trial sandy clay loam.

Experimental design (Table 3). Two factorial field trials were carried out in four replications. Each replication consisted of three tillage systems and each tillage system consisted of three different fertilisation levels. The control treatment of the trials was conventional tillage treatment CT-1 (deep ploughing + presowing shallow cultivation, not fertilised).

Table 1. **Classification of soil physical parameters and indexing according to the Amacher, O'Neill and Perry scheme [2]**

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
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
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
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

Table 2. **Soil texture**

Soil layer (cm)	Soil particles					
	1st trial			2nd trial		
	sand (2.0–0.05 mm)	silt (0.05–0.002 mm)	clay (<0.002 mm)	sand (2.0–0.05 mm)	silt (0.05–0.002 mm)	clay (<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

Table 3. **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 employing the PC programme "Tręšimas" ("Fertilisation") (Švedas, Tarakanovas, 2000).

Methods of analysis. Bulk density (Mg m^{-3}) was determined according to the A. Kachinski method (Нерпин, Чудновский, 1967); penetration resistance (MPa) was measured with a mobile hand-held "Eijkelkamp" penetrometer; air-permeability (l min^{-1}) with A. Andersson's apparatus, total porosity (%) and air-filled porosity (%) were calculated as in (Carter, Gregorich, 2008), soil texture was determined by the pipette method according to FAO, soil aggregate stability by S. Savinov's method (Нерпин, Чудновский, 1967), soil structure coefficient (SSC) has been calculated according to the formula (Нерпин, Чудновский, 1967):

SSC = A÷B,

here A (%) is the aggregates >7 mm + <0.25 mm, and B (%) is Σ (0.25–7 mm).

Statistical analysis. Data were treated by two factorial analysis methods using the "Anova" PC programme. Correlation–regression analysis was done according to Clewer and Scarisbrick (2001) with the "*STAT_ENG*" PC programme. The least significant difference (LSD) was calculated at the 0.05 probability level.

RESULTS AND DISCUSSION

Bulk density (BD). According to investigations of Prof. A. Tindžiulis, the optimal value of BD for plant growing on clay loam soil is about 1.1–1.2 Mg m^{-3} (Tindžiulis, 1979). Our investigations revealed that BD was very much influenced by the tillage system used during the 8th year of investigations (Fig. 1, Table 4). Our data were in line with data of other Lithuanian researchers concerning tillage effects on BD (Šimanskaitė, 1996, 2007; Stancevičius et al., 2003; Cesevičius, Feiza, 2005; Trečiokas, Raudonius, 1999).

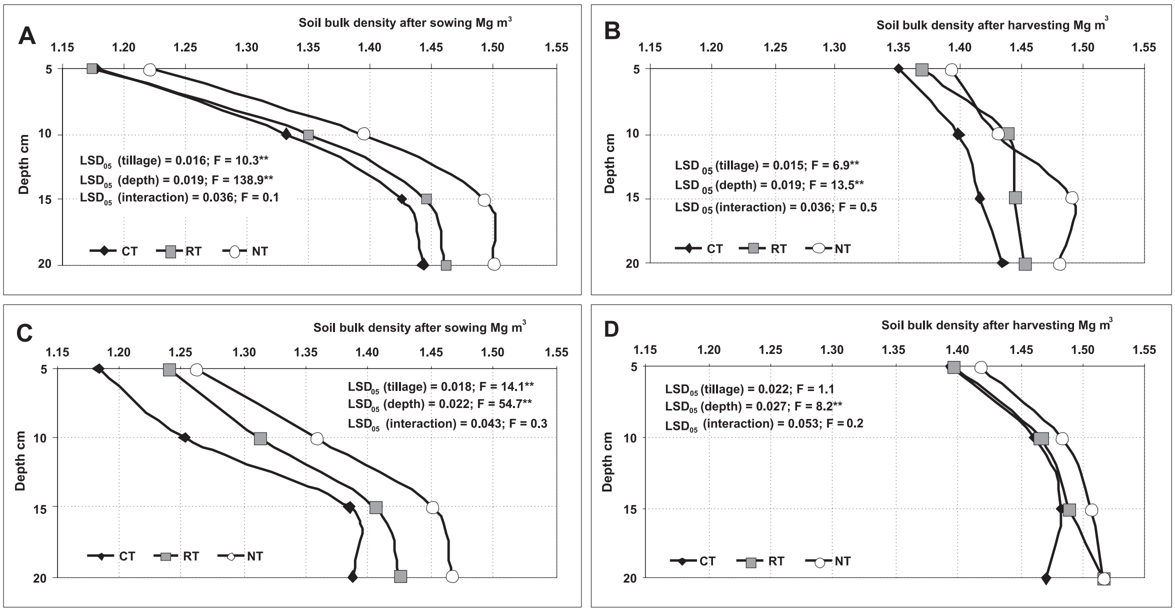

Fig. 1. Soil bulk density in field trials in 2007. A – in the 1st after sowing, B – in the 1st after harvesting, C – in the 2nd after sowing, D – in the 2nd after harvesting

Table 4. **Variance analysis of soil bulk density**

Factor	1st trial						2nd trial					
	After sowing			After harvesting			After sowing			After harvesting		
	MS	$F_{act.}$	LSD_{05}	MS	$F_{act.}$	LSD_{05}	MS	$F_{act.}$	LSD_{05}	MS	$F_{act.}$	LSD_{05}
Tillage (A)	0.014	10.28**	0.016	0.009	6.88**	0.015	0.027	14.12**	0.018	0.003	1.08	0.022
Soil layer (B)	0.194	138.98**	0.019	0.018	13.54**	0.019	0.105	54.67**	0.022	0.024	8.21**	0.027
Interaction (A × B)	0.000	0.11	0.036	0.001	0.48	0.036	0.000	0.25	0.043	0.000	0.15	0.053

The highest BD, soon after spring oil-seed rape sowing, was determined in the NT system. However, in the 0–10 cm soil layer it did not exceed 1.30–1.31 Mg m^{-3}, thus it was suitable for crop sprouting and root development. BD differences in the 0–10 cm layer under CT and RT tillage systems were insignificant in the 1st trial. In the 2nd 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 the CT and RT systems. The deeper soil layer the higher BD was registered whatever the tillage system managed.

BD during crop vegetation 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 noting that by applying different tillage systems for 9 years the BD in each of them reached its own stability-equilibrium. After crop harvesting, BD remained significantly different and still persisted in different tillage systems. The lowest BD was registered in the CT, while the highest in the NT.

It might be concluded that the optimal BD within the ploughed soil layer was ensured only by applying CT (Table 5). This engaged a successful crop establishment, rooting and uniformity of crop development at early growing stages. The appropriate BD under NT application was determined within the 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.

Penetration resistance (PR). PR is a very valuable indicator to describe and evaluate soil physical state. PR is influenced by other soil properties: the size of soil aggregates, soil moisture content and bulk density. As a common rule, the lower soil moisture content the higher bulk density; the larger amount of small-size soil aggregates results in a higher PR. Very often, reduced tillage tends to increase PR compared to conventional tillage (Da Veiga et al., 2007; Reichert et al., 2004).

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 as compared to the CT and RT (Fig. 2, Table 6). PR in the 10–20 cm soil layer under RT was by 12–15% higher and under NT by 92–108% higher than under CT.

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

All tillage systems were not able to ensure optimal PR till the end of the crop vegetation period. For this reason, the soil quality index provided for PR after crop sowing was rather low and after harvesting was even negative (Table 5).

Air-permeability (AP). The best AP was registered under CT system application (Fig. 3, Table 7). In spring, in the 0–10 cm soil layer under RT the AP was by 10–26% lower and under NT by 54–68% lower as compared to the CT system. In the 10–20 cm layer, the differences were 0–67% and 32–47%, respectively. After harvesting the situation somewhat changed.

Table 5. **Soil quality indexing according to data of actual soil physical properties**

Soil properties		1st trial						2nd 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
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
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
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

Table 6. **Variance analysis of soil penetration resistance**

Factor	1st trial						2nd trial					
	After sowing			After harvesting			After sowing			After harvesting		
	MS	$F_{act.}$	LSD_{05}	MS	$F_{act.}$	LSD_{05}	MS	$F_{act.}$	LSD_{05}	MS	$F_{act.}$	LSD_{05}
Tillage (A)	2111570	96.53**	61.4	3012674	13.71**	194.6	5037599	56.47**	124	10411364	106.13**	130.1
Soil layer (B)	1899750	86.85**	75.2	13482209	61.38**	238.4	4002610	44.87**	151.9	16574282	168.95**	159.3
Interaction (A × B)	217711	9.95**	144.0	599075	2.73*	456.5	419263	4.7**	290.9	1093139	11.14**	305.1

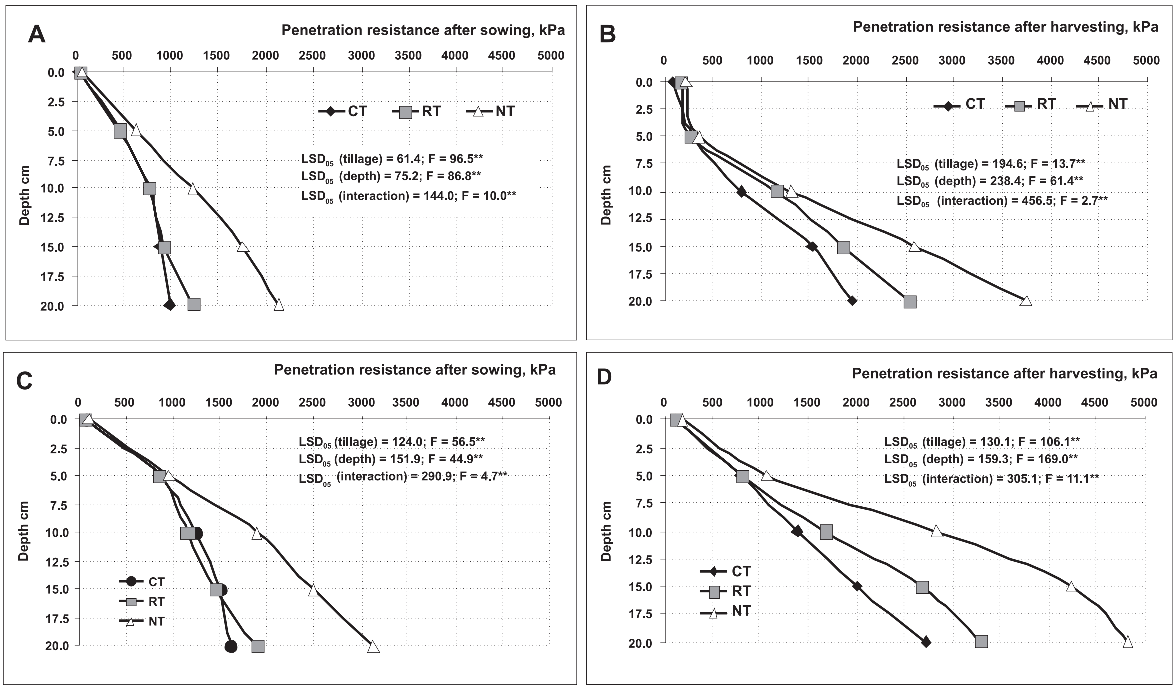

Fig. 2. Soil penetration resistance in field trials in 2007. A – in the 1st after sowing, B – in the 1st after harvesting, C – in the 2nd after sowing, D – in the 2nd after harvesting

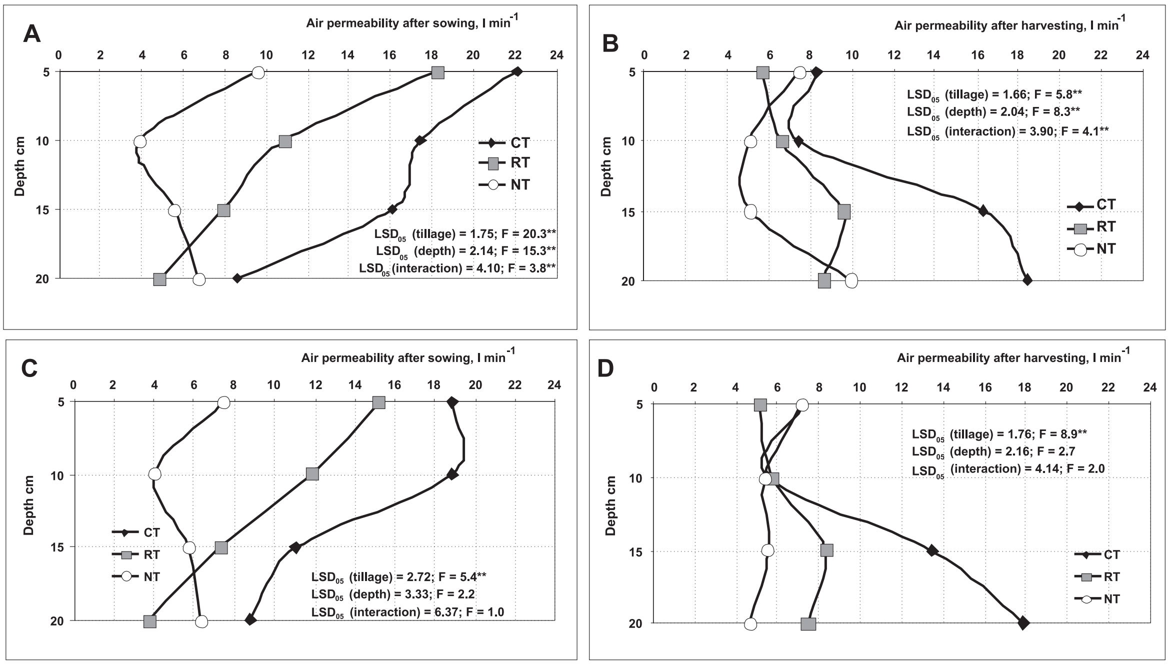

Fig. 3. Soil air-permeability in field trials in 2007. A – in the 1st after sowing, B – in the 1st after harvesting, C – in the 2nd after sowing, D – in the 2nd after harvesting

Table 7. **Variance analysis of soil air-permeability**

Factor	1st trial						2nd trial					
	After sowing			After harvesting			After sowing			After harvesting		
	MS	$F_{act.}$	LSD_{05}	MS	$F_{act.}$	LSD_{05}	MS	$F_{act.}$	LSD_{05}	MS	$F_{act.}$	LSD_{05}
Tillage (A)	464.9	36.35**	1.320	196.9	13.15**	1.420	366.4	20.98**	1.54	161.2	15.67**	1.180
Soil layer (B)	257.7	20.15**	1.610	116.2	7.76**	1.740	173.9	9.96**	1.88	67.2	6.54**	1.440
Interaction (A × B)	46.3	3.62**	3.080	40.7	2.72*	3.340	50.1	2.87*	3.61	56.7	5.51**	2.770

In the 1st trial under RT and NT systems, in the 0–10 cm soil layer the AP was by 24–35% higher as compared to the CT, while in the 2nd trial under RT and NT systems it was by 24–34% lower as 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 and under the NT system by 60–65% lower as compared to the CT system.

At the end of the crop vegetation period, suitable air-permeability conditions were registered under CT within the 10–20 cm soil layer in both 1st and 2nd field trials (Table 5). RT and NT system application did not ensure suitable soil air-permeability at the final stage of crop growing.

Soil moisture content (SM). In 2007, SM met the requirements for crop growing (Fig. 4, Table 8). In the 1st trial, the NT application determined a higher SM on average by 19 and 10% in the 0–10 and in the 10–20 cm soil layers, respectively. In the 2nd trial, in the 0–10 cm soil layer under NT, SM was by 14% and in the 10–20 cm soil layer by 24% lower as compared to SM in the CT system. Importantly, in the 0–5 cm soil layer the SM was 2.1-fold higher under the NT system as compared to that in the CT. During the spring oil-seed rape vegetation period, the SM reduced in all tillage systems. Unfortunately, after crop harvesting, in the 10–20 cm soil layer the SM under NT was by 9–11% lower as compared to SM in the CT.

According to our results, under global warming conditions the application of the NT system may be the right measure to preserve soil moisture at the early stage of crop development.

Total soil porosity (TP). TP of mineral soils may vary from 20 to 70%. It is influenced by bulk density, soil structure, climatic conditions as well as soil management. The soils in both field trials followed the best value of this parameter (Fig. 5, Table 9). Differences in TP were not high in all tillage systems, while under the NT system (in spring and autumn) in both 0–10 cm and 10–20 cm layers TP was significantly lower as compared to the CT system.

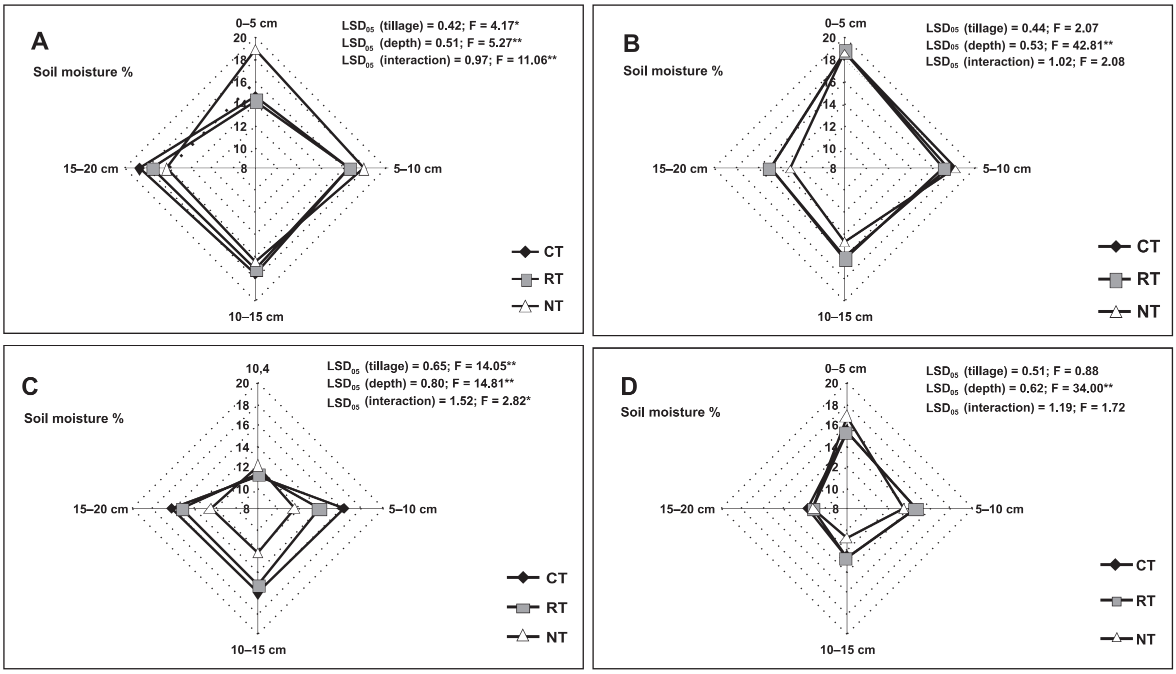

Fig. 4. Soil moisture in field trials in 2007. A – in the 1st after sowing, B – in the 1st after harvesting, C – in the 2nd after sowing, D – in the 2nd after harvesting

Table 8. **Variance analysis of soil moisture**

Factor	1st trial						2nd trial					
	After sowing			After harvesting			After sowing			After harvesting		
	MS	$F_{act.}$	LSD_{05}	MS	$F_{act.}$	LSD_{05}	MS	$F_{act.}$	LSD_{05}	MS	$F_{act.}$	LSD_{05}
Tillage (A)	360.2	20.36**	1.747	92.6	5.78**	1.663	232.9	5.44**	2.717	161.8	8.97**	1.764
Soil layer (B)	270.5	15.29**	2.140	132.9	8.29**	2.037	93.4	2.18	3.328	48.4	2.68	2.160
Interaction (A × B)	68.0	3.85**	4.097	65.1	4.06**	3.900	44.2	1.03	6.372	36.3	2.01	4.137

Table 9. **Variance analysis of total soil porosity**

Factor	1st trial						2nd trial					
	After sowing			After harvesting			After sowing			After harvesting		
	MS	$F_{act.}$	LSD_{05}	MS	$F_{act.}$	LSD_{05}	MS	$F_{act.}$	LSD_{05}	MS	$F_{act.}$	LSD_{05}
Tillage (A)	20.8	10.28**	0.590	13.5	6.88**	0.582	39.3	14.12**	0.693	4.6	1.08	0.853
Soil layer (B)	280.7	138.98**	0.723	26.6	13.54**	0.713	152.2	54.67**	0.849	34.6	8.21**	1.045
Interaction (A × B)	0.2	0.11	1.384	0.9	0.48	1.366	0.7	0.25	1.625	0.6	0.15	2.001

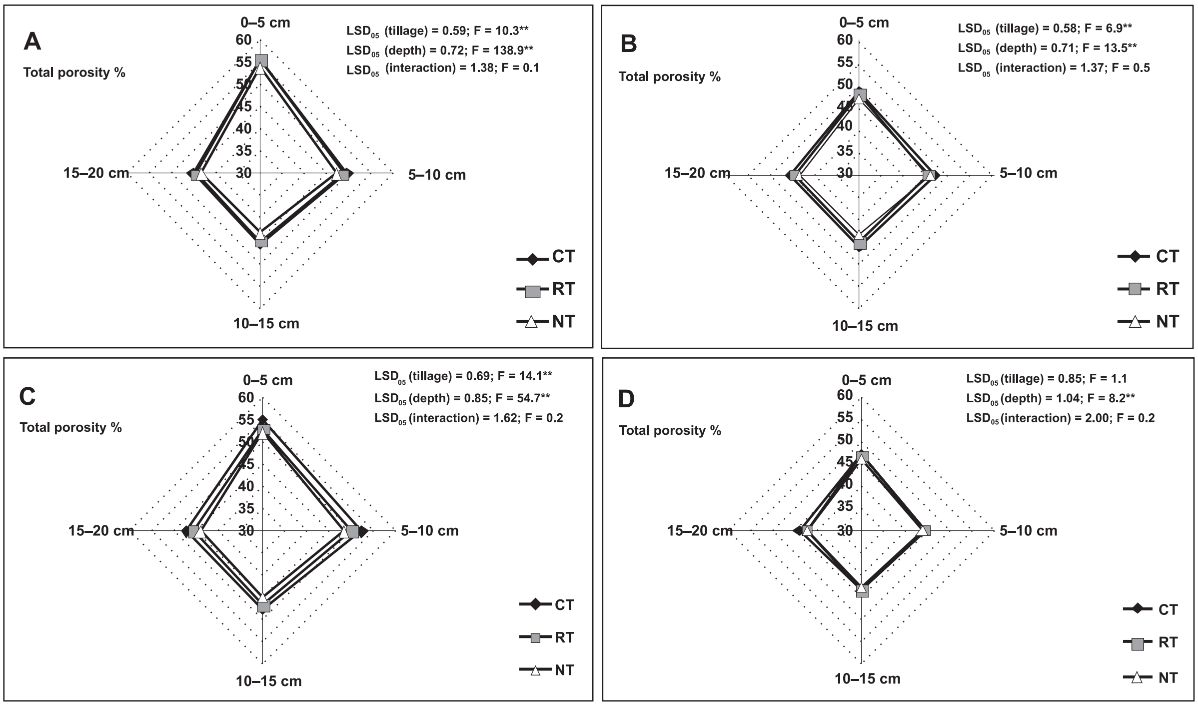

Fig. 5. Total soil porosity in field trials in 2007. A – in the 1st after sowing, B – in the 1st after harvesting, C – in the 2nd after sowing, D – in the 2nd after harvesting

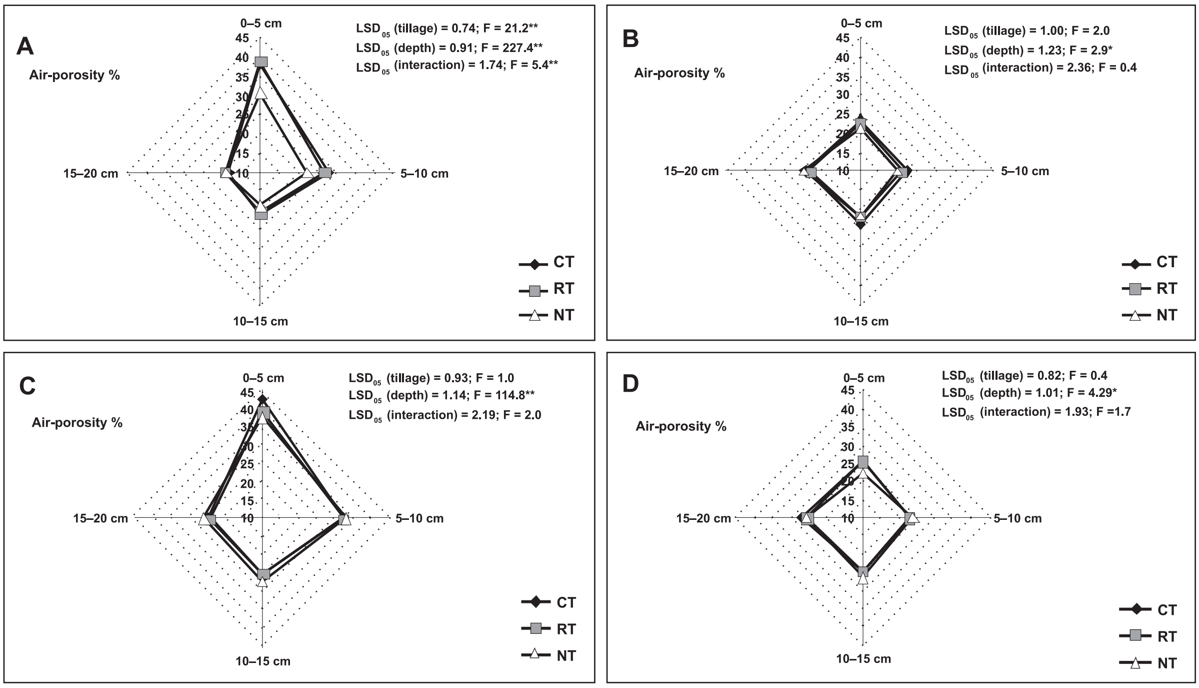

Fig. 6. Air-filled soil porosity in field trials in 2007. A – in the 1st after sowing, B – in the 1st after harvesting, C – in the 2nd after sowing, D – in the 2nd after harvesting

Air-filled soil porosity (AFP). It is suggested that if air-filled porosity is higher than 25%, the soil aeration conditions are good, if it varies between 10–25% soil aeration conditions are moderate, and if it reaches only 10% the aeration conditions are bad (Stepniewski et al., 1994).

Similar to TP, the soils in both field trials followed the best value of AFP (Fig. 6, Table 10). Differences in AFP were not high in all tillage systems, while under the NT system (in spring and autumn), both in the 0–10 cm and in the 10–20 cm soil layers, AFP was significantly lower as compared to the CT system.

It is worth noting that although the total and air-filled soil porosity was good, the soil air-permeability was not high. The reason may be that the soil pores had a poor continuity and had not been connected with each other within the soil matrix. The pores were situated like appendices with no or weak interconnection. We suggest that this phenomenon was the main reason for the low soil moisture content after crop harvesting in the 10–20 cm layer under the NT system.

Soil structure (ST). Soil aggregates 1–5 mm in diameter are the most valuable from the agronomic viewpoint (Tindžiulis,

Table 10. **Variance analysis of air-filled soil porosity**

Factor	1st trial						2nd trial					
	After sowing			After harvesting			After sowing			After harvesting		
	MS	$F_{act.}$	LSD_{05}	MS	$F_{act.}$	LSD_{05}	MS	$F_{act.}$	LSD_{05}	MS	$F_{act.}$	LSD_{05}
Tillage (A)	67.5	21.21**	0.74	11.8	2.01	1.01	5.2	1.04	0.93	1.7	0.42	0.82
Soil layer (B)	723.1	227.38**	0.91	17.1	2.93*	1.23	578.2	114.76**	1.14	16.9	4.29*	1.01
Interaction (A × B)	17.0	5.36**	1.74	2.2	0.37	2.36	10.3	2.04	2.19	6.6	1.67	1.93

1979). In the 1st trial, in the spring of 2007, the highest amount of these aggregates was under NT the 0–10 cm and 10–20 cm soil layers (45.78% and 38.45%, respectively). Under application of RT and CT, no significant differences were registered. The least amount of soil aggregates, > 10 mm and < 0.25 mm (whose presence in soil is an indicator of a poor soil structure), was observed under the NT within both 0–10 cm and 10–20 cm layers (21.13 and 23.55%, respectively). After crop harvesting, the amount of different soil aggregates did not differ among the tillage systems.

In the 2nd trial, in the spring of 2007, the highest amount of 1–5 mm soil aggregates was under the NT in the 0–10 cm and 10–20 cm soil layers (35.07% and 30.67%, respectively). In contrast to the 1st trial, in the 2nd trial the amount of these aggregates significantly reduced under the RT and NT system's, while the amount of aggregates >10 mm and <0.25 mm did not differ in the 0–10 cm soil layer. In the 10–20 cm soil layer, the least amount of soil aggregates >10 mm and <0.25 mm was under the NT system.

After crop harvesting, the amount of soil aggregates was similar under both the RT and NT systems (36.96–37.94% in the 0–10 cm layer and 36.29–36.63% in the 10–20 cm layer), while the amount of soil aggregates was the least and reached 29.64% in both 0–10 cm and 10–20 cm layers under the CT system.

These findings are in line with the other investigations stating that ploughless tillage has a positive influence on soil structure (Šimanskaitė, 2007).

Determination and comparison of soil structure coefficients in different tillage systems also supports this conclusion (Fig. 7, Table 11). In both field trials, the best soil structure coefficients were determined under NT. In addition, the soil structure coefficient in the 1st trial (clay loam) was on average by 44% higher than in the 2nd trial (sandy clay loam).

Soil texture had a strong influence on the evaluation of soil physical quality. This was the reason why soil structure in the 1st trial was evaluated by 2 points, while in the 2nd trial only by 1 point (Table 5).

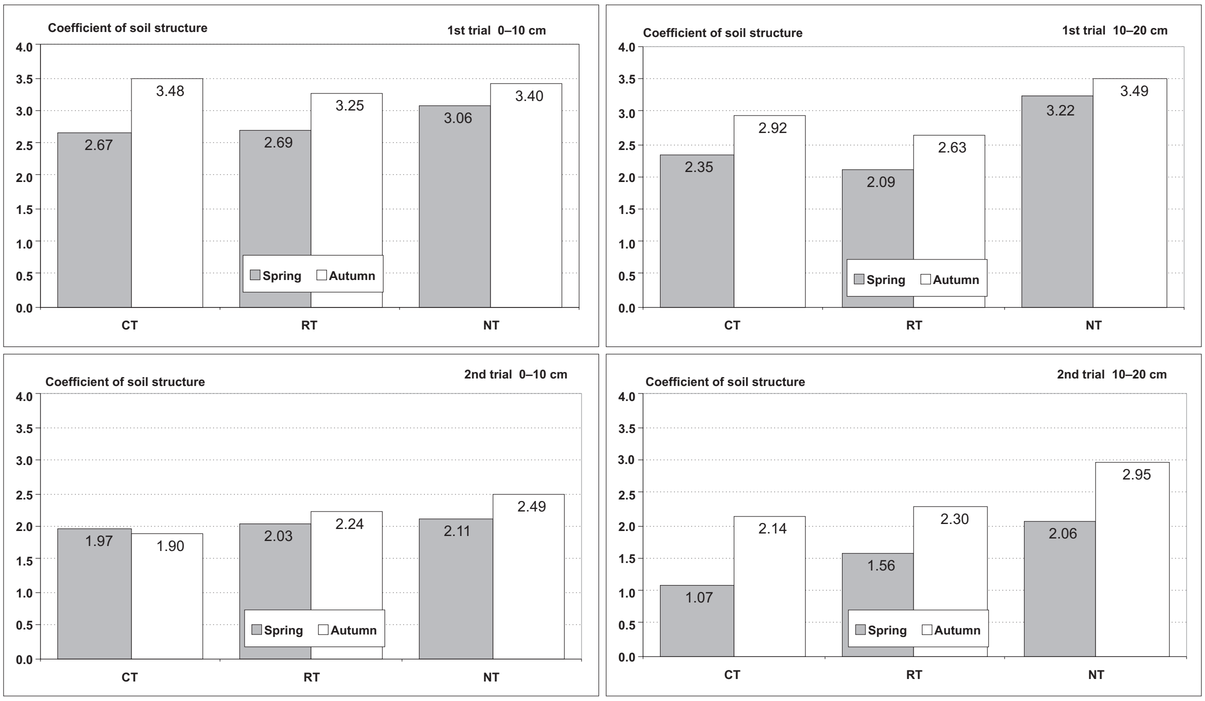

Fig. 7. Tillage influence on soil structure coefficient in the 0–10 and 10–20 cm layers

Table 11. **Variance analysis of soil structure coefficient**

Factor	1st trial						2nd trial					
	After sowing			After harvesting			After sowing			After harvesting		
	MS	$F_{act.}$	LSD_{05}	MS	$F_{act.}$	LSD_{05}	MS	$F_{act.}$	LSD_{05}	MS	$F_{act.}$	LSD_{05}
Tillage (A)	0.93	12.65**	0.146	0.24	3.37	0.144	0.11	0.98	0.181	0.11	2.63	0.110
Soil layer (B)	0.98	13.35**	0.103	0.61	8.49**	0.102	0.67	5.94*	0.128	0.09	2.07	0.078
Interaction (A × B)	0.19	2.62	0.230	0.11	1.56	0.228	0.09	0.77	0.285	0.02	0.39	0.173

GENERAL SOIL PHYSICAL QUALITY EVALUATION

Paired correlation of soil physical properties. Many soil physical properties tend to return to their initial stage over time. This is important to note while evaluating the agrophysical soil quality for crop production. In general, to reach a suitable soil physical quality is very important at the early stages of crop development.

The agrophysical parameters (properties) of soil are interrelated. By changing one of them the rest properties also change. Paired correlation between two different parameters could be expressed as a linear function.

Bulk density, total and air-filled porosity are in close relationship (Fig. 8). Data revealed that after increasing bulk density, total porosity reduced ($LSD_{05} = 0.98^{**}$). Our data confirm that on clay loam, the total porosity reduces close to 40%, if the bulk density increases by more than 1.50 Mg m^{-3}. This is a critical level for successful crop growing.

A moderately strong correlation was determined between bulk density and air-filled porosity ($LSD_{05} = 0.63^{*}$).

The correlation between total porosity and air-filled porosity was also moderately strong ($LSD_{05} = 0.61^{*}$). In our field trials, the total and air-filled porosity were suitable for crop growing. But, if total soil porosity would reduce below 40%, the air-filled porosity would become close to critical also.

A moderately strong correlation was determined between bulk density and penetration resistance ($LSD_{05} = 0.66^{*}$). Exponential regression revealed that if bulk density did not exceed 1.41 Mg m^{-3} and penetration resistance did not exceed 1 MPa, the soil physical conditions still remained suitable for crop growing. However, when bulk density increased to 1.46 Mg m^{-3} and penetration resistance exceeded 2 MPa, the soil physical conditions for crop growing soon deteriorated. Thus, crop growing conditions after sowing in both our field trials could be outlined as suitable under CT and RT application, while under NT only as moderately suitable. After crop harvesting these parameters reached the critical level, but the crop by this time had grown up and soil physical properties did not influence crop yielding.

Agrophysical quality of soil. The sum of indexes of different soil physical properties revealed the influence of long-term application of contrasting tillage systems on the total agro physical soil quality (Fig. 9).

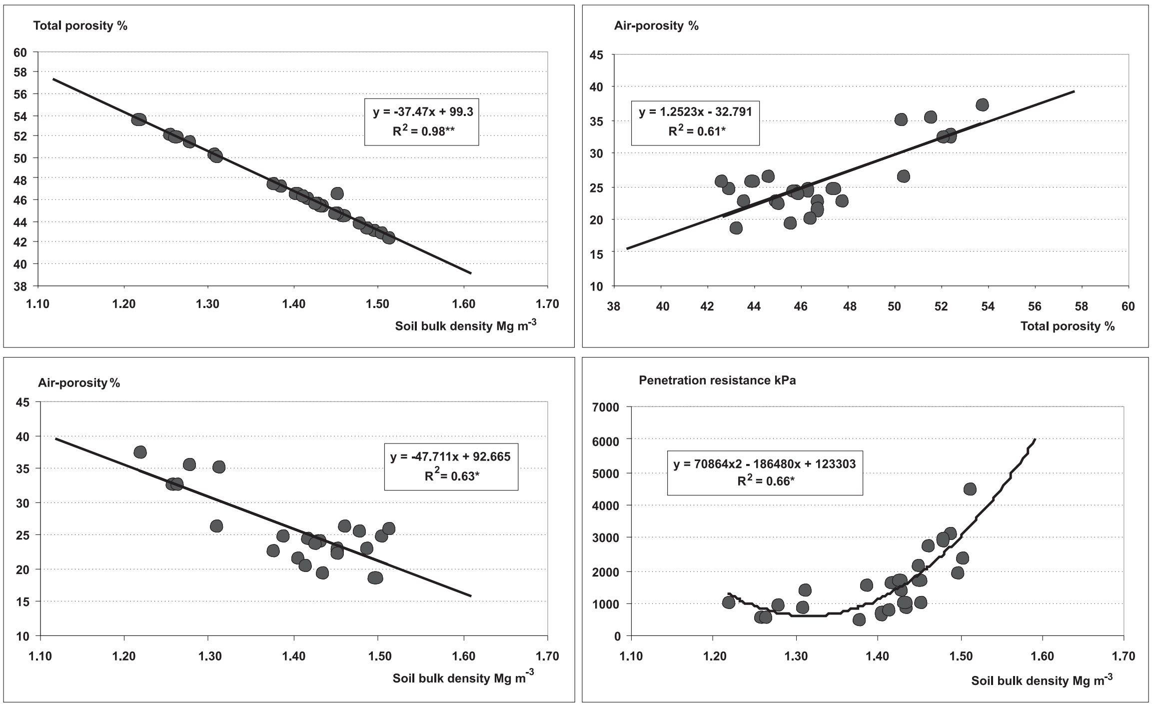

Fig. 8. Correlation between total soil porosity and bulk density, air-filled porosity and bulk density, air-filled porosity and total porosity, and also between bulk density and penetration resistance (mean data for the 1st and the 2nd trials)

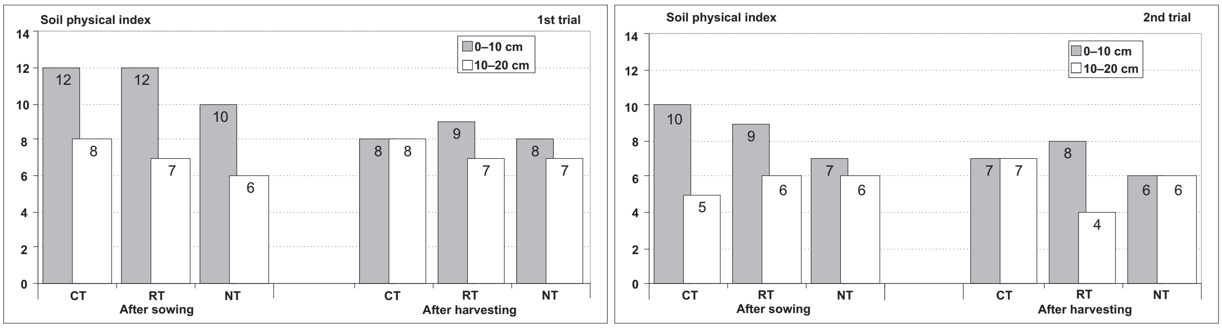

Fig. 9. The $SQI_{physical}$ under different soil tillage systems, 2007

The highest possible agro-physical soil quality index (SQI$_{physical}$) in the field trials equalled 14. The SQI$_{physical}$ of the 1st trial in the 0–20 cm layer was evaluated by 10, while the SQI$_{physical}$ of the 2nd trial of the same layer only by 7. This means that in general soil quality in the ploughed layer is not very high and should be improved.

The SQI$_{physical}$ after crop sowing in the 1st trial revealed that in the 0–10 cm layer the application of the NT system conditioned a lower soil physical quality (Index 10) compared to the CT and RT (the average index 12). The SQI$_{physical}$ in the 0–10 cm layer after crop sowing in the 2nd trial was also lower under NT (Index 7) compared to the CT (Index 10) and RT (Index 9). In the 10–20 cm layer of the 1st trial, the SQI$_{physical}$ was higher under CT (Index 8) compared to the RT (Index 7) and NT (Index 6). In the 2nd trial, the SQI$_{physical}$ in the 10–20 cm layer was similar under different tillage systems and varied from 5 to 6.

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

Thus, in both field trials over the 9 years of applying different tillage systems, the best SQI$_{physical}$ in the 0–20 cm layer was reached by employing the CT system.

CONCLUSIONS

1. The optimal bulk density in the ploughed soil layer was ensured by applying the conventional tillage system. The appropriate bulk density under direct drilling was determined in the 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 as compared to conventional and reduced tillage systems. After harvesting, changes in penetration resistance were the least by under the conventional tillage system.

3. The best air-permeability was registered under the application of the conventional tillage system. Reduced tillage and direct drilling application did not ensure a proper soil air-permeability at the final stage of crop growing.

4. Under global warming conditions, the application of the direct drilling system could be the right measure to preserve soil moisture at the early stages of crop development.

5. Under direct drilling (in spring and autumn), in both 0–10 cm and 10–20 cm soil layers, the total and air-filled porosity were significantly lower as compared to conventional tillage.

6. Ploughless tillage has a positive influence on soil structure. The best soil structure coefficients were determined under direct drilling.

7. Over the 9 years of applying different tillage systems, the best agro-physical soil quality index (SQI$_{physical}$) in the 0–20 cm soil layer was determined by employing the conventional tillage system.

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GLĖJIŠKO RUDŽEMIO (*ENDOCALCARI-EPIHYPOGLEYIC CAMBISOL*) ARMENS AGROFIZIKINIŲ SAVYBIŲ POKYČIAI TAIKANT ILGAMETES ŽEMDIRBYSTĖS SISTEMAS

Santrauka

Straipsnio tikslas – giliau karbonatinio sekliai glėjiško rudžemio (*Endocalcari-Epihypogleyic Cambisol*) armens (vidutinio sunkumo priemolis (p_1/L) ant p_1/L bei smėlingas lengvas priemolis (sp/SL) ant sp/SL) agrofizikinių savybių skirtumų ir kitimo pobūdžio nustatymas skirtingo intensyvumo žemdirbystės sistemose; dirvožemio agrofizikinės kokybės įvertinimas pagal Amacher, O'Neill ir Perry schemą. Nustatyta, kad optimalų dirvožemio tankį armenyje laidavo tradicinė žemės dirbimo sistema. Taikant tiesioginę sėją patenkinamas tankis buvo tik 0–10 cm dirvožemio sluoksnyje, o 10–20 cm sluoksnyje jis buvo didelis ir artimas augalų šaknų augimo kritinei ribai. Dirvožemio kietumas 0–10 cm dirvožemio sluoksnyje po javų sėjos buvo panašus ir tradiciškai, ir supaprastintai dirbant žemę, tačiau taikant tiesioginę sėją, jis buvo 49–54% didesnis, palyginus su tradicinio ir supaprastinto žemės dirbimo sistemomis. Dirvožemio kietumas po derliaus nuėmimo mažiausiai pakito tradiciškai dirbtoje dirvoje. Geriausias oro laidumas taip pat nustatytas tradiciškai dirbant žemę. Supaprastinta žemės dirbimo sistema bei tiesioginė sėja negarantavo tinkamo dirvožemio oro laidumo augalų vegetacijos pabaigoje. Globalinio klimato atšilimo akivaizdoje tiesioginė augalų sėja į nedirbtą dirvą būtų priimtina, siekiant tausoti dirvožemio drėgmę pavasarį ankstyvuose augalų augimo tarpsniuose.

Bendrasis ir aeracinis dirvožemio poringumai abiejuose, 0–10 ir 10–20 cm, dirvožemio sluoksniuose rudenį bei pavasarį taikant tiesioginę sėją buvo nustatytas mažesnis, palyginus su tradicine žemės dirbimo sistema. Geriausias dirvožemio struktūringumo koeficientas nustatytas laukeliuose, kuriuose aštuonerius metus iš eilės taikyta tiesioginė sėja. Aštuntaisiais skirtingų žemės dirbimo sistemų naudojimo metais geriausias dirvožemio agrofizikinės kokybės indeksas nustatytas dirbant žemę tradiciškai.

Raktažodžiai: agrofizikinės dirvožemio savybės, žemės dirbimas, dirvožemio agrofizikinės kokybės indeksas