Agronomy Research **3**(1), 45–54, 2005

Effect of fertilisation systems on the balance of plant nutrients and soil agrochemical properties

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Abstract. Clay loam soils are rich in available potassium, however, they contain a low or moderate content of phosphorus. At the Lithuanian Institute of Agriculture's Joniskelis Research Station trials were carried out over the period of 1960–2000 on a *Endocalcari-Endohypogleyic Cambisol (CMg-n-w-can)* – a clay loam soil in a five-course crop rotation, in which we investigated mineral, organic and organic-mineral fertilisation systems. Results of the sixth rotation showed that the annual application of mineral $N_{56}P_{48}K_{60}$ fertilisers resulted in an increase of the content of available phosphorus in 5 mg kg^{-1} of the soil, and the reduction of potassium content in 3 mg kg^{-1} of the soil, compared with the initial level. In the organic fertilisation system, the application of only 80 t ha^{-1} of farmyard resulted, compared with the mineral fertilisation system, in a humus content increase in the plough layer by 0.12 percentage units and that in the phosphorus content by 26.0 mg kg^{-1} and potassium content by 31.0 mg kg^{-1}. In this system the crop productivity, compared with unfertilised crops, increased by 34.1%, however, compared with the mineral fertilisation system, it declined by 14.1%. In the organic-mineral fertilisation system, the application of 40, 60 and 80 t ha^{-1} of farmyard manure and NPK fertilisers in the same amount as in the mineral fertilisation system resulted in the following increases – soil humus content by 0.18; 0.24 and 0.21 percentage units, phosphorus content by 41.0, 61.0 and 61.0 mg kg^{-1}, potassium content by 36.0; 46.0 and 54.0 mg kg^{-1}, and crop rotation productivity by 6.2, 7.6 and 7.8, respectively, compared with the mineral fertilisation system.

Key words: heavy loam brown soil, fertilising system, crop rotation, phosphorus and potassium, humus

INTRODUCTION

The crop rotation productivity depends not only on the amount of organic and mineral fertilisers but also on their combination. Fertilisation intensity changes the level of available potassium and phosphorus in soil. Therefore, the role of a fertilisation system is very important. Experimental evidence suggests that in crop rotation the application of an optimum fertiliser rate $N_{84}P_{72}K_{84}$ to the crops with a low phosphorus status in the soil (50–100 mg kg^{-1}) increase the content of phosphorus by 31 mg kg^{-1} in the soil. In the soil with a medium content of phosphorus (101–150 mg kg^{-1}) it did not change, and in the soil with a high content of phosphorus (151–200 mg kg^{-1}) it declined insignificantly. Such fertiliser rates maintained a stable, 150–200 mg kg^{-1}, potassium content in a clay loam (Bagdoniene & Arlauskiene, 1999). An optimum content of potassium in the soil was established to be 130–160 mg kg^{-1} in Germany and 170–200 mg kg^{-1} in Lithuania (Kerschberger & Richter, 1988; Petraitiene, 1995; Vaisvila, 1996). Nutrient balance must be calculated in the way that nutrients distributed in the crop rotation could not only secure normal crop nutrition during the vegetative growth period but also not reduce the soil fertility (Bushmanis & Jansons, 1999). A combination of mineral fertiliser and farmyard manure enables to supply plants with nutrients for more than one vegetative growth season. Such fertilisation system secures good plant nutrition with mineral nutrients for later growth and development stages of plants (Bagdoniene, 1997). Variation of nutrients in soil depends not only on the fertilisation system but also on the crop variety, soil tillage, potential productivity of crops, and other factors. Findings of the experiments conducted at the Lithuanian Institute of Agriculture show that plants annually utilise only about 5–10% of phosphorus and 14% of potassium from the soil, and 10–25% and 60–70%, respectively, from the fertilisers applied. To achieve a positive balance, the amount of phosphorus removed with the yield must be compensated by 300% and that of potassium by 150% (Masauskas et al., 1995). The objective of the research was to establish the productivity of the crop rotation, nutrient balance, and variation agrochemical soil properties of a clay loam Gleyic Combisol.

MATERIALS AND METHODS

Experiments were started in 1960 at the Joniskelis Research Station of the Lithuanian Institute of Agriculture located in the northern part of Central Lithuanian Lowland. According to the FAO soil classification system, the soil of the experimental site is characterised as an *Endocalcari-Endohypogleyic Cambisol (CMg-n-w-can)*, and according to its texture – clay loam on silty clay. The following fertilisation systems were investigated: mineral, organic, and organic-mineral. The initial plot size was 105.0–112.5 m^2, and that of the record sub-plots 45–50 m^2. The trial involved the following five-course crop rotation: sugar beet, barley undersown with perennial grasses, perennial grasses of the first harvest year, perennial grasses of the second harvest year, winter wheat. Organic fertilisers (farmyard manure) at a rate of 40; 60 and 80 t ha^{-1} were applied to a member of the first rotation – sugar beet. The average composition was as follows: total N (according to Kjeldahl) – 0.38 %, phosphorus (calorimetric method) – 0.21%, potassium (flame photometer) – 0.67%. Ammonium nitrate, granulated superphosphate and potassium chloride were used as mineral fertilisers. The crop fertilisation scheme is shown in Table 1.

The soil establishment agrochemical characteristics of the topsoil were as follows: pH – 6.0, humus – 2.0%, available phosphorus – 62–129 mg kg^{-1}, potassium – 175–218 mg kg^{-1} of the soil. Agrochemical analyses of the soil were performed by using the following methods: pH_{KCl} – potentiometrically, humus – by Tjurin, available phosphorus and potassium (were determined in the soil by the – AL method. For statistical analysis (LSD_{05}), yield variations across the years were taken as replications. The phosphorus and potassium balance by agricultural crops was calculated according to a simple methodology: the input was PK amount applied with farmyard manure (FYM) and mineral fertilisers, and output – the one removed from the soil with agricultural crop yield. Recovery rate was considered as a ration between PK applied with fertilisers and PK removed by crops, expressed as a percentage.

Table 1. Distribution of fertilisers for the crops of the rotation in 1996–2000.

Fertilisation systems (treatment)	Sugar beet	Spring barley	Perennial grasses of the first year of use	Perennial grasses of the second year of use	Winter wheat
I. Without fertilisers	-	-	-	-	-
II. Mineral NPK	$N_{120}P_{90}K_{120}$	$N_{30}P_{60}K_{60}$	$P_{50}K_{60}$	N_{60}	$N_{70}P_{40}K_{60}$
III. Organic-mineral	FYM* 40 t ha^{-1} $N_{120}P_{90}K_{120}$	$N_{30}P_{60}K_{60}$	$P_{50}K_{60}$	N_{60}	$N_{70}P_{40}K_{60}$
IV. Organic-mineral	FYM* 60 t ha^{-1} $N_{120}P_{120}K_{120}$	$N_{30}P_{60}K_{60}$	$P_{50}K_{60}$	N_{60}	$N_{70}P_{40}K_{60}$
V. Organic-mineral	FYM* 80 t ha^{-1} $N_{120}P_{90}K_{120}$	$N_{30}P_{60}K_{60}$	$P_{50}K_{60}$	N_{60}	$N_{70}P_{40}K_{60}$
VI. Organic	FYM* 80 t ha^{-1}	-	-	-	-

* FYM – farmyard manure

Experimental findings were processed by the analysis of variance and correlation regression methods (Tarakanovas, 1999). The credibility of equations was determined according to the Fisher criterion (r of ŋ) at a 95% probability level (marked as*), 99% (marked as**).

RESULTS AND DISCUSSION

Experiments carried out at the Joniskelis Research Station on a clay loam soil suggest that after five rotations on such soils it is possible to use organic fertilisers in a single treatment for the whole crop rotation to sugar beet or winter wheat, while phosphorus and potassium fertilisers can be applied in every 2–3 years. Annual application of $N_{73}P_{58}K_{78}$ fertiliser on average and farmyard manure resulted in an increase of mobile phosphorus by 34–52 mg kg^{-1} in the soil and a reduction of potassium content by 12–17 mg kg^{-1}. The average data from 1996–2000 show that mineral fertilisers caused 56.1% of the total yield increase of the crop rotation; farmyard manure – 34.1%; 40 t ha^{-1} of farmyard manure and NPK fertiliser – 65.9%; 60 t ha^{-1} of farmyard manure with mineral fertilisers – 68.0%; 80 t ha^{-1} farmyard manure with NPK fertiliser – 68.4% (Table 2).

After the application of 40 t ha^{-1} of farmyard manure and $N_{56}P_{48}K_{60}$ kg ha^{-1} of fertiliser, the yield of the crop rotation increased by 6.3%, and after increasing the farmyard manure rate to 60 t ha^{-1}, the yield increased by 7.6% in the soil, compared with mineral fertilisation. Following the application of 80 t ha^{-1} of farmyard manure and NPK fertiliser (annual average $N_{117}P_{82}K_{167}$), the yield of the crop rotation plants increased by 7.8%, compared with mineral fertilisation, and by 25.5%, compared with the application of only 80 t ha^{-1} of manure.

Table 2. Effect of fertilisation systems on the crop rotation productivity. Average data of 1995–2000.

Treatment	Yield of primary and secondary produce		Min.–Max.	Variation coef. %
	feed unit ha^{-1}	rel. values		
Unfertilised	6174 ± 502	100.1	4852–7484	18
NPK	9639 ± 826	156.1	7530–12510	19
40 t ha^{-1} FYM*+NPK	10243 ± 785	165.9	8209–12788	17
60 t ha^{-1} FYM*+NPK	10372 ± 722	168.0	8733–12850	16
80 t ha^{-1} FYM*+NPK	10394 ± 817	168.4	8732–13269	18
80 t ha^{-1} FYM*	8281 ± 658	134.1	6630–9697	18
LSD_{05}	603.3			

* FYM – farmyard manure

The yield of the crop rotation and its content of individual elements determined the accumulation of nutrients in the yield. The five-course crop rotation application of 40, 60 and 80 t ha^{-1} of farmyard manure and mineral fertiliser $N_{120}P_{90}K_{120}$ resulted in large root and top yields with the highest accumulation of nutrients ($N_{235-257}$, P_{68-76}, $K_{360-365}$ kg ha^{-1}). The application of mineral NPK fertilisers resulted in a root yield increase by 65.7%, compared with the unfertilised treatment and the yield accumulated 223 kg ha^{-1} of N, 66 kg ha^{-1} of phosphorus and 372 kg ha^{-1} of potassium. Having applied 80 t ha^{-1} of farmyard manure only, a lower nutrient content accumulated in the yield (N – 30.7%, phosphorus – 6.2% and potassium – 17.3%), compared with mineral fertilisation. After the fertilisation of barley with an undercrop with N-30, P-60, K-60, the yield accumulated 65–77 kg ha^{-1} of nitrogen, 30–33 kg ha^{-1} of phosphorus, and 58–71 kg ha^{-1} of potassium.

Following the treatment of perennial grasses of the first harvest year at average PK fertiliser rates, the yield (5.7–6.1 t ha^{-1} dry matter) contained 117–153 kg $ha^{-1}$of N, 32–38 kg ha^{-1} of phosphorus, and 138–170 kg ha^{-1} of potassium. Due to the fertilisation of perennial grasses of the second harvest year with N_{60}, the yield accumulated 95–106 kg ha^{-1} of N, 25–28 kg ha^{-1} of phosphorus and 99–108 kg ha^{-1} of potassium.

The grain and straw yield of unfertilised winter wheat accumulated 63 kg ha^{-1} of nitrogen, 29 kg ha^{-1} of phosphorus and 36 kg $ha^{-1}$of potassium. After the application of $N_{70}P_{40}K_{60}$, the grain yield contained 63.2–78.8% of nitrogen, 44.4–70.1% of phosphorus and 80.6–102.0% of potassium more, compared with the unfertilised.

During the sixth rotation, the amount of phosphorus applied with fertilisers in the mineral and mineral-organic fertilisation systems was higher than that accumulated in the crop yield, which resulted in a positive phosphorus balance. Unfertilised crops take up 126.0 kg ha^{-1} of phosphorus, while in the treatment with the application of $N_{280}P_{240}K_{300}$ in the crop rotation the crop yield accumulated 197.7 kg ha^{-1} of phosphorus or by 71.7 kg ha^{-1} more than in the fertilised treatment (Table 3).

Table 3. Effect of fertilisation systems on the balance of phosphorus in the crop rotation by the average of 1995–2000.

Treatment	Applied with fertilisers, kg ha^{-1} (manure+ mineral fertilisers)	Removed with crops, kg ha^{-1} (main+by – product)	Balance, kg ha^{-1}	Recovery rate, %	Content of phosphorus in the soil, mg kg^{-1}		±2000 1995
					1995	2000	
Unfertilised	-	126.0±24.32	-126.0	-	66±1.94	45±3.20	-21
NPK	240.0	197.7±35.18	42.3	121.4	89±2.93	94±4.77	+5
40 t ha^{-1} FYM*+NPK	324.0	206.2±36.68	117.8	157.1	116±7.10	135±5.93	+19
60 t ha^{-1} FYM*+NPK	366.0	210.0±42.29	156.0	174.3	126±7.13	155±7.13	+29
80 t ha^{-1} FYM*+NPK	408.0	223.3±42.26	184.7	182.7	124±7.28	155±4,79	+31
80 t ha^{-1} FYM*	168.0	178.8±33.77	-10.8	94.0	124±8.21	120±9,36	-4
LSD_{05}		10.03			11.833	12.523	

* FYM – farmyard manure

Table 4. Effect of fertilisation systems on the balance of potassium in the crop rotation by the average of 1995–2000.

Treatment	Applied with fertilisers, kg ha^{-1} (manure + mineral fertilisers)	Removed with crops, kg ha^{-1} (main+ by – product)	Balance, kg ha^{-1}	Recovery rate, %	Content of potassium in the soil, mg kg^{-1}		±2000 1995
					1995	2000	
Unfertilised	-	461.4±153.54	-461.4	-	187±2.18	183±1.98	-4
NPK	300.0	743.1±290.63	-443.3	40.4	194±2.99	191±3.20	-3
40 t ha^{-1} FYM*+NPK	568.0	748.2±274.77	-180.2	75.9	207±6.46	227±5.30	+20
60 t ha^{-1} FYM*+NPK	702.0	771.4±274.53	-69.4	91.0	218±8.96	238±6.22	+20
80 t ha^{-1} FYM*+NPK	836.0	783.5±275.77	+52.5	106.7	210±6.27	245±2.84	+35
80 t ha^{-1} FYM*	536.0	644.2±237.15	-108.2	83.2	214±9.21	222±2.75	+8
LSD_{05}		32.05			14.742	12.034	

* FYM – farmyard manure

After the application of organic-mineral fertilisers, the soil received a different amount of phosphorus and its surplus was 117.8–184.7 kg ha^{-1}, and the compensation rate was 157.1–182.7%. When phosphorous removal was compensated by fertiliser phosphorus 121.4–182.7%, its content increased in 5–31 mg kg^{-1} of the soil over the rotation. The entering into ground of average and high norms of phosphorus has ensured both positive balance of phosphorus and an increase of the content of phosphorus in ground (Stikans et al., 2000).

The content of phosphorus applied in the soil with 80 t ha^{-1} of farmyard manure (168.0 kg ha^{-1}) was insufficient to compensate the content of phosphorus taken up by plants, which resulted in a negative balance and a reduction of phosphorus content by 4 mg kg^{-1}. During the sixth crop rotation, the crops accumulated a higher content of potassium than these treated with fertiliser (Table 4).

Unfertilised crop rotation accumulated 461.4 kg ha^{-1} of potassium in the yield, while the application of $N_{280}P_{240}K_{300}$ gave a higher yield that accumulated a content of potassium higher by 281.7 kg ha^{-1}, compared with the unfertilised treatment, and the fertilisers compensated only 40.4% of plant-accumulated potassium. The application of 40; 60 t ha^{-1} of farmyard manure with mineral fertilisers caused the yield to be higher by 61.2–63.2% than in the control, whereas potassium fertiliser compensated 76–91% of plant-uptake potassium, and its content increased by 20 mg kg^{-1}. Due to the effect of farmyard manure, the potassium deficit declined to 69.4–180.2 kg ha^{-1}.

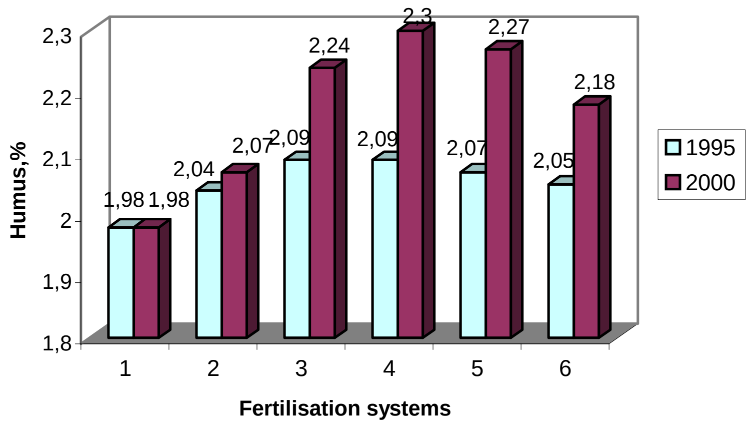
The application of 80 t ha^{-1} of farmyard manure and mineral fertilisers (annual average $N_{117}P_{82}K_{167}$) resulted in a positive potassium balance. Potassium taken up by plants was compensated by 106.7%, and its content increased by 35 mg kg^{-1} in the soil. Findings of the experiments conducted in Belarus show that in crop rotation the application of organic and mineral fertilisers increased the content of phosphorus by 3.7–5.5 mg kg^{-1} and that of potassium by 5.7–113.0 mg kg^{-1} per year (Lapa et al., 2000). The application of only 80 t ha^{-1} of farmyard manure resulted in a negative potassium balance, however, its content was increased by 8 mg kg^{-1} in the soil over the rotation. A negative potassium balance (67.8 kg ha^{-1} years) was also demonstrated (by Okruszko et al., 1993).

A correlation-regression analysis suggests that the content of nutrients accumulated in the yield of primary and secondary production showed a different response to the nitrogen, phosphorus and potassium fertilisers applied. The relation of nitrogen (y_1) and phosphorus (y_2) accumulation (kg ha^{-1}) in the crop yield with the applied N (x_1) and P (x_2) amount is described by the respective linear regression equation:

$$y_1 = 418.232+0.731x_1; r = 0.909^{**}$$

$$y_2 = -33.539+0.709 x_2; r = 0.788^{**}$$

A strong linear-direct correlation was established between the amount of phosphorus fertiliser and its amount accumulated in the crop yield. Nitrogen fertiliser application tended to increase nitrogen accumulation in plants. Potassium accumulation in the yield of the crop rotation was least affected by its fertilisation with potassium (r = 0.475*).



LSD$_{05}$ 1995 - 0.034; 2000 - 0.078.

Fig. 1. Humus content in the soil in relation to fertilisation systems.
Fertilisation systems: 1. Unfertilised; 2. NPK; 3. 40 t ha^{-1} FYM+NPK; 4. 60 t ha^{-1} FYM+NPK; 5. 80 t ha^{-1} FYM+NPK; 6. 80 t ha^{-1} FYM.

Studies carried out at the LIA Joniskelis Research Station on a clay loam soil showed that application of different rates of farmyard manure and mineral fertilisers during the five-course crop rotation resulted in a humus content increase. Changes in the humus content of the topsoil, resulting from the effect of fertilisation systems during the crop rotation, are presented in Figure 1.

The highest content of humus, 2.24–2.30%, in the topsoil layer (0–20 cm) was established in the organic-mineral fertilisation system, which was significantly by 13.1–16.2% more than in the control treatment (without fertilisers). In the organic fertilisation system, the humus content was by 10.1% higher than in the control treatment. In the organic-mineral fertilisation system, the application of 40 t ha^{-1} of farmyard manure resulted in a humus content increase in the topsoil by 8.7%, whereas 60 t ha^{-1} of FYM gave a humus increase of 11.7%, and 80 t ha^{-1} of FYM – 10.2%, as compared with only mineral fertilisation. Increasing FYM rates (40, 60 and 80 t ha^{-1}) did not increase the humus content significantly. When clay loam soil was fertilised with only 80 t ha^{-1} FYM (or 16.0 t ha^{-1} per year), the humus content increased by 5.8%, compared with the mineral fertilisation system. Following the application of $N_{280}P_{240}K_{300}$ kg ha^{-1} in the mineral fertilisation system, an increase in humus content in the topsoil was considerably lower than that in the organic-mineral systems and insignificant, compared with the unfertilised treatment. In the mineral fertilisation system, the content of soil humus remained close to the initial during the crop rotation. In the organic fertilisation system, the application of only 80 t ha^{-1} of farmyard manure resulted, compared with initial level of the humus content, in an increase in the topsoil layer by 0.13 percentage units. In the organic-mineral fertilisation system, the application of 40, 60 and 80 t ha^{-1} of farmyard manure and NPK fertilisers resulted in an increase of soil humus content by 0.15, 0.21 and 0.20 percentage units, respectively, as compared with the initial level.

CONCLUSIONS

1. In a clay loam soil poor in phosphorus (94 mg kg^{-1}) and rich in potassium (191 mg kg^{-1}), crop fertilisation at a $N_{56}P_{48}K_{60}$ fertiliser rate resulted in a yield increase by 56.1% in the soil. In a soil rich in phosphorus (135–155 mg kg^{-1}) and very rich in potassium (227–245 mg kg^{-1}), the application of organic-mineral fertilisation to the crop rotation plants resulted in an increase in the average crop rotation yield by 65.9–68.4% in the soil. The application of only 80 t ha^{-1} of farmyard manure on the soil with a medium phosphorus content and a high potassium content resulted in a crop yield increase on 34.1% of the soil.

2. When the crops had not been fertilised over the rotation, the content of phosphorus in the soil declined in 21 mg kg^{-1} and that of potassium by 4 mg kg^{-1} in the soil. In the mineral fertilisation system, the application of $N_{56}P_{48}K_{60}$ fertiliser rate resulted in an increase in mobile phosphorus content in 5 mg kg^{-1} and a reduction in potassium content in 3 mg kg^{-1} of the soil. In the organic-mineral fertilisation system, the content of phosphorus in the soil was increased by 19–31 mg kg^{-1} and that of potassium by 20–35 mg kg^{-1} in the soil while, in the organic fertilisation system, the content of mobile phosphorus declined by 4 mg kg^{-1} and that of potassium increased by 8 mg kg^{-1} in the soil.

3. In all fertilisation systems, the nitrogen balance in the crop rotation was negative. Phosphorus balance in the mineral and mineral-organic fertilisation systems was positive; and phosphorus fertiliser compensated 121.4–182.7% of the uptake by plants, whereas in the organic fertilisation system its balance was negative. After the application of 80 t ha^{-1} of farmyard manure and NPK fertiliser, the potassium balance in the organic-mineral fertilisation system was positive. The part uptakes by crops were compensated by 106.7%. The balance in the other fertilisation system was negative.

4. Organic fertilisation on clay loam soil during the five-course crop rotation had a positive effect on the humus content of the topsoil in all the fertilisation systems. In the organic-mineral fertilisation systems, the application of 40; 60 and 80 t ha^{-1} of FYM humus content in the topsoil increased by 13.1–16.2–14.6%, respectively, and in the organic fertilisation system (80 t ha^{-1} FYM) by 10.1%, compared with the unfertilised treatment.

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