The effect of tillage and crop rotation on the content of available nitrogen, phosphorus and potassium

E. Lauringson[1], L. Talgre[1], H. Roostalu[2] and H. Vipper[1]

[1]Department of Field Crop Husbandry, Estonian Agricultural University, Kreutzwaldi 64, 1008 Tartu, Estonia; e-mail: ennlaur@eau.ee
[2]Department of Soil Science and Agrochemistry, Estonian Agricultural University, Kreutzwaldi 64, 1008 Tartu, Estonia; e-mail: roostalu@eau.ee

Abstract. This research (A long-term field experiment from 1982 to 1997) was conducted at the experimental station of the Department of Field Crop Husbandry of the Estonian Agricultural University. The soil of the experimental site is moderately moist slightly podzolised sandy clay.

Insofar as field crop husbandry is concerned the soil should contain optimal amounts of available nutrients. If the level of available nutrients in the soil is low the plants will suffer and the yield will be low. A rise in soil available nutrient content leads to increased yield of crops, but only up to a certain level (optimal content). Thereafter, a further rise in soil nutrient content fails to effect any significant increase in the harvest.

The soils of the Eerika trial plot have optimal nutrient content and little need for fertilisation. After two crop rotations significant changes in nutrient content and location were observed in the ploughed layer. Compared to the nutrient content determined at the start of the trial period (1982), the greatest changes occurred in the soils under a crop rotation involving cereals, potato and a mixture of red clover and timothy, in which the supply of available phosphorus decreased by 19 mg kg^{-1} and that of potassium by 121 mg kg^{-1} on average after two rotations. Compared to the cereal rotation and the rotation containing 50% of cereals and 50% of potato the available phosphorus content dropped by 12–33% and the potassium content by 41–46% in the upper 25-cm soil layer.

Key words: Phosphorus, potassium, nitrogen, ploughing, loosening, plant nutrient balance

INTRODUCTION

In recent years (1992–2002), fertilisation failed to ensure preservation of soil fertility. It returned to the soil a mere 1/2 to 1/3 of the nutrients removed with the harvest (Roostalu, 2000). Accordingly, the production was kept up at the expense of the soil nutrient supplies.

Statistical analysis of Estonian field trial data has shown that the farming technology of modern varieties and today's ratio of crops put the optimal content of available phosphorus in our soils at 50–80 mg kg^{-1} and of potassium at 120–170 mg kg^{-1} (Hannolainen et al., 2002). The soils of the Eerika experimental station have optimal nutrient content and little need for fertilisation. Accordingly, crop response to manure has been insignificant (Kuldkepp, 1996).

Following a legume-rich crop rotation the soil nutrient supplies decrease (Starko, 1990; Zarina, 2000; Źekoniene, 2000). Legumes require large amounts of phosphorus and potassium for normal development. Reduced soil supplies lead to a reduction in the biological nitrogen fixation. Typically, plants respond to a lack of phosphorus by making the soil around their roots slightly more acid, which leads to increased phosphorus solubility (Bockman et al., 1991).

Similarly, soil nutrient supplies were reduced under the cereal monoculture rotation. Cereal yield remove relatively little phosphorus from the soil. Therefore its supply is not necessarily reduced in phosphorus-rich soils under cereal monoculture (Maikšteniene, 2000).

As regards soil nutrient supplies the most stable rotation was that including 50% of potato. Potato-rich rotations enrich the soil with nutrient elements. This is accompanied by intensive decomposition of the soil organic matter.

Ploughing depth did not have any marked effect on the accumulation of available phosphorus and potassium in the soil (Maikšteniene, 2000). Some researcher find that ploughing depths are influence nutrient element content in the soil (Viil 1997; Rasmussen, 1999;).

MATERIALS AND METHODS

The research was performed on the trial fields of the Estonian Agricultural University Institute of Field Crop Husbandry at Eerika in 1982–1997. The effect of crop rotation on plant nutrient element content in the soil was investigated.

The trial involved three crop rotations: A – a cereal rotation (oats, early barley, winter rye, barley, oats, early barley, winter rye and barley), B – a rotation including 25% of a mixture of red clover and timothy (red clover-timothy mixture I, red clover-timothy mixture II, winter rye, barley, oats, potato, spring wheat and barley) and C – a rotation involving cereals (50%) and potato (50%) (potato, potato, spring wheat, barley, potato, potato, spring wheat and barley). In crop rotation A ploughing depths were used: 1) shallow -16–17 cm, 2) medium - 21–22 cm, 3) deep - 24–25 cm. In Rotation A ploughing was replaced with stubble cultivation the same depth. In crop rotation B and C analysed medium ploughing depths (cereals 21–22 cm, root crops 24–25 cm). Soil nutrient balance in the crop rotations calculated on medium ploughing depths (21–22 cm).

Mineral fertilisers were applied as follows: 1st rotation – N 80 kg ha^{-1}, P 45 kg ha^{-1}, K 66 kg ha^{-1}; 2nd rotation – N 60 kg ha^{-1}, P 26 kg ha^{-1}, K 50 kg ha^{-1}. In addition to mineral fertilizers manure was applied to winter rye and potato – 60 t ha^{-1}.

The trial was carried out on the moderately moist slightly podzolised sandy clay soils (*Podzoluvisoils* – FAO-UNESCO). The thickness of the ploughing layer is approximately 27–nutrient element content in the soil 29 cm, soil pH_{KCl} was 5,6–5,7. Soil measured bulk density was 1,45–1,50 g cm^{-3}. The content of humus in humus layer was 18,8 g kg^{-1} (1982).

The methods of determining available nutrient elements in the soil were as follows: available phosphorus and potassium – DL (Egner-Riehm) method. The methods of analysing plant samples were as follows: general nitrogen – Kjeldahl's method, K – flame photometry.

The plant nutrient element supplies in the soil were determined by calculating the element losses using the methods employed at the Estonian Land Cultivation Institute (Kärblane & Kevvai, 1988; Kärblane, 1996).

Nitrogen volatilisation losses were put at 20% of the amount of nitrogen applied in fertiliser. Nutrient element losses caused by leaching were put at 1.5% of the nitrogen, 0.2% of the phosphorus and 4% of the potassium applied in fertiliser. As there was no slope in the surface of the trial area the losses caused by erosion were not considered here. The amount of nitrogen bound by the red clover-timothy mix was calculated based on the coefficients determined by H. Kärblane (1991).

RESULTS AND DISCUSSION

The fertiliser levels used caused substantial changes in nutrient contents and locations in the ploughed layer after two rotations. Compared to the nutrient contents determined at the start of the trial period (1982) the greatest changes were observed in the soils of Rotation B. Likewise, the content of available nutrient of the soil had decreased in the cereal monoculture rotation (Table 1). Cereals remove relatively little phosphorus from the soil. Furthermore, their need for potassium is small and they are capable of making good use of the after-effect of potassium fertilisers.

As regards soil nutrient supplies the most stable rotation was Rotation C, which included 50% of potato.

As less phosphorus was removed from the field with potato harvest (11 kg ha^{-1} on average) than with cereal yield (13 kg ha^{-1}) or red clover-timothy mixture harvest (28 kg ha^{-1}), and less than was returned to the soil by fertilisation, the soil available phosphorus content increased.

Table 1. The effect of crop rotation on soil nutrient contents (mg kg^{-1}); autumn tillage depth 21–22 cm.

Soil layer	Available phosphorus content			Available potassium content		
	Crop rotation					
	A	B	C	A	B	C
0–10 cm	65	55	84	252	130	270
10–15 cm	58	50	80	220	130	245
15–20 cm	59	51	77	205	125	215
20–25 cm	63	54	70	200	130	195
1997 average of 0–25 cm	62	53	79	226	129	239
LSD_{95}	6.62			27.4		
1982 average of 0–25 cm	73	72	71	252	250	260
LSD_{95}	8.23			22.3		

A, B, C – crop rotation

As less phosphorus was removed from the field with potato harvest (11 kg ha^{-1} on average) than with cereal yield (13 kg ha^{-1}) or red clover-timothy mixture harvest (28 kg ha^{-1}), and less than was returned to the soil by fertilisation, the soil available phosphorus content increased.

Although potato harvest removes from the soil large amounts of potassium (in our trial, 138 kg ha^{-1} per year on average), the fertilisation variant used in the trial (60–80 kg ha^{-1} of mineral fertilisers + 60 t ha^{-1} of manure) ensured minimal reduction in the soil available potassium content.

To enable evaluation of fertiliser use and of the practicability of the ratio of nutrient elements provided with fertilisers, balances of plant nutrients were calculated. To calculate the active balance, the amounts of nutrients taken in by plants were determined based on the results of the general balance and on the availability of one or the other plant nutrient element depending on the fertiliser used (Kärblane & Kevvai, 1988; Kärblane et al., 2002).

The plant nutrient balance takes account of all the sources of plant nutrient taken up on the one hand and the nutrients removed with the harvest as well as all the other sources of nutrient loss on the other (Tables 2, 3, 4).

In recent years, we have witnessed a negative balance between the removal and return of soil nitrogen. On average, a mere 47% of nitrogen is returned to the soil (Kärblane, 2002). According to A. Piho's recommendations the percent of nitrogen returned should fall within the range of 65–80 (Piho, 1976; Piho, 1978). Of the crop rotations employed in the trial, the requirements of the plants and the environment were met in Rotations A and B. Although in Rotation A the percent of nitrogen (as well as other nutrients) returned was greater than in Rotation B, it failed to produce greater harvests (Table 2).

Table 2. The average effect of crop rotation on the nitrogen balance (kg ha^{-1}) in 1982–1997.

	A	B	C
Removal			
Yield+weeds	69.1	119.9	68.3
By volatilisation	26.9	22.6	39.8
Leaching	2,0	1,7	3,0
Total	98.0	144.2	111.1
Return			
With mineral fertilisers	35.0	26.3	35.0
With organic fertilisers	38.7	38.7	77.4
Symbiotically bound biological N		21.9	
Asymbiotically bound biological N	2.0	2.0	2.0
With precipitation	0.2	0.2	0.2
With seeds	2.8	2.6	5.0
Total	78.7	91.7	119.6
Balance	-19.3	-52.5	8.5
Return %	80	64	108

A, B, C – crop rotation

This was due to the generally bad phytosanitary condition of the cereal monocultures. This clearly demonstrates that greater amounts of fertilisers are no remedy for other faults in the farming system. Although the protein-rich red clover and timothy harvest removes a large amount of nitrogen from the field it is partially compensated for by biologically bound nitrogen.

In this regard, a clear conflict with the environment conditions was evidenced in Rotation C. All the nutrients were returned to the soil in greater amounts than were removed. Accordingly, it is impractical to apply manure in the average amount of 30 t ha^{-1}.

A. Piho (1976) considered the phosphorus balance satisfactory when 75–85% of the phosphorus removed with the harvest was covered by available phosphorus. Although in Rotations B and A the percent of phosphorus returned was 87–130 it failed to stop the reduction in soil available phosphorus supply. Apparently, a smaller coefficient of total-to-available phosphorus should be employed than the commonly used 0.4–0.5.

Table 3. The average effect of crop rotation on the phosphorus balance (kg ha^{-1}) in 1982–1997.

Phosphorus	A	B	C
Removal			
Yield+weeds	14.7	18.9	12.8
Leaching	0.1	0.1	0.1
Total	14.8	19.0	12.9
Return			
With mineral fertilisers	9.3	6.9	9.3
With organic fertilisers	9.0	9.0	18.0
With seeds	0.6	0.6	1.1
Total	18.9	16.5	28.4
Balance	4.1	-2.5	15.4
Return %	128	87	220
Change in soil nutrient supplies	-36	-62	26

A, B, C – crop rotation

As regards potassium, it is considered optimal when the amount of available potassium returned with fertilisers accounts for 70–100% of the amount removed (Kärblane & Kevvai, 1989). In calculating the amount of available potassium we should apparently also employ a smaller coefficient than the current 0.6. In our trial, the fertiliser amounts used were insufficient for satisfying the need for potassium under a mixture of red clover and timothy.

In the trial we also investigated the effect on soil nutrient content of different autumn main tillage techniques. In the variants where deeper ploughing depths were employed the soil phosphorus and potassium contents were relatively homogeneous (Table 5).

Table 4. The average effect of crop rotation on the potassium balance (kg ha^{-1}) in 1982–1997.

Potassium	A	B	C
Removal			
Yield+weeds	68.3	135.6	96.2
Leaching	4.8	4.2	7.3
Total	73.1	139.8	103.5
Return			
With mineral fertilisers	34.9	26.1	34.9
With organic fertilisers	36.9	36.9	61.5
With precipitation	0.2	0.2	0.2
With seeds	1.7	3.4	10.1
Total	73.7	66.6	106.7
Balance	-0.6	-73.2	3.2
Return %	101	48	104
Change in soil supplies	-85	-419	-68

A,B,C – crop rotation

Shallow ploughing depths as well as stubble cultivator loosening, however, resulted in the differentiation of nutrients across the ploughed layer. Loosening led to a decrease in the available phosphorus content in the 10–25 cm layer without, however, ensuring a higher content in the upper 0–10 cm layer. The same tendency was observed in Ausmane's (2000) and Maikšteniene's (2000) trials. According to Rasmussen (1999) and Viil (1997), however, shallow tillage depths lead to higher levels of available phosphorus in the 0–5 cm layer.

Table 5. The effect of tillage on available phosphorus and potassium contents (mg kg^{-1}).

Investigated soil layer	Ploughing			Stubble cultivator loosening		
	16–17 cm	21–22 cm	24–25 cm	16–17 cm	21–22 cm	24–25 cm
	Available phosphorus content					
0–10 cm	61	65	66	62	57	57
10–15 cm	60	58	68	60	53	54
15–20 cm	51	59	65	50	53	51
20–25 cm	48	63	57	44	46	52
	Available potassium content					
0–10 cm	250	252	230	265	280	270
10–15 cm	215	220	250	225	250	240
15–20 cm	190	205	240	170	215	240
20–25 cm	160	200	215	155	170	170

As regards available potassium, its levels increased in the upper layer and decreased in the lower (10–20 cm) layers. Similar results have been obtained by other researchers (Comia et al., 1994; Rasmussen, 1999; Ausmane, 2000). Under stubble cultivator loosening, the resultant higher potassium content in the upper level also ensured a greater supply of available potassium in the 25 cm layer (Fig. 1). One of the reasons for the tendency was that the potassium turned deep underground by ploughing was now easier to be washed out.

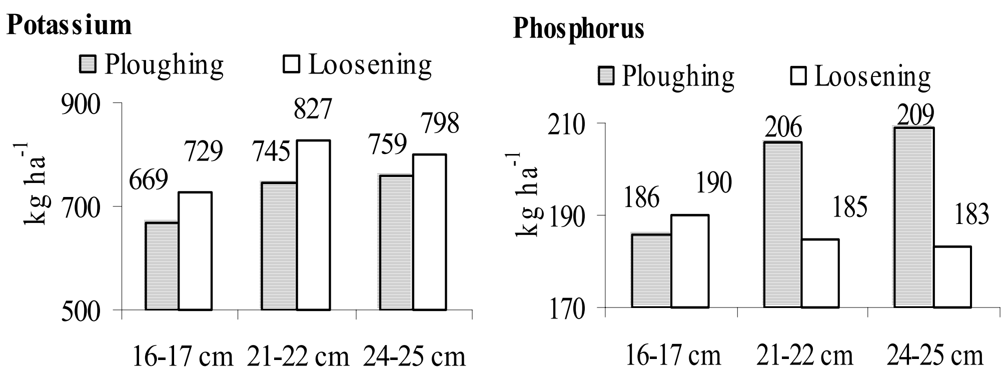

Fig. 1. The effect of long-term ploughing and stubble cultivator loosening on available phosphorus and potassium supplies in the ploughed layer (0–25 cm) in 1997.

CONCLUSIONS

The greatest changes were observed in the cereal-mixture of red clover and timothy-potato rotation, in which the available phosphorus supply decreased by 12–33% and the potassium supply by 41–46% in the 25 cm layer after two rotations compared to the cereal culture and the potato-cereal rotations.

As regards soil nutrient supplies the most stable rotation was that of cereals and potato. As less phosphorus was removed from the field with potato harvest than with cereal harvest or red clover-timothy mixture harvest, and less than was returned to the soil with fertilisation, the soil available phosphorus content increased.

In the cereal monoculture rotation the greater amounts of nutrients returned to the soil failed to ensure greater harvests. The yield-inhibiting factor proved to be the generally bad phytosanitary condition of the crop rotation.

When 87–130% of the phosphorus removed with the harvest was returned with fertilisation the soil available phosphorus content decreased. The content increased when twice the amount removed was returned.

Shallow ploughing depths as well as stubble cultivator loosening resulted in the differentiation of nutrients across the ploughed layer. Loosening led to a decrease in the available phosphorus content in the 10–25 cm layer and to an increase in the K content in the 0–25 cm layer; in addition, the potassium turned deep underground by ploughing was easier to be washed out.

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