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Influence of various farming systems on agrochemical indices and amount of microorganisms in Haplic Luvisol

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Abstract. The article presents data from a study comparing the influence on plant productivity of three different farming systems – ecological, sustainable and chemical – and the use of various plants grown for green manure. Crops were lupine, white mustard and red clover. Calculations of the nutritional content of the soil in the experiments show that various crop rotations (treatments) affect the phosphorus and potassium balance.

The data indicate that productivity of plant rotations depends on the plants cultivated and the applied farming system. In all farming systems, the highest yield was achieved cultivating plants after fertilization with green manure (lupines and white mustard). The results of the experiments show that crop rotations result in negative nitrogen, phosphorus (except in sustainable and chemical farming systems) and potassium balance in the soil.

Crop rotations had no effect on the soil acidity and increased total nitrogen and organic carbon content in the soil. The amount of phosphorus in the soil increased in all farming systems; potassium increased only in the sustainable and chemical farming systems.

Data indicating the number of micromycetes, organic and mineral nitrogen assimilating bacteria in the rizosphere soil of various grown plants are also presented.

Key words: farming systems, yield, nutrients balance, soil, agrochemical properties, micromycetes, bacteria

INTRODUCTION

One of the most important tasks of this research is to preserve soil productivity in ecological farms, among others. The properties of soil, the balance of nutrition and migration of chemical elements in soil may be changed substantially if organic fertilizers are used systematically. There is a lack of good quality fertilizers other than manure for ecological farming. Therefore, agriculture systems preserving humus must be applied while dehumification processes are progressing (Krull et al., 2004; Horwath, 2005).

Field plants are the most important components of agrocoenosis. The influence of plants on the soil quality is associated with the quantity of the remaining roots and stubble, their chemical composition and the intensity of dissolution, depending on the water, air and heat mode in the soil (MacRae & Mehuys, 1985; Evanylo & McGuinn, 2000; Rachman et al., 2004). Leguminous plants and their remains are rich in protein nitrogen and can improve soil quality for a long period of time (Sanchez et al., 2004). Humus damages occur when grain crops are reseeding or grown in longer chains, because heterotrophic micro-organisms use humus as an energy source when there is a lack of easily dissolvable organic materials (Richling et al., 2000; Janusiene, 2002).

We can maintain humus balance in the soil by interchanging grain crops with leguminous plants and fertilizing them with manure or green fertilizer. When plants are fertilized with manure and green fertilizer rather than with mineral fertilizers (Tripolskaja, 1999; Evanylo & McGuinn, 2000; Horwath, 2005), nutritious matter loosens gradually from organic fertilizers and vegetal remains, they are better absorbed by growing plants, there is no surplus in the soil and fewer nutrients are washed into deeper soil layers. Leguminous plants such as lupines, beans grown for feed, vetches, bird's-feet, clovers and lucernes are the recommended choices for the production of green fertilizer, however, cruciferous plants, such as oil-bearing radishes, white mustard and rapes (Nedzinskas & Nedzinskiene, 1999) can also be grown. According to investigations of the Voke Branch of the Lithuanian Institute of Agriculture, the most valuable green fertilizer was clover, which accumulated 171–260 kg ha^{-1} of nitrogen depending on the year of use. Cruciferous plants can grow 40 t ha^{-1} and more of green mass, however, they accumulate only half as much nitrogen in the green mass as clover (Zekoniene & Janusiene, 1999).

Micro-organisms are essential components of soil biocenosis. The interaction of populations in the micro-organism community provides the conditions to utilize various substrates which would not be possible in the presence of only one species (Jenzen, 1995). Micro-organisms of the rhizosphere are particularly important to plants: they stimulate plant growth by facilitating the assimilation of phosphorus and iron, nitrogen fixation, releasing phytohormones, inhibiting root pathogens, synthesising antibiotics (Glick, 1995). The season, soil humidity, pH, fertilization and other factors predetermine the number and species composition of micro-organisms in soil. For example, the supplement of organic fertilizers particularly stimulates bacteria and actinomycetes, reducing the fungal population (Novak et al., 1993). Plant residues supplemented the soil with organic matter and improved its microbiological and biochemical characteristics (Perucci et al., 1997).

Light soils are characterized by weak sorption recipiency, large permeability of water and have a natural acid reaction to small quantities of nutritious and organic matter. For this reason these soils are ecologically sensitive and require a special crop structure. They are used mostly for growing winter rye and potatoes.

The market demands a continuous and rich supply of plants. It is important for Southeast Lithuania to develop an eco-organic agricultural system, however it must be grounded on scientific research and recommendations, based not only on efficiency of economic activity, but on environmental protection as well.

The purpose of the experiments was 1) to investigate the influence of ecological, sustainable and chemical farming systems and crop rotations on winter rye, potatoes, lupines and pea harvests, and 2) to research chemical properties of soil, the balance of nutrients and changes in the number of micro-organisms in various crop rotations.

MATERIALS AND METHODS

Field experiments. Field experiments were conducted in 2003–2005 to study the efficacy of ecological, sustainable and chemical farming systems in sandy loam Haplic Luvisols (54°37′ N, 25°07′ E). Soil agrochemical parameters before the experiment were the following: pH_{KCl} - 5.9, P - 70–92, K - 142–165 mg kg^{-1}, organic carbon - 0.79–0.84%. The treatments in the experiments include various crop rotations using plants grown for green fertilizer to equip soil with nitrogen (the main element of light soils) without mineral fertilizers: 1) lupines (*Lupinus angustifolius* L.) for green manure, winter rye (*Secale cereale* L.), potatoes (*Solanum tuberosum* L.); 2) lupines for green manure and intermediary white mustard (*Sinapis alba* L.), potatoes, winter rye with undersown red clover (*Trifolium pratense* L.); 3) lupines for grain (*Lupinus luteus* L.), potatoes, winter rye and intermediary white mustard; 4) pea (*Pisum arvense* L.), winter rye, lupines for grain. All treatments (crops rotations) were investigating 3 factors (farming systems): 1) crops not fertilized with mineral NPK fertilizers in the ecological farming system (**E**); 2) the plants were fertilized only with bonemeal (as the source of phosphorus) and magnesia of potassium in the sustainable farming system (**S**); 3) the plants were fertilized with mineral NPK fertilizers: lupines for grain – $P_{26}K_{75}$, winter rye – $N_{60}P_{31}K_{75}$, potatoes – $N_{90}P_{26}K_{100}$, pea – $P_{26}K_{75}$ in the chemical system (**Ch**). Mineral fertilisers were spread on the soil before sowing each crop of the rotation every year. Size of experimental plots – 72 m^2, replications – 3.

Soil sampling. 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 2005.

The soil samples for the observation of micro-organism abundance were taken at the beginning and the end of plant vegetation. Micro-organisms were isolated, applying the dilution method by sowing soil suspension in 5 replications on the surface of various standard media for different physiological groups: malt agar – for fungi; nutrient agar – for organic nitrogen- assimilating bacteria; ammonium starch agar – for mineral nitrogen-assimilating bacteria (Mirchink, 1988). The number of bacteria cells and fungi colony forming units (cfu) was calculated per gram of dry soil (g d. s.).

Analytical methods. 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).

Statistics. The metabolic energy (ME) was calculated with coefficient: lupines grain kg ha^{-1} (dry matter) × 10.18; lupines for green manure kg ha^{-1} (dry matter) × 9.70; winter rye grain kg ha^{-1} × 12.91 and straw kg ha^{-1} × 6.06; potatoes kg ha^{-1} (dry matter) × 12.74; white mustard kg ha^{-1} (dry matter) × 8.52; pea grain kg ha^{-1} × 11.40 and straw kg ha^{-1} × 5.49; clover kg ha^{-1} (dry matter) × 8.85; (Jankauskas et al., 2000).

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

The data regarding chemical properties of the soil 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

Experimental treatments were performed by crop rotation aiming to accumulate as much nutritious substance in soil as possible and to obtain a larger yield expressed as metabolic energy.

The research results show that productivity of various crop rotations depends upon the cultivated plants and the applied farming systems (Table 1).

Table 1. Influence of farming system to metabolic energy (MJ ha^{-1}) in the various crop rotations.

Treatments	Investigation year	Crop in rotation	Metabolic energy (MJ ha^{-1})		
			Ecological farming systems	Sustainable farming systems	Chemical farming systems
1	2003	lupines for green	58.3	59.6	62.4
	2004	manure	43.8	48.5	72.2
	2005	winter rye	65.6	69.5	93.3
	Total	potatoes	167.7	177.9	228.0
2	2003	lupines for green	84.8	85.1	85.2
	2004	manure and	68.2	81.9	113.2
	2005	intermediary white	44.1	52.6	74.3
	Total	mustard	197.1	219.6	272.8
		potatoes			
		winter rye with			
		undersown red			
		clover			
3	2003	lupines for grain	10.4	10.7	11.0
	2004	potatoes	58.8	72.9	103.6
	2005	winter rye and	37.8	43.5	77.4
	Total	intermediary white	107.0	127.2	192.0
		mustard			
4	2003	pea	37.2	37.6	40.1
	2004	winter rye	35.1	35.1	72.9
	2005	lupines for grain	30.5	30.6	34.1
	Total		102.8	103.3	147.1
LSD_{05}	2003		7.5	8.9	10.2
	2004		15.0	21.8	12.6
	2005		10.6	20.0	20.6
	Total		25.7	26.3	11.2

Table 2. Effect of farming system to the balance of nutrients in the various crop rotations.

Treatments	Fertilizers application, kg ha^{-1}	Accumulation in the yield, kg ha^{-1}	Balance (+ -), kg ha^{-1}	Compensation coefficient, %
		NITROGEN		
		Ecological farming system		
1	174	328	-153	53
2	242	381	-139	64
3	11	189	-178	6
4	48	371	-323	13
		Sustainable farming system		
1	178	345	-166	52
2	244	404	-160	60
3	12.3	216	-204	6
4	51	373	-322	14
		Chemical farming system		
1	336	422	-85	80
2	372	482	-110	77
3	166	312	-146	53
4	117	466	-350	25
		PHOSPHORUS		
		Ecological farming system		
1	10.	32	-22	32
2	19	39	-20	48
3	2	24	-22	7
4	7	38	-31	17
		Sustainable farming system		
1	49	34	15	144
2	58	42	16	137
3	58	28	31	211
4	59	38	21	154
		Chemical farming system		
1	68	45	23	152
2	74	54	20	136
3	85	41	44	208
4	91	50	41	182
		POTASSIUM		
		Ecological farming system		
1	61	230	-169	27
2	150	311	-161	48
3	20	168	-148	12
4	68	172	-104	39
		Sustainable farming system		
1	196	244	-48	80
2	287	342	-54	84
3	206	202	4	102
4	222	177	45	125
		Chemical farming system		
1	241	316	-76	76
2	309	419	-110	74
3	279	300	-21	93
4	304	235	70	130

The yield increased evenly as the following systems were applied: ecological farming system < sustainable farming system < chemical farming system. In all treatments and all systems the highest yield was obtained from potatoes (58.8–113.2 MJ ha^{-1} of metabolic energy), cultivating them after using green manure of lupines and white mustard (68.2–113.2 MJ ha^{-1} of metabolic energy) in the 2nd treatment. General productivity of the rotation employing this treatment was the highest in all systems (197.1–272.8 MJ ha^{-1} of metabolic energy), and was statistically valid. The lowest yield was obtained in the 4th treatment where peas, winter rye and lupines for grain were cultivated. The yield of all plants was equal in the ecological and sustainable farming systems and was higher (except for rye) in the chemical system. Those results were not surprising: the pea roots accumulated considerably less nitrogen and other nutrients than lupines, and nutrient deficiency was evident in winter rye. There were better yields only after the application of mineral NPK fertilizers in the chemical farming system.

A deficiency of nutrients is also evident regarding the calculated balance of nutritious elements in the soil (Table 2). The balance of nutrients is given in relation to the three year crop rotation. The compensation coefficient is expressed in percent. The nitrogen deficiency was the highest (-349.8 kg ha^{-1}) in the 4^{th} treatment of the chemical farming system. Calculations of the balance of nutritious elements in soil show that the highest amounts (242–244 kg ha^{-1}) of nitrogen entered soil with green manure (treatment 2) in the ecological and sustainable farming systems, and mineral NPK fertilizers (336–371 kg ha^{-1}) (treatments 1 and 2) in the chemical farming system. Nevertheless in all farming systems negative nitrogen balance was determined (-139–350 kg ha^{-1}). In light textured soil, nitrogen is among the most essential elements, best assimilated by plants.

A negative balance of phosphorus was determined only in the ecological farming system where only small amounts of this element moved into the soil with green manure. In the sustainable farming system, a larger amount of phosphorus was inserted with bonemeal (49–59 kg ha^{-1}), while the chemical farming system used superphosphate (68–91 kg ha^{-1}). A positive phosphorus balance was determined in all treatments in these farming systems. The compensation coefficient reached 137–211 %. A smaller amount of potassium, equal to phosphorus, was also inserted in the ecological farming system, however, in various crop rotation treatments and systems a negative potassium balance was determined. In the 4th treatment of the sustainable and chemical farming systems, where peas, winter rye and lupines for grain were cultivated, less potassium was used; a positive balance of this element was determined. Various crop rotations and farming systems influence the agrochemical soil properties (Table 3). Although indices of soil acidity (pH and exchangeable bases) varied within the limits of error, a tendency towards soil acidification was noticed: pH reduced from 5.8–6.0 to 5.6–5.8, exchangeable bases from 7.7–8.9 to 5.4–7.0 cmol kg^{-1} of soil.

Although negative nitrogen balance in the soil was determined, agrochemical indices show an increase of this element from 0.099 to 0.113 % in all crop rotations (treatments) and farming systems. However, the increases are not statistically significant. Similar changes were also observed in the indices of organic carbon. Its larger amount (0.04–0.11 %) was also determined in all crop rotations and farming systems.

Table 3. Effect of farming system to the agrochemical indices in the various crop rotations.

No of treatments	pH_{KCl}	Exchangeable bases, mquiv kg[1]	Total N	Organic carbon	Phosphorus	Potassium
			%		mg kg^{-1}	
Ecological farming system						
1	5.9*	8.2	0.105	0.82	83	155
	5.6**	6.2	0.107	0.85	105	160
2	6.0	8.5	0.103	0.81	88	159
	5.8	7.0	0.111	0.87	93	123
3	5.9	8.2	0.101	0.79	80	154
	5.7	6.1	0.103	0.83	94	129
4	5.8	7.7	0.100	0.81	70	165
	5.6	6.2	0.107	0.90	94	160
LSD_{05}	0.25	1.9	0.008	0.13	21	47
	0.32	1.3	0.015	0.08	30	60
Sustainable farming system						
1	6.0	8.6	0.105	0.80	86	150
	5.7	6.9	0.107	0.90	121	206
2	5.9	8.8	0.103	0.81	77	144
	5.7	6.2	0.103	0.88	105	167
3	5.9	8.1	0.104	0.82	88	156
	5.8	6.3	0.107	0.84	108	173
4	5.8	8.5	0.102	0.81	76	159
	5.7	6.9	0.110	0.92	89	167
LSD_{05}	0.42	2.0	0.016	0.13	24	41
	0.29	2.3	0.011	0.12	18	42
Chemical farming system						
1	5.9	8.3	0.105	0.84	84	142
	5.7	6.2	0.110	0.89	112	175
2	6.0	8.4	0.103	0.84	92	159
	5.6	6.3	0.113	0.91	102	196
3	5.9	7.8	0.099	0.80	87	159
	5.6	5.4	0.110	0.85	95	213
4	5.8	7.9	0.099	0.84	77	157
	5.7	6.4	0.110	0.91	93	184
LSD_{05}	0.39	2.1	0.013	0.12	26	33
	0.23	1.8	0.010	0.12	37	67

* – agrochemical indices before the experiments in 2003;
** – agrochemical indices after harvest in 2005.

In the sustainable and chemical farming systems, a larger amount of phosphorus was inserted with bonemeal and superphosphate, but agrochemical tests show that even in the ecological farming system, phosphorus increased from 71 to 105 mg kg^{-1} of soil after 3 years of crop rotation. Meanwhile the amount of potassium in this farming system considerably decreased (5–37 mg kg^{-1} of soil). In the sustainable farming system the amount of potassium increased up to 11–56, and in the chemical farming system – 27–54 mg kg^{-1} of soil.

The increase in the amount of phosphorus and potassium in the soil is not statistically significant and systematic because initial indices in the same field are also different. Those of phosphorus vary from 71 to 92, of potassium – from 142 to 165 mg kg^{-1} of soil. According to agrochemical data of analyses we discovered that the ecological farming system, like the sustainable and chemical systems, does not exhaust the light textured soils.

The influence of the farming system and growing plants on the occurrence of micromycetes was noticed at the beginning of vegetation in 2003 (Table 4).

Table 4. Effect of farming system to the amount of various groups of microorganisms in the different crop rotation.

Treatment	Investigation year	Micromycetes, cfu x 10^3		Bacteria on NA, cells x 10^6		Bacteria on SAA, cells x 10^6	
		I	II	I	II	I	II
Ecological farming system							
1	2003	287.5	484.6	3.3	12.5	9.5	20.4
	2004	430.9	144.0	5.0	5.4	14.8	11.4
	2005	255.8	314.1	6.2	3.4	14.3	19.4
2	2003	207.6	624.0	2.9	10.2	11.2	21.1
	2004	555.6	196.1	4.9	3.3	19.0	14.8
	2005	252.7	289.0	6.6	3.1	25.8	9.2
3	2003	477.8	627.5	3.9	5.4	13.5	17.5
	2004	444.7	141.2	7.9	3.9	24.7	11.0
	2005	418.2	236.2	5.8	2.7	26.7	16.4
4	2003	442.4	681.5	3.8	4.6	13.0	21.2
	2004	272.0	167.4	7.5	3.3	16.2	15.3
	2005	334.5	390.4	5.3	2.5	17.1	20.5
LSD_{05}	2003	121.6	97.4	1.3	1.7	1.8	3.9
	2004	62.7	22.4	2.3	0.8	3.1	1.6
	2005	35.7	33.3	1.4	0.6	3.5	0.4
Sustainable farming system							
1	2003	211.4	592.6	4.3	13.2	11.2	20.7
	2004	412.5	154.4	3.1	5.0	10.7	13.4
	2005	292.7	178.3	3.5	3.1	15.1	17.7
2	2003	311.1	644.7	2.9	8.8	9.4	17.8
	2004	250.9	160.7	4.8	3.9	20.9	9.3
	2005	270.0	149.8	9.1	2.1	24.7	5.8
3	2003	208.6	228.9	3.8	7.2	7.5	23.4
	2004	321.4	164.1	3.7	3.2	16.0	11.0
	2005	325.5	200.4	4.3	2.0	20.2	17.0
4	2003	343.9	454.9	3.7	7.4	9.4	18.8
	2004	183.5	188.4	3.5	2.6	11.8	14.0
	2005	225.9	329.5	5.3	3.0	16.0	18.0
LSD_{05}	2003	31.8	58.9	0.9	2.6	3.0	2.5
	2004	32.2	18.1	0.6	0.6	6.1	2.1
	2005	40.0	33.3	0.9	1.0	4.7	0.9

Continuation

Chemical farming system							
1	2003	127.6	623.6	5.1	10.8	7.6	21.9
	2004	565.7	137.8	6.1	2.5	10.7	12.6
	2005	342.7	280.0	4.9	2.3	19.7	16.1
2	2003	210.7	368.6	3.2	7.2	8.1	14.4
	2004	451.8	288.3	5.2	2.4	13.2	9.7
	2005	329.3	233.7	7.7	3.3	12.6	8.9
3	2003	266.5	653.6	3.9	6.5	12.0	20.8
	2004	487.9	141.9	7.7	3.8	12.5	15.4
	2005	262.7	296.1	5.5	2.2	25.7	12.1
4	2003	336.3	509.0	3.4	6.7	10.3	22.3
	2004	335.2	170.1	7.3	1.4	14.4	13.4
	2005	217.4	309.6	5.0	3.1	13.8	20.9
LSD_{05}	2003	57.9	60.1	0.8	3.2	0.8	6.1
	2004	38.4	27.7	1.2	0.8	6.3	2.9
	2005	40.4	43.2	0.6	0.2	4.8	1.2

I – at the beginning of vegetation
II – at the end of vegetation

The largest amount of colony-forming units of fungi was isolated from the rizosphere soil when the ecological farming system was used, especially when lupines for grain and pea were grown. In 2004 more fungi were isolated from the rizosphere of potatoes and winter rye in treatments where lupines and lupines with mustard were grown under ecological and chemical farming systems. The least number of fungi was obtained in soil of rye grown after pea when sustainable farming was used. At the end of vegetation, due to unfavourable weather conditions, the number of fungi significantly decreased in all treatments in the experiment. In spring 2005 the largest amount of fungal cfu was isolated from the rizosphere of winter rye with mustard and from lupines in the ecological farming system. In the rizosphere of potatoes and winter rye with clover, their amount was largest under the chemical system, therefore at the end of vegetation their number decreased whereas in the ecological soil it slightly increased. At the same time the number of fungi in lupine soil increased in all treatments.

The number of organic nitrogen-assimilating bacteria at the beginning of plant vegetation was similar in the soil of all farming systems and fluctuated from 2.9 to 9.1×10^6 cells g^{-1} d. s. At the end of vegetation the amount was 2.0–12.5 $\times10^6$ cells g^{-1} d. s. The largest increase in bacteria was noticed in 2003 in the soil of all farming systems in treatments where lupines for green manure were grown. In the next year this tendency was observed only in the ecological and sustainable farming systems (treatment 1). The chemical farming system slightly inhibited the development of this micro-organism group.

The largest amount of mineral nitrogen-assimilating bacteria in spring was estimated in autumn, 2003 and in 2005. The increase of bacteria in autumn was noticed in the soil of ecological farming in all treatments in the first year of the experiment and in the variants 1 and 4 in 2005. Under sustainable farming their amount increased in all three years of the experiment in 1 and 4 treatments but, in 2 and 3 treatments, only in 2003. The positive effect of chemical farming on the increase in this group of bacteria during the experiment was observed in treatment 4.

CONCLUSIONS

1. Summarized results of the experiment on sandy loamy soil have shown that productivity of plant rotations depends upon the plants cultivated and the applied farming system. The highest yield (197.1–272.8 MJ ha^{-1} of metabolic energy) was established in the second treatment where plants were cultivated after soil treatment with green manure of lupines and white mustard.

2. The results of the experiments show that crop rotations resulted in negative nitrogen (-139 – -350 kg ha^{-1}), phosphorus (-20 – -31 kg ha^{-1}) (except in sustainable and chemical farming systems) and potassium (-21 – -169 kg ha^{-1}) balance in the soil.

3. The use of various crop rotations in all farming systems on sandy loam Haplic Luvisols was shown to have no effect on soil acidity, but the total nitrogen and organic carbon content in the soil increased. 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 ecological 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 and chemical farming systems.

4. The application of the ecological farming system was favourable for the distribution of micromycetes. The number of fungi in the soil of sustainable farming depended on the plants grown: the best results were obtained when lupines for green manure, lupine and rye with mustard were grown. The chemical farming system had a positive affect on micromycetes in the rizosphere of lupines grown for grain and for green manure.

5. The chemical farming system had a negative effect on the development of organic nitrogen- assimilating bacteria in the rizosphere of plants. The leguminous plants had positive influence on the distribution of mineral nitrogen-assimilating bacteria.

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