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Effects of organic farming and crop rotations on crop productivity and nutrient amount in the soil

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Abstract. The trials were carried out at the Voke Branch of the Lithuanian Institute of Agriculture during the period 2003–2007 and were designed to investigate the influence of organic (without fertilizers) and sustainable farming systems on plants (the plants were fertilized only with bonemeal as a source of phosphorus and magnesia of potassium as a source of potassium) and to explore their productivity, chemical properties of soil and balance of nutrients in the soil.

The experiments were conducted in the trial field with 4 treatments, in various crop rotations with the plants grown for green manure for the soil supply with nitrogen (the main nutritional element of sandy loam soil) without mineral fertilizers.

The experimental results show that higher productivity was achieved when cultivating plants after green manure of lupines and white mustard. We established negative nitrogen, phosphorus (except in the sustainable farming system) and potassium balance in the soil. The use of various crop rotations in all farming systems on sandy loam *Haplic Luvisol* showed that there was no definite effect on soil acidity but an increase in the total nitrogen and organic carbon content in the soil was observed. The amount of phosphorus increased and potassium decreased only in the organic farming system. Phosphorus and potassium amounts in the soil increased in the sustainable farming system.

Key words: farming systems, productivity, soil properties, balance

INTRODUCTION

Organic and sustainable agriculture is especially important for industrialized countries where high rates of fertilizers and pesticides are often applied to maximize crop productivity. However, there are fewer opportunities for organic and sustainable agriculture on less productive (acid, eroded or sandy) soils and these systems could lower quality standards. Therefore, conservation agriculture could be complementary and integrated with organic and sustainable agriculture. For the development of integrated arable farming systems, tools are needed to evaluate the achievement of agronomic and environmental objectives, in order to optimize the systems (Neker, 1992; Bockstaller et al., 1997).

Organic agriculture could not develop without the base knowledge that represents the fundamentals of ecology, sustainable and environmental protection. The object of ecology is formed by the study of the ecosystem, understood as a fundamental unit structure of nature, which integrates biogenesis with the physical environment on which it lives and in which there is a permanent flow of energy (Richling et al., 2000).

Many farmers around the world replaced legume rotations and other traditional sources of nitrogen (N) fertility with synthetic N fertilizers. Some researchers suggest that legumes, which can support biological N_2 fixation, offer a more environmentally sound and sustainable source of N to cropping systems. This perspective is countered by researchers who argue that legume-derived N has equally negative environmental impacts as the N derived from synthetic fertilizers; further, the human population now exceeds the carrying capacity of agricultural systems that depend on legumes for N inputs. Obtaining N from legumes is potentially more sustainable than from mineral fertilizers (Crews & Peoples, 2004).

The influence of plants on the soil quality is associated with the quantity of remaining roots and stubble, their chemical composition and the intensity of dissolution, because these factors depend on the water, air and heat model in the soil (MacRae & Mehuys, 1985; Evanylo & McGuinn, 2000; Rachman ey al., 2004). Leguminous plants and their remains are rich in protein nitrogen, so they can improve soil quality even during a longer period of time (Sanchez et al., 2004).

The aim of these investigations is to establish the influence of organic and sustainable farming systems and the change of crops in rotations on winter rye, potatoes, lupines and pea yield, and to research chemical properties of soil, and the balance of nutrients.

MATERIALS AND METHODS

Field experiments were conducted during 2003–2007 to study the efficacy of organic and sustainable farming systems on sandy loam *Haplic Luvisol* (54°37^1 N, 25°07^1 E). Soil agrochemical parameters before the experiment were as follows: pH_{KCl} – 5.9, P – 70–92, K – 142–165 mg kg^{-1}, organic carbon – 0.79–0.84 %. The treatments of experiments were various crop rotations with plants grown for green manure to supply the soil with nitrogen (the main element of light soils) without mineral fertilizer (Table 1).

All treatments (crop rotations) were investigating for 2 factors (farming systems): 1) plants were not fertilized with mineral NPK fertilizers in the organic farming system (**E**); 2) plants were fertilized only with bonemeal (as the source of phosphorus) and magnesia of potassium in the sustainable farming system (**S**).

Soil samples were taken from 0–25 cm depth in four treatments in three agricultural systems (total – 12) and three replications before the experiments in 2003 and after harvest in 2007.

Basic soil properties were determined using the following methods: pH_{KCl} – potentiometrically (ISO 10390, 1994), exchangeable bases – 0.1 M $BaCl_2$ (1:10) extract (ISO 11260, 1994), mobile P and K by Egner – Riem – Domingo method (AL method) (GOST 26208-91, 1993), total nitrogen – by Kjeldahl apparatus (ISO 11261, 1995), the content of organic carbon was measured spectrophotometrically after sulfochromic oxidation (ISO 14235, 1998).

The balance of nutrients was calculated using the amount of nitrogen, phosphorus and potassium introduced into the soil with fertilizers and in the yield of lupines for grain and for green manure, winter rye, potatoes, pea and white mustard for green manure.

Table 1. The treatments of experiments: various crop rotations.

No of treatments	2003	2004	2005	2006	2007
1	Lupines (*Lupinus angustifolius* L.) for green manure	Winter rye (*Secale cereale* L.)	Potatoes (*Solanum tuberosum* L.)	Buckwheat (*Fagopyrum esculentum)*	Barley (*Hordeum* L.)
2	Lupines (*Lupinus angustifolius* L.) and intermediary white mustard (*Sinapis Alba* L.) for green manure	Potatoes (*Solanum tuberosum* L.)	Winter rye (*Secale cereale* L.) with undersown red clover (*Trifolium pratense* L.)	Buckwheat (*Fagopyrum esculentum)*	Barley (*Hordeum* L.)
3	Lupines (*Lupinus luteus* L.) for grain	Potatoes (*Solanum tuberosum* L.)	Winter rye (*Secale cereale* L.) and intermediary white mustard (*Sinapis Alba* L.) for green manure	Buckwheat (*Fagopyrum esculentum)*	Barley (*Hordeum* L.)
4	Pea (*Pisum arvense* L.)	Winter rye (*Secale cereale* L.)	Lupines (*Lupinus luteus* L.) for grain,	Buckwheat (*Fagopyrum esculentum)*	Barley (*Hordeum* L.)

The compensation coefficient is calculated by dividing the content of the element incorporated with fertilizer by the amount of the element accumulated in the yield. The obtained result is multiplied by 100. This indicator shows how nutrients are utilised to produce yield and which part of the element remains in the soil. It is positive when it exceeds 100%.

The data of soil chemical properties and crop yield were processed using the computer programme ANOVA for $EXCEL_{2000}$ version 2.2. All data were evaluated according to Fisher criteria (F) and LSD_{05} (Clewer & Scarisbrick, 2001).

RESULTS AND DISCUSSION

The experiments revealed that the use of various crop rotations and farming systems had a positive effect on the chemical properties of sandy loam *Haplic Luvisol* (Table 2). Although indices of soil acidity (pH and exchangeable bases) varied within the limits of the error, the tendency towards soil acidification was noticed: pH reduced from 5.8–6.0 to 5.6–5.8, exchangeable bases from 7.7–8.8 to 6.2–7.6 mequiv kg^{-1} of soil.

The amount of total nitrogen varies fractionally in all crop rotations (treatments) and farming systems and data are not statistically significant (LSD_{05}=0.008–0.015; $Sx_{\%}$=2.18–3.90). Similar changes were observed in the indices of organic carbon. Its larger amount (0.38–0.55 %) was determined in all crop rotations and farming systems.

Table 2. Effect of farming system to the agrochemical indices in the various crop rotations.

No of treatments	pH_{KCl}	Exchangeable bases, mequiv kg^{-1}	Total N	Organic carbon	Phosphorus	Potassium
			%		mg kg^{-1}	
Organic farming system						
1	5.9*	8.2	0.105	0.82	189	187
	6.0**	6.9	0.107	1.25	228	174
2	6.0	8.5	0.103	0.81	201	192
	6.0	6.8	0.111	1.36	232	150
3	5.9	8.2	0.101	0.79	183	186
	6.0	7.6	0.103	1.17	256	173
4	5.8	7.7	0.100	0.81	161	199
	5.9	7.2	0.107	1.32	212	204
LSD_{05}	0.25	1.3	0.008	0.13	48	57
	0.27	1.3	0.015	0.25	61	37
$Sx_{\%}$	1.22	6.87	2.18	4.77	7.52	8.62
	1.30	5.11	3.90	5.62	7.65	6.17
Sustainable farming system						
1	6.0	8.6	0.105	0.80	197	181
	6.1	6.9	0.107	1.26	270	234
	5.9	8.8	0.103	0.81	176	173
	6.0	6.2	0.103	1.23	277	233
3	5.9	8.1	0.104	0.82	202	187
	5.9	6.3	0.107	1.21	266	225
4	5.8	8.5	0.102	0.81	173	191
	6.0	6.9	0.110	1.21	239	245
LSD_{05}	0.42	2.0	0.016	0.13	56	49
	0.49	2.3	0.011	0.14	79	40
$Sx_{\%}$	2.04	6.72	4.55	4.75	8.66	7.73
	2.37	6.65	2.99	3.30	8.66	4.97

* - agrochemical indices before the experiments in 2003;
** - agrochemical indices after harvesting in 2007.

In the sustainable farming systems, a larger amount of phosphorus was incorporated with bonemeal, but agrochemical tests show that even in the organic farming system after 5 years of crop rotation its amount increased from 161 to 256 mg kg^{-1} of soil. Meanwhile the amount of potassium in this farming system considerably decreased (13–42 mg kg^{-1} of soil). In the sustainable farming system the amount of potassium increased up to 11–56. The increase in the amount of phosphorus and potassium in the soil is not statistically significant and systematic because initial indices are also different in the same field. Those of phosphorus vary from 71 to 92, of potassium – from 142 to 165 mg kg^{-1} of soil. According to agrochemical data of our investigations we can predict that the organic farming system as sustainable does not impoverish the light-textured soils.

A deficiency of nutrients is also evident regarding the calculated balance of nutrients in the soil (Fig. 2). The balance of nutrients is given in relation to the five-year rotation. The compensation coefficient is given in percent.

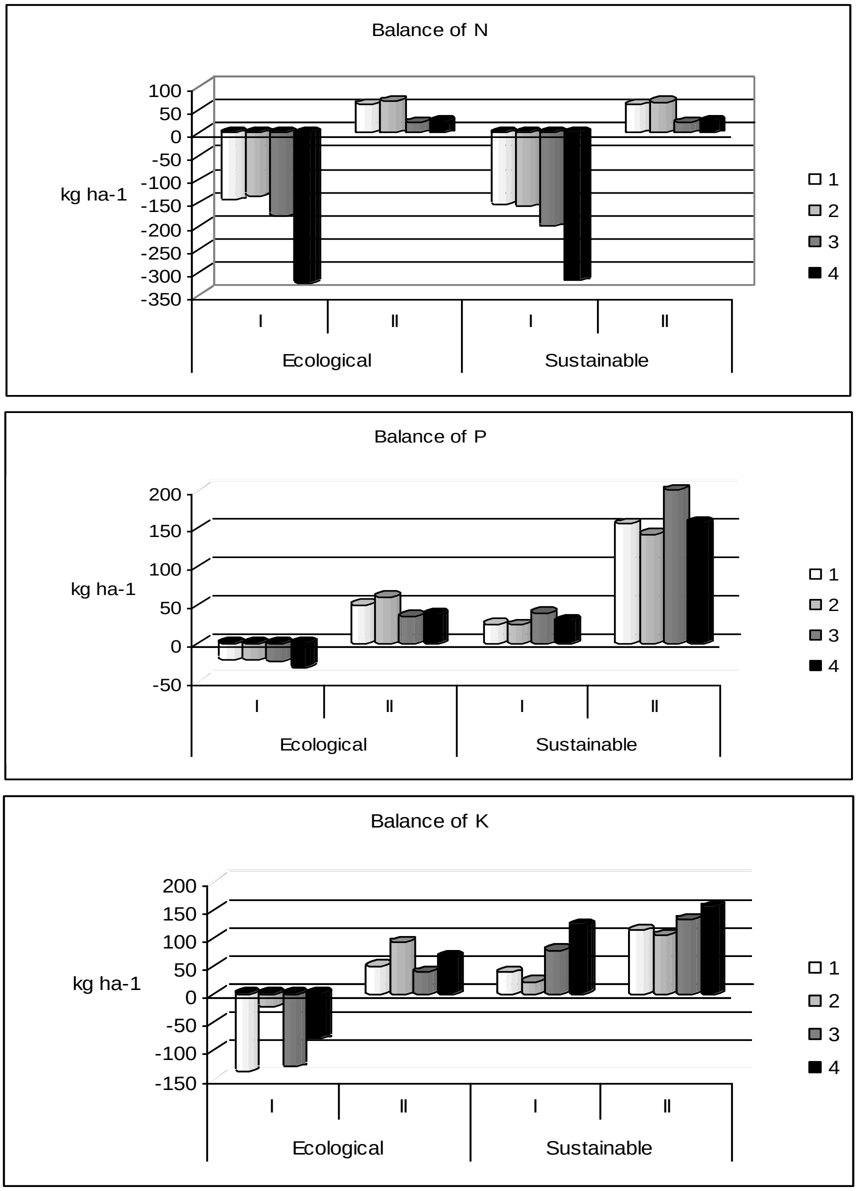

Fig. 2. Effect of farming system on the balance of nutrients in the various crop rotations.

I – balance of nutrients (+ - kg ha^{-1}); II – compensation coefficient (%). 1-4 - number of treatments: 1) lupines for green manure, winter rye, potatoes, buckwheat, barley; 2) lupines for green manure and intermediary white mustard, potatoes, winter rye with undersown red clover, buckwheat, barley; 3) lupines for grain, potatoes, winter rye and catch crop white mustard, buckwheat, barley; 4) pea, winter rye, lupines for grain, buckwheat, barley.

Calculations of the nutrient balance in the soil show that the highest amounts (242–244 kg ha^{-1}) of nitrogen were incorporated into the soil with green manure (treatment 2) in the organic and sustainable farming systems. Nevertheless, in all farming systems negative nitrogen balance was determined (-139 – -350 kg ha^{-1}). In the light-textured soil, nitrogen is among the most essential elements, best assimilated by plants.

A negative balance of phosphorus was determined in the organic farming system where only small amounts of this element were introduced into the soil with green manure. In the sustainable farming system, a higher amount of phosphorus was introduced with bonemeal (69–79 kg ha^{-1}).

A smaller amount of potassium, like that of phosphorus, was also inserted in the organic farming system, however, in many various crop rotation treatments and in various systems a negative potassium balance was determined. In the 4th treatment of the sustainable farming system, where peas, winter rye and lupines for grain were cultivated, less potassium was used; a positive balance of this element was determined.

Experimental treatments were formed by crop rotation aiming to accumulate as much nutrient content in the soil as possible and to obtain higher yield expressed as metabolic energy. The research results show that the productivity of various crop rotations depends on the cultivated plants and the farming systems applied (Fig. 3).

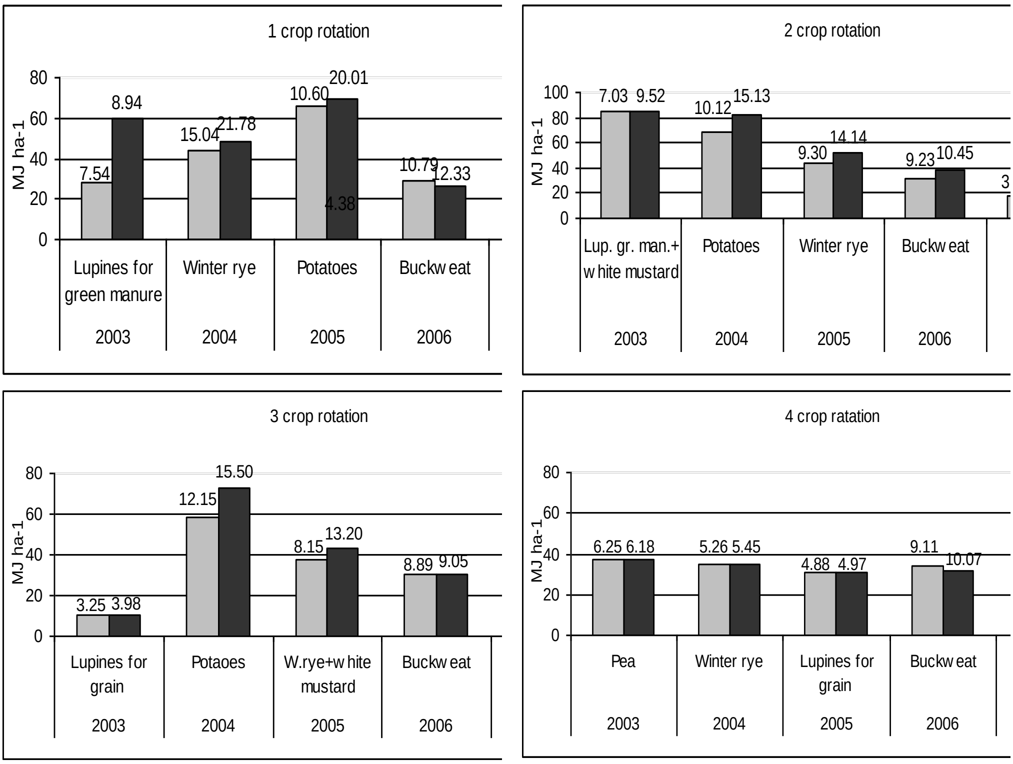

Fig. 3. Influence of farming systems on metabolizable energy (MJ ha^{-1}) in the various crop rotations.

E - organic farming system; S - sustainable farming system. 7.54–4.88 - LSD_{05}.

The yield evenly increased in the organic farming system, followed by the sustainable farming system. In all treatments and all systems, the highest yield was obtained from potatoes (58.8–113.2 MJ ha^{-1} of metabolizable energy). The highest yield was produced cultivating them after application of green manure of lupines and white mustard (68.2–113.2 MJ ha^{-1} of metabolic energy) in the 2nd treatment.

The lowest yield was obtained in the 4th treatment where peas, winter rye and lupines for grain were cultivated. It is only natural because pea roots accumulated considerably less nitrogen and other nutrients than lupines, and nutrient deficiency was evident in winter rye.

Fertilization with bonemeal and magnesia of potassium had no influence on the buckwheat and barley yield. These plants' yield was similar and not statistically significant (LSD_{05} = 4.23–10.45) in organic and in sustainable farming systems in all crop rotations.

CONCLUSIONS

1. The use of various crop rotations in all farming systems on sandy loam *Haplic Luvisol* showed that they had no effect on soil acidity and increased total nitrogen and organic carbon content in the soil. Phosphorus increased (from 701 to 105 mg kg^{-1} of soil) and potassium decreased (from 165 to 123 mg kg^{-1} of soil) only in the organic farming system. Phosphorus (from 76 to 12 mg kg^{-1} of soil) and potassium (from 142 to 213 mg kg $^{-1}$ of soil) increased in the sustainable farming system.

2. The experimental results indicated that crop rotations gave a negative balance of nitrogen -139 – -332 kg ha^{-1} in organic and -160 – -322 kg ha^{-1} in sustainable farming systems, negative balance of phosphorus -20 – -31 kg ha^{-1} in organic and positive balance 15–39 kg ha^{-1} in sustainable farming systems and negative balance of potassium -104 – -169 kg ha^{-1} and positive balance 4–45 kg ha^{-1} in sustainable farming systems in the soil.

3. Summarized experimental results showed that on sandy loam soil the productivity of crop rotations depended on the plants cultivated and farming system applied. The highest yield was established in the second treatment where plants were cultivated after green manure of lupines and white mustard.

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