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Endocalcari-Epihypogleyic Cambisol plough layer quality in long-term soil management systems

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The goal of the research was to investigate soil plough layer quality status and changes on *Endocalcari-Epihypogleyic Cambisol* in the Middle Lowland of Lithuania by applying different long-term soil management systems.

The results revealed that the tillage method, the intensity and level of fertilisation on *Endocalcari-Epihypogleyic Cambisol* must be determined according to soil texture and the degree of a possible influence of these contributors on soil quality changes. The duration of a tillage system practical application (reduced tillage or direct drilling) should be motivated by soil physical and chemical properties. Soil tillage-fertilisation systems should be replaced by another one, if the soil quality index value has reduced.

At the 8th year of field trials, the total SQI value did not differ essentially in conventional tillage (CT), reduced tillage (RT) and direct drilling (NT) in loam soil (soil rich in macronutrients (PK) and moderately rich in humus), while in sandy loam soil (soil moderately rich in macronutrients (PK) and poor in humus) in the direct drilling system the SQI value was significantly lower compared to CT and RT.

After 8 years since the different soil management systems have been used, the best $SQI_{chemical}$ for the 0–20 cm soil layer in the 1st (loam, rich in macronutrients (PK) and moderately rich in humus) field trial was determined when the following management systems were implemented: reduced tillage + not fertilised; reduced tillage + moderate rates: NPK fertilisers according to soil properties and expected yield; direct drilling + moderate rates. $SQI_{chemical}$ for the 0–20 cm soil layer in the 2nd (sandy loam, moderately rich in macronutrients (PK) and poor in humus) field trial was registered to be similar whatever the tillage system and their combination with either moderate or high rates of NPK fertilisers applied.

Over the 8 years of applying different tillage systems, the best $SQI_{physical}$ in the 0–20 cm soil layer was determined by managing the conventional tillage system.

Key words: multifunctional properties, tillage, fertilisation, soil quality indexing

INTRODUCTION

The effects of tillage and the cropping system on soil chemical and physical characteristics have been documented in many long-term studies. The frequent use of the mouldboard plough was found to cause a decline in soil organic C, decrease in soil structure and aggregation, reduction in water infiltration rates. After ploughing, soil bulk density, total porosity and microporosity decreased, while macroporosity increased as compared with no-till management (Cesevičius et al., 2005; Kettler et al., 2000; Stancevičius et al., 2003; Šimanskaitė, 2007).

Soil quality is not a new topic. Early scientific endeavours recognized the importance of categorizing soil type and soil variables or properties in regard to land or soil use, especially for agricultural purposes (Buivydaitė et al., 2001; Carter et al., 1997; Juodis et al., 2001; Kinyangi, 2007). The concept of soil health and soil quality has consistently evolved with an increase in the understanding of soils and soil quality attributes. Soil quality cannot be measured directly, but soil properties that are sensitive to changes in management can be used as indicators (Andrews et al., 2004; Letey et al., 2003; Wienhold et al., 2004). To achieve high crop yields, smallholder farmers have to provide soil nutrients in large quantities. Results of chemical tests are soil quality indicators which provide information on the capacity of soil to supply mineral nutrients. Soil physical properties are estimated from the texture, bulk density, porosity, water-holding capacity of soil. The presence or absence of hard pans usually presents barriers to rooting depth. These properties are all improved through addition of organic matter to soils. Therefore, the suitability of soil for sustaining plant growth is a function of its physical properties – porosity, water holding capacity, structure and tilth (Hillel, 1998).

Evaluation of agricultural soil quality is difficult. Agricultural soils are not only important for supporting crop production now and in the future, but also for maintaining clean water and air, reducing greenhouse gas emissions, preserving natural biodiversity and ensuring food quality. Indicators communicate a correct and relevant information quickly and easily to people who are not necessarily experts in the field. Indicators might be based on many measurements related to the information needed. Indicators of soil quality were initially developed to provide information on the suitability and relative value of land for different types of agricultural production. More recently, indicators have been developed to provide information on the impacts of agricultural practices on land and environmental degradation. Indicators have also been developed to provide an integrated assessment of soil conditions in programmes that monitor a wide range of soil properties. Unfortunately, no single indicator of soil quality is suitable for all purposes and contexts. One purpose for a soil quality indicator is communicating information on potential impacts of a change in land management on the outcomes of soil functions. A soil quality indicator based on detailed information of soil properties could also be developed, but it would need to be based on clear objectives for soil functions and a sufficient understanding of the linkages between measured soil properties and soil functions (Brejda et al., 2000; Bremer, Ellert, 2004; Carter et al., 1997).

There is an important need to distinguish between soil and land quality. Land comprises all elements of the physical environment, including climate, relief, soil, hydrology and vegetation, as well as includes the results of past and present human activity. Soil is one compartment of the physical environment (land) and receives the influence of its other elements. In this respect, soil is examined as a subset of land, and its characteristics are determined by other land forming factors. Meanwhile soil is also regulating environmental processes, thus influencing other elements of the physical environment. The present approach follows the perception of classical soil science and considers soil as a medium that integrates, transforms, stores and filters material (and energy) relevant to its environmental and management conditions in the spatial context. Soil, on the other hand, is a medium that is challenged by changing environmental and management conditions, therefore variable in time as well (Toth et al., 2007).

The increasing attention paid to local soil knowledge results from a greater recognition that farmer knowledge can offer many insights into the sustainable management of soils and that the integration of local and technical knowledge systems helps advisers and scientists work more closely with farmers. A participatory approach and a methodological guide were developed to identify and classify local indicators of soil quality and relate them to technical soil parameters, and thus develop a common language among scientists, farmers and advisers (Barrios et al., 2006).

Traditional soil survey, classification and interpretation activities have defined land capability classes, a Storie index and other land inventory and monitoring indices based primarily on inherent soil properties. Each of them is important and useful for certain applications, but none is the same as indexing dynamic soil quality. The inherent differences among soils, the complexity of environments within which soils exist, and the variety of soil and crop management practices used around the world currently preclude establishing a specific rating or value against which all soils can be compared. What can be developed is a framework or indexing procedure that can be easily modified for different soils and used to enumerate dynamic soil quality ratings, determine trends in those ratings, and thus used to quantify long-term effects of alternate land uses or soil management decisions (Karlen et al., 2001, 1997, 2003).

Soil qualitative evaluation in Lithuania has a long history (Ozolinčius, 2005). The New Classification of Soils of Lithuania (as the main natural resource of the country) is officially used since 1999 (Mažvila et al., 2006). The newest scales and coefficients were developed in 1990. There were established influences of numerous indices (soil pH, P, K, erosion and deflation, organic mater content, climate conditions) on soil quality (fertility). However, this evaluation did not propose methodical measures concerning soil quality changes under different soil management.

The goal of the research was to investigate plough layer quality status and changes on *Endocalcari-Epihypogleyic Cambisol (RDg8-k2)* in the Middle Lowland of Lithuania by applying long-term different soil management systems.

The targets of the research are: 1) determination of the status of selected soil agrochemical and agro-physical properties and changes under a long-term application of different intensity soil management systems; 2) the evaluation-indexing of soil properties according to Amacher, O'Neill and Perry's scheme (Amacher et al., 2007, 2003); 3) determination of soil quality influence on spring oil-seed rape yield and its quality.

MATERIALS AND METHODS

Indexing. Details of the soil indexing methodology are presented elsewhere (Amacher et al., 2007, 2003; O'Neill et al., 2005, 2005a). This paper focuses solely on the development of the soil quality index (SQI) from the measured soil properties of the *Endocalcari-Epihypogleyic Cambisol*. Mineral soil properties, their threshold levels, interpretations, and associated soil index values are listed in Table 1. The individual index values for all mineral soil properties measured in field trials are summed up to give a total SQI:

Total SQI = Σ individual soil property index values.

We investigated 14 selected soil properties, so the maximum value of the total SQI was 27. In addition, missing properties do not contribute to the index.

Field trial conditions. The experiment was carried out at the Lithuanian Institute of Agriculture on *Endocalcari-Epihypogleyic Cambisol* during 1999–2007. Two field trials were set up on soils with a different texture and fertility. The first of them was established on soil rich in macronutrients (320 mg kg^{-1} P_2O_5 and 261 mg kg^{-1} K_2O) and moderately rich (2.10%) in humus (1st trial) and the second on moderately rich in macronutrients (108 mg kg^{-1} P_2O_5 and 158 mg kg^{-1} K_2O) and poor (1.60%) in humus (2nd trial) soil (Feizienė et al., 2008). Soil texture of the trials is presented in Table 2. According to FAO classification system, the soil in the 1st trial was loam on loam and in the 2nd trial sandy loam on sandy loam.

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

Table 1. **Classification of soil agrophysical and agrochemical parameters and indexing according to scheme of Amacher, O'Neill and Perry**

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	Acceptable, 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	Acceptable, 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	Acceptable, 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	Acceptable 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	Acceptable 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	Acceptable for plant root growing	1
	>1.5	Optimal for plant root growing	2
Available P_2O_5 mg kg^{-1}	<50	Very low content of phosphorus	0
	50–100	Low content of phosphorus	1
	100–150	Moderate content of phosphorus	1
	150–200	Acceptable content of phosphorus, adequate for plant growing	1
	>200	High content of phosphorus	2
Available K_2O mg kg^{-1}	<50	Very low content of potassium	0
	50–100	Low content of potassium	1
	100–150	Moderate content of potassium	1
	150–200	Acceptable content of potassium, adequate for plant growing	1
	>200	High content of potassium	2
Soil pH_{KCl}	<3.5	Extremely acid soils	0
	3.6–4.5	Very acid soils	1
	4.6–5.0	Moderately acid soils	1
	5.1–5.5	Low acidity soils	1
	5.6–6.0	Very low acidity soil, optimal for most plants growing	2
	6.1–6.5	Close to neutral acidity, optimal for most plants growing	2
	6.6–6.9	Very close to neutral acidity, optimal for most plants growing	2
	7.0–8.5	Neutral and close to alkaline soils	1
	>8.5	Alkaline soil	0
Humus % (in mineral soils or organic carbon; C = Humus:1.74)	<1.0	Very low content of humus; denoted for degraded soils	–1
	1.1–2.0	Low content of humus, low N source for plant growing	0
	2.1–3.0	Moderate content of humus, moderate N source for plant growing	1
	3.1–4.0	Optimal content of humus, sufficient N source for plant growing	1
	>4.0	High content of humus, sufficient N source for plant growing	2
Total C %	<0.5	Very low content of C; denoted for degraded soils	0
	0.5–1.0	Low content of C, poor source for plant growing	1
	>1.0	Optimal content of C, sufficient source for plant growing	2
Total N % (in mineral soils)	<0.1	Very low content of N; denoted for poor soils	0
	0.1–0.5	Low content of N, low source for plant growing	1
	>0.5	Optimal content of N, sufficient source for plant growing	2
Total S mg kg^{-1}	<100	Low content of S; critical content for plant growing	0
	100–200	Optimal content of S for plant growing	1
	>200	Critically noxious content of S for plant growing	0

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	

Tillage, sowing and fertilisation. The last crop in the crop rotation was spring oil-seed rape following winter wheat – sugar beet – spring wheat – spring barley – peas – winter wheat. The deep and shallow mouldboard plough treatments (CT and RT) were conducted during the autumn soon after harvest each season. Deep ploughing disrupted the soil down to a depth of approximately 22–25 cm, while shallow ploughing down to 14–16 cm. Deep and shallow ploughing resulted in a complete inversion of soil surface and a nearly 100% incorporation of crop residues (stubble, small leaves) by using a 4-body reversible plough. No-tillage treatments received herbicide glyphosate application (4 l ha^{-1}) in autumn soon after weeds and volunteer plants had appeared. In this research, the NT system is defined as having neither autumn nor presowing individual-mechanical tillage operations for soil manipulation.

Presowing tillage for conventional and reduced tillage treatments received one-pass shallow cultivation.

Moderate and high rates of mineral PK fertilisers were top-dressed and slightly incorporated in the topsoil by presowing shallow cultivation as a seed-bed preparation in CT and RT systems. Under direct drilling the PK fertilisers were also broadcast before sowing, but not incorporated into soil. Moderate and high rates of mineral N fertiliser (ammonium nitrate) in all three tillage systems investigated were broadcast twice as a split-application, i. e. at an early- and medium-stage of spring oil-seed rape development. The rates of mineral NPK fertilisers were calculated according to the PC programme "*Tręšimas*" ("Fertilisation") (Švedas, Tarakanovas, 2000). During crop rotation, different rates of fertilisers were incorporated (Table 4).

Spring oil-seed rape in CT and RT systems was sown with a common light disc seed drill, while direct drilling under NT was performed employing a heavy duty pre-seed shallow disc tillage drilling machine.

Table 4. **Rates of mineral NPK fertilisers kg ha^{-1}**

Rate	Nutrients	Crop rotation							Total amount of nutrients per rotation
		Winter wheat (*Triticum aestivum* L.)	Sugar beet (*Beta vulgaris,* L.)	Spring wheat (*Triticum aestivum* L.)	Spring barley (*Hordeum vulgaris* L.)	Peas (*Pisum sativum* L.)	Winter wheat (*Triticum aestivum* L.)	Spring oil-seed rape (*Brasica napa* L.)	
1st trial (loam)									
Moderate	N	109	114	32	30	0	160	83	528
	P_2O_5	0	0	0	0	0	20	0	20
	K_2O	0	101	9	30	29	50	47	266
High	N	190	205	114	120	30	205	163	1027
	P_2O_5	0	0	0	0	0	30	0	30
	K_2O	0	136	24	44	56	74	63	397
2nd trial (sandy loam)									
Moderate	N	104	150	90	91	0	187	148	770
	P_2O_5	93	30	36	7	69	149	7	391
	K_2O	47	137	54	25	52	96	56	467
High	N	192	227	160	159	30	283	213	1264
	P_2O_5	183	75	40	14	221	268	11	812
	K_2O	65	166	60	41	90	170	72	664

Methods of analysis. Soil bulk density (Mg m^{-3}) was determined according to A. Kachinski method (Нерпин, Чудновский, 1967); penetration resistance (MPa) – with a mobile hand-held "Eijkelkamp" penetrometer; air-permeability (l min^{-1}) – with A. Andersson's apparatus (Green, Fordham, 1975); total porosity (%) and air-filled porosity (%) were calculated (Hao et al., 2008); soil texture was determined by the pipette method according to FAO, soil aggregate stability by the S. Savinov method (Нерпин, Чудновский, 1967), the soil structure coefficient (SSC) according to the formula (Нерпин, Чудновский, 1967):

SSC = A÷B,

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

available P_2O_5 and K_2O mg kg^{-1} – by the A–L method (Egner et al., 1960), humus (organic C = humus / 1.724) – by the Tyurin titrimetric (classical) method (Александрова, Найденова, 1986), total C – by VARIO EL III, total N – by VARIO EL III, total S – by VARIO EL III, pH – with a potentiometer.

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

RESULTS AND DISCUSSION

Soil agrochemical quality index ($SQI_{chemical}$). Reduced intensity of tillage or direct drilling (no-tillage) used for successive 8 years influenced available P, K, pH, humus and total C stratification and soil agrochemical quality (Feizienė et al., 2008, 2006, 2007). The $SQI_{chemical}$ reached 7.5–9.3 (out of 14 possible agrochemical points) on soil rich in macronutrients (PK) and containing moderate levels of humus in the 1st field trial, while on soil moderately rich in macronutrients and containing low levels of humus in the 2nd field trial the $SQI_{chemical}$ reached only 5.3–5.5 (Table 5).

Reduced (RT) and direct drilling (NT) implementation resulted in a higher agrochemical soil quality index (on average 9.9) as compared to traditional tillage (on average 7.7) in the 0–10 cm soil layer of the first field trial. In the second field trial, the $SQI_{chemical}$ did not depend on the intensity of tillage systems and reached 5.7–6.0. Soil quality at the depth of 10–20 cm in the 1st field trial was higher in RT (9) than in CT or NT (7.3 and 8.0, respectively), while in the 2nd field trial the $SQI_{chemical}$ of the same soil layer was very similar under different tillage systems and reached 5.0. After 8 years when the different soil management systems had been used, the best $SQI_{chemical}$ for the 0–20 cm soil layer in the 1st field trial was determined when the following

Table 5. ***Endocalcari-Epihypogleyic Cambisol*** **quality index determination according to data of actual plough layer agrochemical properties after spring oil-seed rape harvesting**

Soil management systems	Soil depth (cm)	Available P_2O_5		Available K_2O			Humus	Total C		Total N		Total S		pH_{KCl}	
		Trials													
		I	II	I	II	I	II	I	II	I	II	I	II	I	II
CT-1	0–10	2	1	1	1	0	0	1	0	0	0	1	1	2	2
	10–20	2	1	1	1	0	0	1	0	0	0	1	1	2	2
CT-2	0–10	2	2	1	2	0	0	1	0	1	0	1	1	2	2
	10–20	2	1	2	1	0	0	1	0	1	0	1	0	2	2
CT-3	0–10	1	2	2	1	0	0	1	0	1	0	1	0	2	2
	10–20	1	2	1	1	0	0	1	0	0	0	1	1	2	2
RT-1	0–10	2	1	2	1	1	0	1	0	1	0	1	0	2	2
	10–20	2	1	1	1	1	0	1	0	1	0	1	1	2	2
RT-2	0–10	2	2	1	1	1	0	1	0	1	0	1	1	2	2
	10–20	2	1	1	1	1	0	1	0	1	0	1	1	2	2
RT-3	0–10	2	2	2	2	1	0	1	0	1	0	1	1	2	2
	10–20	2	1	1	1	1	0	1	0	1	0	1	1	2	2
NT-1	0–10	2	1	2	1	1	0	1	0	1	0	1	1	2	2
	10–20	2	1	1	1	0	0	1	0	0	0	1	1	2	2
NT-2	0–10	2	2	2	2	1	0	1	0	1	0	1	1	2	2
	10–20	2	1	1	1	0	0	1	0	1	0	1	1	2	2
NT-3	0–10	2	2	2	2	1	0	1	0	1	0	1	1	2	1
	10–20	2	1	1	1	1	0	1	0	1	0	1	1	2	2
CT Σ	0–10	1st field trial (loam)				**7.7**				2nd field trial (sandy loam)			**5.7**		
	10–20					**7.3**							**5.0**		
	0–20					**7.5**							**5.3**		
RT Σ	0–10					**9.7**							**5.7**		
	10–20					**9.0**							**5.0**		
	0–20					**9.3**							**5.3**		
NT Σ	0–10					**10.0**							**6.0**		
	10–20					**8.0**							**5.0**		
	0–20					**9.0**							**5.5**		

management systems were implemented: reduced tillage + not fertilised; reduced tillage + moderate rates: NPK fertilisers according to soil properties and expected yield; direct drilling + moderate rates. $SQI_{chemical}$ for the 0–20 cm soil layer in the 2nd field trial was similar in all tillage systems applied and their combination with either moderate or high rates of NPK fertilisers applied (Feizienė et al., 2008). Consequently, fertilisation rates must be calculated not only according to expected yields, but also with regard to the integrity of soil chemical properties and environmental health.

Soil agro-physical quality index ($SQI_{physical}$). Optimal bulk density in the plough 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, soil 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 as 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 application did not ensure a suitable soil air-permeability at the final stage of crop growing. Under global warming conditions, the application of the direct drilling system could be a right measure to preserve soil moisture at the early stage of crop development (Feizienė et al., 2006, 2007).

Under direct drilling (in spring and autumn), in both 0–10 cm and 10–20 cm soil layers the total and air-filled porosity was significantly lower compared to the conventional tillage. Ploughless tillage had a positive influence on soil structure. The best soil structure coefficients were determined under direct drilling. Over the 8 years of applying different tillage systems, the best $SQI_{physical}$ in the 0–20 cm soil layer was determined under the conventional tillage system (Table 6) (Feiza et al., 2008).

So, in loam and sandy loam *Endocalcari-Epihypogleyic Cambisol*, the management methods and intensity must be determined according to the initial soil physical status (primarily soil texture), the degree of a possible influence of these methods and the intensity on soil quality changes. Application of RT and NT must be based on soil observation and an objective evaluation of toward changes.

Soil Quality Index (SQI) variation. The maximum value of the total SQI was 27 according to the indexing scheme. In spring, in the 1st trial (loam), the SQI ranged from 19 to 21 in the 0–10 cm layer and from 12 to 15 in the 10–20 cm layer (Fig. 1). It reduced in both 0–10 and 10–20 cm layers during spring oil-seed rape vegetation by 19% and 14% in the CT, by 15% and 9% in the RT, by 9% and 19% in the NT system. Hence, in the 0–10 cm layer in all tillage systems SQI changes were comparable, while in the 10–20 cm layer the decrease of SQI in NT was significantly higher than in CT and RT.

In the 2nd trial (sandy loam), the SQI ranged from 12 to 16 in the 0–10 cm layer and from 13 to 16 in the 10–20 cm layer. SQI variation during vegetation in both soil layers was cardinally inverse compared to SQI variation in the 1st trial. This index

Table 6. ***Endocalcari-Epihypogleyic Cambisol* quality index determination according to data of actual plough layer agrophysical properties after spring oil-seed rape sowing and harvesting**

Soil properties		1st trial (loam)						2nd trial (sandy loam)					
		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
Σ	0–10	**12**	**8**	**12**	**9**	**10**	**8**	**10**	**7**	**9**	**8**	**7**	**6**
	10–20	**8**	**8**	**7**	**7**	**6**	**7**	**5**	**7**	**6**	**4**	**6**	**6**
	0–20	**20**	**16**	**19**	**16**	**16**	**15**	**15**	**14**	**15**	**12**	**13**	**12**

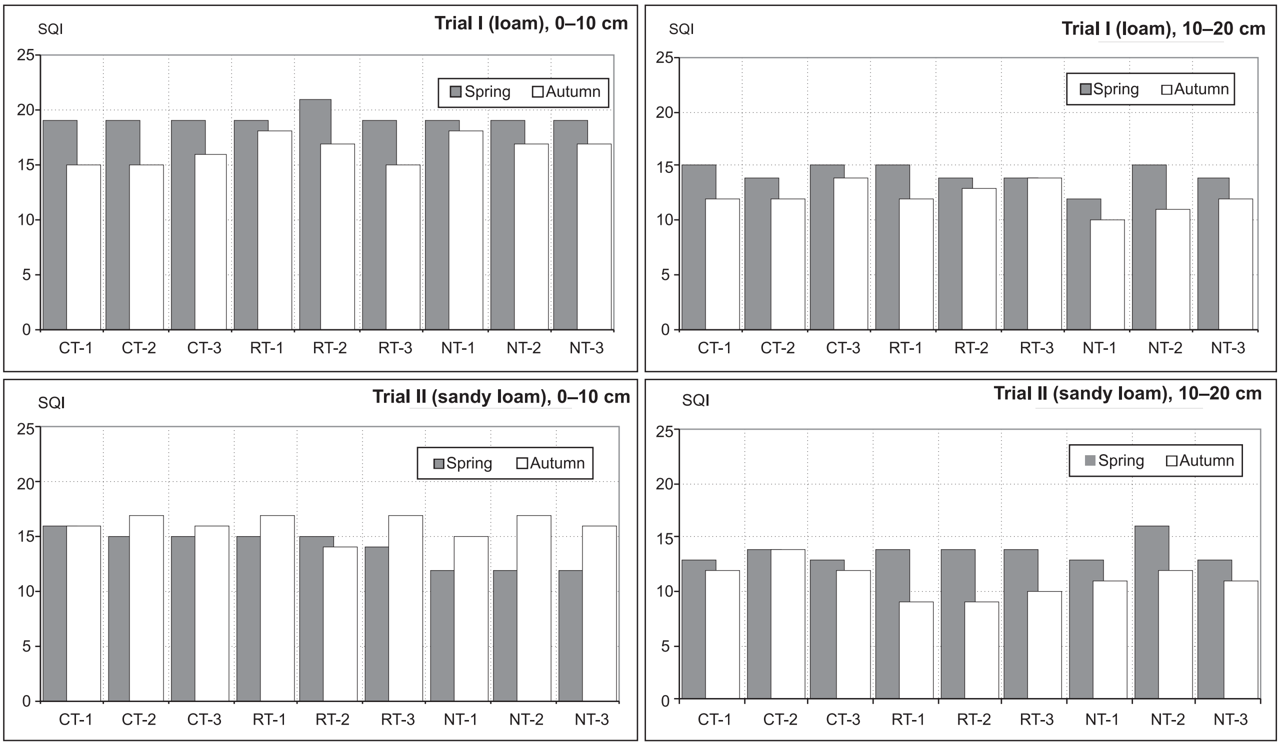

Fig. 1. SQI variation in different plough soil layers in loam and sandy loam *Endocalcari-Epihypogleyic Cambisol* in the 8th year under different tillage-fertilisation systems

in the 0–10 cm layer increased by 7%, 9% and 33% in the CT, RT and NT systems, respectively. In the 10–20 cm layer, reduction by 5%, 33% and 19%, respectively, was registered. These changes were obvious.

The above-mentioned changes of the SQI, like changes of individual soil properties, indicate a possibility of stratification of the integrated SQI (Table 7). Our data revealed that without primary deep tillage and applying reduced tillage or direct drilling alone increased soil quality in the 0–10 cm layer because of the decreased quality of the 10–20 cm layer, even in the fertile lands (1st trial).

In the 2nd trial, the ratio SQI 0–10 cm / SQI I 10–20 cm in the RT and NT systems increased by 64% and 65%, respectively. This demonstrated positive changes in the 0–10 cm soil layer because of a decreased soil quality in the 10–20 cm layer.

Influence of soil quality on spring oil-seed rape quality. Soil quality influenced the chemical composition and quality of spring oil-seed rape (Fig. 2). By increasing the SQI value, the qualitative parameters of the production also increase according to the relationship $y = ax^2 + bx + c$; $n = 18$.

The correlation between individual indices of spring oil-seed rape quality and the SQI was strong. The N content had a tendency to increase when the SQI increased up to value of 19. When the SQI was > 19, the curve started to decline ($R_{05} = 0.43$). The increasing SQI value had a tendency to increase P content ($R_{05} = 0.56$*) and significantly raised the K content ($R_{05} = 0.42$) and oil output ($R_{05} = 0.75$*).

Soil quality influence on spring oil-seed rape yield. Spring oil-seed rape yield in both 1st and 2nd trials ranged from 1.14 to 2.96 t ha^{-1} (in the 1st trial 1.48–2.96, in the 2nd trial 1.14–1.80 t ha^{-1}). Seed yield increased coherently and significantly when the SQI value also rose up (R_{05}= 0.52*) (Fig. 3). In the 1st trial, the best seed yield was obtained in the NT system with the application of high rates of fertilisers (NT-3) while

Table 7. **The SQI in the 0–10 cm layer / SQI ratio in the 10–20 cm layer**

	SQI 0–10 cm / SQI 10–20 cm								
	CT-1	CT-2	CT-3	RT-1	RT-2	RT-3	NT-1	NT-2	NT-3
1st trial (loam)									
Spring	1.27	1.36	1.27	1.27	1.50	1.36	1.58	1.27	1.36
Autumn	1.25	1.25	1.14	1.50	1.31	1.07	1.80	1.55	1.42
Change of ratio, %	–1	–8	–10	18	–13	–21	14	22	4
Mean		–6			–5			13	
2nd trial (sandy loam)									
Spring	1.23	1.07	1.15	1.07	1.07	1.00	0.92	0.75	0.92
Autumn	1.33	1.21	1.33	1.89	1.56	1.70	1.36	1.42	1.45
Change of ratio, %	8	13	16	76	45	70	48	89	58
Mean		12			64			65	

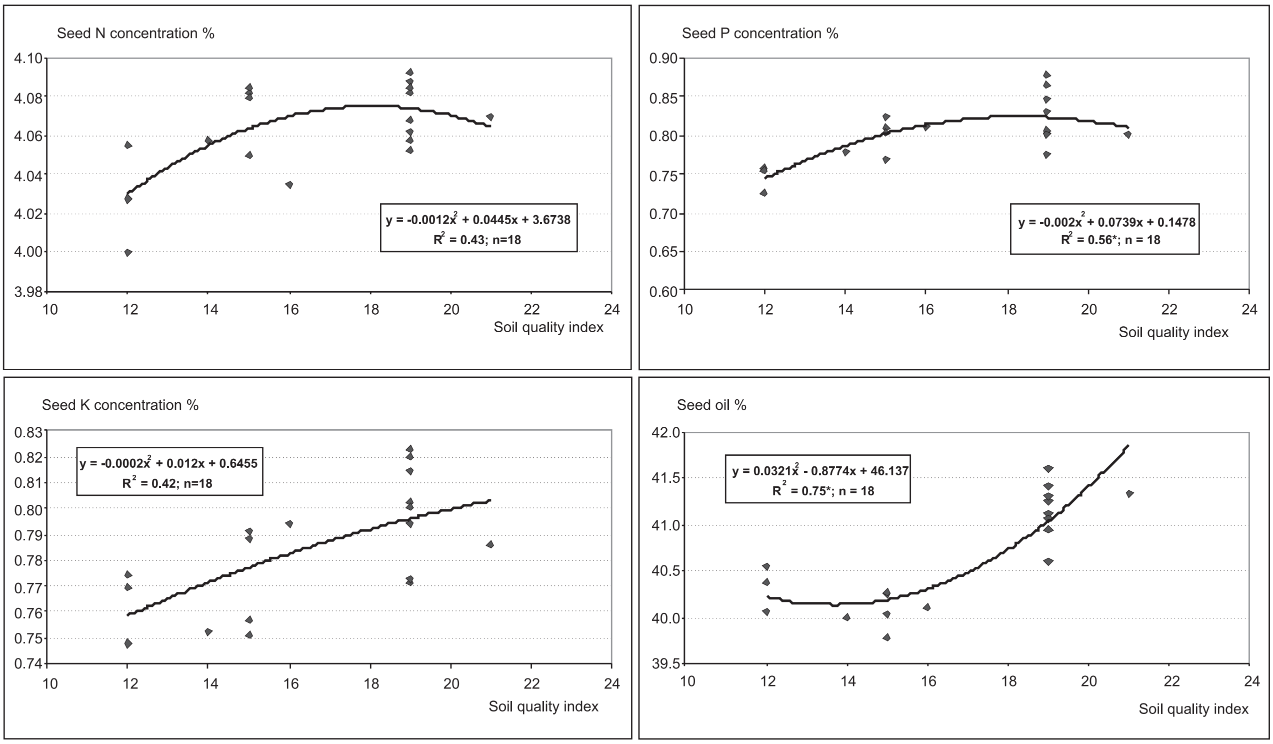

Fig. 2. Correlation between SQI value and spring oil-seed rape qualitative parameters in long-term tillage-fertilisation trials (mean data of trials I and II, 2007)

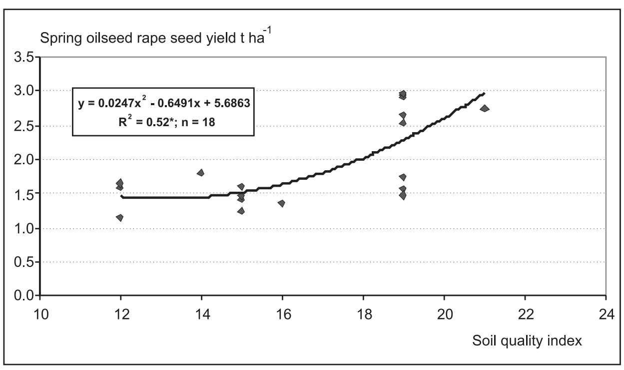

Fig. 3. Correlation between spring oil-seed rape yield and SQI value

seed yield in the RT and NT systems without fertilisers or with a moderate fertilisation level (RT-1, RT-2, NT-1, NT-2) was lower by 2–5% versus CT-1 and CT-2. In the 2nd trial, the best seed yield was obtained in the RT system with a high rate of fertilisers (RT-3) and amounted to 1.80 t ha^{-1}. The mean seed yield in the RT was higher on average by 10% and in the NT system by 4% as compared to CT.

CONCLUSIONS

1. In loam and sandy loam *Endocalcari-Epihypogleyic Cambisol*, the management methods and intensity must be determined according to the initial soil physical status (primarily soil texture) and the degree of the possible influence of these methods and their intensity on soil quality changes. Application of RT and NT must be based on the observation of soil and an objective evaluation of toward changes.

2. At the 8th year of field trials, the total SQI value did not essentially differ in CT, RT and NT in the loam soil, while in the sandy loam soil in the direct drilling system the SQI value was significantly lower as compared to CT and RT.

3. After 8 years when the different soil management systems had been used, the best $SQI_{chemical}$ for the 0–20 cm soil layer in the 1st (loam, rich in macronutrients (PK) and moderately rich in humus) field trial was determined when the following management systems were implemented: reduced tillage + no fertilisation; reduced tillage + moderate rates: NPK fertilisers according to soil properties and expected yield; direct drilling + moderate rates. The $SQI_{chemical}$ for the 0–20 cm soil layer in the 2nd field trial (sandy loam, moderately rich in macronutrients (PK) and poor in humus) was registered to be similar whatever the tillage system applied and their combination with either moderate or high rates of NPK fertilisers.

4. Over 8 years of applying different tillage systems, the best agro-physical $SQI_{physical}$ in the 0–20 cm soil layer was obtained employing the conventional system of tillage.

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References

1. Amacher M. C., O'Neill K. P., Perry C. H. 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. 2007. 12 p.
2. Amacher M. C., O'Neill K. P., Dresbach R. et al. Forest Inventory and Analysis Manual of Soil Analysis Methods. U. S. Department of Agriculture, Forest Service. 2003. http://socrates.lv-hrc.nevada.edu/fia/ia/IAWeb/Soil.htm
3. Andrews S. S., Karlen D. L., Cambardella C. A. The soil management assessment framework: A quantitative soil quality evaluation method // Soil Science Society of America Journal. 2004. Vol. 68. P. 1945–1962.
4. Barrios E., Delve R. J., Bekunda M. et al. Indicators of soil quality: A South–South development of a methodological guide for linking local and technical knowledge // Geoderma. 2006. Vol. 135. P. 248–259.
5. Brejda J. J., Moorman T. B., Karlen D. L. et al. Identification of regional soil quality factors and indicators: I. Central and Southern High Plains // Soil Science Society of America Journal. 2000. Vol. 64. P. 2115–2124.
6. Bremer E., Ellert K. Soil Quality Indicators: A Review with Implications for Agricultural Ecosystems in Alberta. 2004. http://www1.agric.gov.ab.ca/Review_final.pdf
7. Buivydaitė V. V., Grybauskas J., Juodis J. ir kt. Lietuvos dirvožemio duomenų bazė // Eidukevičienė M., Vasiliauskienė V. (sud.). Lietuvos dirvožemiai. Vilnius: Lietuvos mokslas, 2001. P. 1063–1084.
8. Carter M. R., Gregorich E. G., Anderson D. W. et al. Concepts of soil quality and their significance // Gregorich E. G., Carter M. R. (eds.). Soil Quality for Crop Production and Ecosystem Health. Amsterdam: Elsevier, 1997. P. 1–19.
9. Cesevičius G., Feiza V., Feizienė D. Tausojančių žemės dirbimo būdų ir augalinių liekanų įtaka dirvožemio fizikinėms savybėms ir vasarinių miežių derliui // Vagos. Mokslo darbai. 2005. Nr. 69(22). P. 7–18.
10. Clewer A. G., Scarisbrick D. H. Practical Statistics and Experimental Design for Plant and Crop Science. John Wiley and Sons, Ltd., 2001. 331 p.
11. Egner H., Riehm H., Domingo W. R. Untersuchungen über die chemische Boden–Analyse als Grundlage für die Beurteilung des Nährstoffzustandes der Boden: II Chemische Extraktionsmethoden zur Phosphor und Kaliumbestimmung // Kunglija Lantbruks-högskolans Annale. 1960. Bd. 26. S. 199–215.
12. Feiza V., Feizienė D., Kadžienė G. Agro-physical properties of *Endocalcari-Epihypogleyic* Cambisol arable layer in long-term soil management systems // Žemės ūkio mokslai. 2008. T. 15. Nr. 2. P. 13–23.
13. Feizienė D., Feiza V., Kadžienė G. et al. Changes of *Endocalcari-Epihypogleyic* Cambisol arable layer agrochemical properties in long-term soil management systems // Žemės ūkio mokslai. 2008. T. 15. Nr. 2. P. 1–12.
14. Feizienė D., Feiza V., Kadžienė G. Tillage–fertilisation management practices to sustain soil properties integrity and yields in crop rotation // Žemdirbystė. LŽI ir LŽŪU mokslo darbai. 2006. T. 93. Nr. 4. P. 32–46.
15. Feiziene D., Feiza V., Lazauskas S. et al. The influence of soil management on soil properties and yield of crop rotation // Žemdirbystė. LŽI ir LŽŪU mokslo darbai. 2007. T. 94. Nr. 3. P. 129–145.
16. Feizienė D., Kadzienė G., Feiza V. Tillage and fertilisation influence on available PK status in unequal soils of Central Lithuania // Žemės ūkio mokslai. 2006. Nr. 4. P. 22–30.
17. Green R. D., Fordham S. J. A field method for determining air permeability in soil // Soil Physical Conditions and Crop Production. Ministry of Agriculture. Fisheries and Food Technical Bulletin. 1975. Vol. 29. P. 273–288.
18. Hao X., Ball B. C., Culley J. L. B. et al. Soil density and porosity // Carter M. R., Gregorich E. G. (eds.). Soil Sampling and Methods Analysis. 2nd edn. 2008. P. 743–760.
19. Hillel D. Environmental Soil Physics. Academic Press, USA, 1998. P. 59–123.
20. Juodis J., Pakutinskas J., Vaičys M. Dirvožemio bonitavimas ir ekonominis žemės vertinimas // Eidukevičienė M., Vasiliauskienė V. (sud.). Lietuvos dirvožemiai. Vilnius: Lietuvos mokslas, 2001. P. 1046–1062.
21. Karlen D. L., Andrews S. S., Doran J. W. Soil quality: Current concepts and applications // Advances in Agronomy. 2001. Vol. 74. P. 1–40.
22. Karlen D. L., Mausbach M. J., Doran J. W. et al. Soil quality: a concept, definition, and framework for evaluation // Soil Science Society of America Journal. 1997. Vol. 61. P. 4–10.
23. Karlen D. L., Ditzler C. A., Andrews S. S. Soil quality: why and how? // Geoderma. 2003. Vol. 114. P. 145–156.
24. Kettler T. A., Lyon D. J., Doran J. W. et al. Soil quality assessment after weed-control tillage in a no–till wheat–fallow cropping system // Soil Science Society of America Journal. 2000. Vol. 64. P. 339–346.
25. Kinyangi J. Soil Health and Soil Quality: A Review. 2007. http://worldaginfo.org
26. Letey J., Sojka R. E., Upchurch D. R. et al. Deficiencies in the soil quality concept and its application // Journal of Soil and Water Conservation. 2003. Vol. 58. P. 180–187.
27. Mažvila J., Vaičys M., Buivydaitė V. V. Lietuvos dirvožemių makromorfologinė diagnostika. Lietuvos žemdirbystės institutas, 2006. P. 234–240.
28. O'Neill K. P., Amacher M. C., Palmer C. J. A national approach for monitoring physical and chemical indicators of soil quality on U.S. forestlands as part of the Forest Inventory and Analysis program // Environmental Monitoring and Assessment. 2005. Vol. 107. P. 59–80.
29. O'Neill K. P., Amacher M. C., Perry C. H. Soils as an Indicator of Forest Health: A Guide to the Collection, Analysis, and Interpretation of Soil Indicator Data in the Forest Inventory and Analysis Program. General Technical Report. NC–GTR–258. U.S. Department of Agriculture, Forest Service, North Central Research Station. St. Paul, MN, 2005a. 53 p.
30. Ozolinčius R. Aplinkos ištekliai. Kaunas: VDU leidykla, 2005. P. 61–69.
31. Šimanskaitė D. Arimo ir beplūgio žemės dirbimo įtaka dirvožemio fizikinėms savybėms ir augalų produktyvumui // Žemės ūkio mokslai. 2007. T. 14. Nr. 1. P. 9–19.

32. Stancevičius A., Jodaugienė J., Špokienė N. ir kt. Ilgamečio arimo ir beplūgio žemės dirbimo įtaka dirvožemiui ir vasarinių miežių pasėliui // Žemdirbystė. LŽI ir LŽŪU mokslo darbai. 2003. T. 83. P. 40–51.
33. Švedas A., Tarakanovas P. Tręšimo planavimas. Kompiuterinė versija „Tręšimas". Akademija, 2000. 34 p.
34. Tóth G., Stolbovoy V., Montanarella L. Soil Quality and Sustainability Evaluation – An Integrated Approach to Support Soil-Related Policies of the European Union. EUR 22721 EN. Office for Official Publications of the European Communities, Luxembourg, 2007. 40 p.
35. Wienhold B. J., Andrews S. S., Karlen D. L. Soil quality: A review of the science and experiences in the USA // Environmental Geochemistry. 2004. Vol. 26. P. 89–95.
36. Александрова Л. Н., Найденова О. А. Лабораторно-практические занятия по почвоведению. Ленинград: Агропромиздат, 1986. 295 с.
37. Нерпин С., Чудновский А. Физика почвы. Москва: Наука, 1967. С. 13–18.

Dalia Feizienė

GILIAU KARBONATINGO SEKLIAI GLĖJIŠKO RUDŽEMIO (*ENDOCALCARI-EPIHYPOGLEYIC CAMBISOL*) ARMENS KOKYBĖ ILGALAIKĖSE ŽEMDIRBYSTĖS SISTEMOSE

Santrauka

Straipsnio tikslas – Vidurio Lietuvos giliau karbonatingo sekliai glėjiško rudžemio armens (vidutinio sunkumo priemolis (p_1/L) ant p_1/L bei smėlingas lengvas priemolis (sp/SL) ant sp/SL) kokybės įvertinimas skirtingo intensyvumo žemės dirbimo–tręšimo sistemose.

Glėjiško rudžemio žemės dirbimo būdas ir intensyvumas turėtų būti nustatomi pagal dirvožemio granuliometrinę sudėtį ir galimą pasirinktų žemės dirbimo būdų ir priemonių poveikį dirvožemio kokybės kitimui. Vienos žemės dirbimo sistemos praktinio taikymo (visų pirma supaprastinto ariminio dirbimo bei tiesioginės sėjos) ilgaamžiškumas ir periodiškumas turėtų būti pagrįsti dirvožemio fizikinių ir agrocheminių savybių kitimo stebėjimu ir objektyviu vertinimu. Žemės dirbimo–tręšimo sistemas, kurias naudojant dirvožemio kokybės indeksas pastebimai mažėja, reikėtų pakeisti naujomis, pasirenkant kitokius žemės dirbimo būdus bei kitokį tręšimo lygį.

Aštuntaisiais tyrimų metais vidutinio sunkumo priemolio dirvožemyje, turtingame PK ir vidutiniškai humusingame, CT, RT bei NT sistemose dirvožemio kokybės indeksas (SQI) buvo panašus. Smėlingo lengvo priemolio dirvožemyje, vidutiniškai turtingame PK ir mažai humusingame, NT sistemoje SQI buvo esminiai mažesnis nei CT ir RT sistemose.

Per aštuonerius šių sistemų taikymo metus I bandyme (vidutinio sunkumo priemolis, turtingas PK ir vidutiniškai humusingas) geriausia dirvožemio 0–20 cm sluoksnio agrochemine kokybe pasižymėjo plotai, kuriuose taikyta: supaprastintas žemės dirbimas + netręšta, supaprastintas žemės dirbimas + gausiau tręšta mineralinėmis trąšomis bei tiesioginė sėja + gausiau tręšta mineralinėmis trąšomis, o II bandyme (smėlingas priemolis, vidutiniškai turtingas PK ir mažai humusingas) labai panaši kokybė nusistovėjo visose žemės dirbimo sistemose vidutiniškai arba gausiai tręšiant mineralinėmis trąšomis.

Aštuntaisiais skirtingų žemės dirbimo sistemų naudojimo metais geriausias dirvožemio agrofizikinės kokybės indeksas nustatytas dirbant žemę tradiciškai.

Raktažodžiai: multifunkcinės savybės, žemės dirbimas, tręšimas, dirvožemio kokybės indeksavimas