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THE EFFECT OF NPK FERTILIZATION ON MINERAL PHOSPHORUS FRACTION CONTENT IN SOIL

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A b s t r a c t. A field experiment, conducted on loess-derived gray-brown podzolic soil, evaluated the effect of different levels of intensive fertilization with nitrogen, phosphorus and potassium on the soil content of mineral phosphorus fractions which are the major but varying source of this nutrient for crop plants. Before the establishment of the experiment, the soil contained 77.2 mg P kg^{-1}, 187 mg K kg^{-1}, 44 mg Mg kg^{-1}, and 1.18% of humus, whereas pH_{KCl} was 4.9. The experiment consisted of twenty seven fertilization treatments – nine nitrogen and potassium fertilization treatment combinations, each in four replicates, were carried out in relation to three increasing levels of phosphorus fertilization. Phosphorus fraction was indicated with the modified Chang-Jackson method. Mineral nitrogen, phosphorus and potassium fertilization after timothy grass harvest significantly affected the easily soluble phosphate fraction content in soil. Phosphorus fertilization caused the highest increase, while this increase was lower in the case of potassium and nitrogen fertilization. Mineral fertilization (with nitrogen, phosphorus, and potassium) used in the experiment caused a significant increase of the content of aluminium phosphate fractions in soil. Evaluating iron phosphate fraction content in soil, it can be concluded that it was the most stable fraction and that mineral fertilization at increasing NPK rates essentially did not have any statistically proven effect on its occurrence. Among the three fertilizer nutrients applied (NPK), phosphorus and potassium fertilization caused a significant increase in calcium phosphate fraction content in soil. The application of nitrogen was not found to have such an effect. Mineral NPK fertilization significantly affected the total mineral phosphorus fraction content in soil. A systematic increase in the total fraction analysed was found primarily under the influence of phosphorus and potassium fertilization. Phosphorus applied as granulated triple superphosphate was primarily transformed in the soil into fractions of iron and aluminium phosphates, to lower extent into calcium phosphate fraction, and – to the lowest extent – into easily soluble phosphates fraction.

K e y w o r d s: NPK fertilization, mineral phosphorus fractions, soil

INTRODUCTION

Soil fertility is a trait that is of utmost interest to a farmer. In the first place, the quantity and quality of crop yield depend on it (Bednarek 2011). Fertility depends on many soil properties, among which the availability of macro- and micronutrients (mainly their soluble forms) is particularly important (Adhami *et al.* 2012, Amaizah *et al.* 2012, Adhami *et al.* 2013). Phosphorus is one of the three (alongside nitrogen and potassium) major nutrients for plants. Phosphorus available to plants accounts for only a dozen or so percent of its total content in the soil (Moskal and Dełczewa-Walewa 1969, Samadi 2003, Kashem *et al.* 2004). Apart from knowing the content of this (available) form of phosphorus, it is also important to know mineral P fractions which are not an equivalent source for plants (Smith 1969, Kęsik and Pietrasz-Kęsik 1981). The occurrence of fractions depends on some physicochemical properties of the soil, among which pH should be considered to be the major one, as well as on fertilization, in particular fertilization with this nutrient (Minhas and Kick 1977, Chmielewska *et al.* 1980, Bednarek and Dechnik 1991, Wang *et al.* 2010). The form of phosphorus fertilizer plays a lesser role than the rate applied.

The aim of the present study was to determine the effect of different levels of intensive fertilization with nitrogen, phosphorus and potassium on the soil content of mineral phosphorus fractions which are the major but varying source of this nutrient for crop plants.

MATERIALS AND METHODS

This paper is based on the results collected from a three-year field experiment established and carried out at the Experimental Farm at Elizówka near Lublin on loess-derived grey-brown podzolic soil (2003-2005). Before the establishment of the experiment, the soil contained 77.2 mg P kg^{-1}, 187 mg K kg^{-1}, 44 mg Mg kg^{-1}, and 1.18% of humus, whereas pH_{KCl} was 4.9. The experiment consisted of twenty seven fertilization treatments – nine nitrogen and potassium fertilization treatment combinations, each in four replicates, were carried out in relation to three increasing levels of phosphorus fertilization. The area of one plot was 50 m^2, while the harvested plot area was 36 m^2. Nitrogen was applied as ammonium nitrate (34% N) at a rate of 120 kg N ha^{-1} (N_1) as well as at a rate two times (N_2) and three times (N_3) higher. Phosphorus was introduced in the form of granulated triple superphosphate (20.1% P) at a rate of 34.9 kg P ha^{-1} (P_1) as well as at a rate two times (P_2) and three times (P_3) higher. Potassium was applied as potassium salt (47.3% K) at a rate of 83 kg K ha^{-1} (K_1) as well as at a rate two times (K_2) and three time (K_3) higher. The full dose of phosphorus and a half dose of potassium were applied to the soil before sowing timothy grass cv. 'Skrzeszowicka'. In the second and third years, these fertilizers were applied after harvest of the third hay cutting; the second dose of potassium was applied each year after the first hay cutting. Nitrogen was incorporated into the soil in early spring (at the beginning of plant growth) as well as after the first and second hay cuttings in three equal parts. The first harvest of timothy grass was done in the third 10-day period of May or in the first ten days of June, the second hay cutting – in the third 10 day-period of July, while the third one – in the third 10 day-period of September or in the first ten days of October. After grass harvest, soil samples were collected from the individual treatments from the 0-20 cm soil layer (after each of the three hay cuttings and after three years), and mineral phosphorus fractions were determined in duplicate by the Chang-Jackson method with modifications according to Askinazi, Ginzburg and Lebiedew (the easily soluble phosphate fraction, the aluminium phosphate fraction, the iron phosphate fraction, the calcium phosphate fraction) (Chang and Jackson 1957, Askinazi *et al.* 1963). These analyses were performed at the laboratory of the Department of Agricultural and Environmental Chemistry, University of Life Sciences in Lublin. The contents of the phosphorus fractions determined were analysed by three-way cross-classification analysis of variance using Tukey's confidence half-interval ($p = 0.05$). Symbols N, P, and K, placed under the Tables, indicate that the Lowest Significant Difference (LSD) is the same for experimental factors calculated separately, and NP; NK; PK; NPK indicate the LSD for the interaction terms of these factors.

RESULTS AND DISCUSSION

The easily soluble phosphate fraction content in soil after timothy grass harvest was significantly dependent on mineral fertilization applied (Tab. 1). This influence can be best observed by analysing the application of the successive, increasingly higher rates of phosphorus as granulated triple superphosphate (relative to NK). After the application of the single dose of this nutrient (P_1), the content of the fraction in question was 4.83 mg P kg^{-1}, after the double dose (P_2) – 10.6 mg P kg^{-1}, whereas after the triple dose (P_3) – 15.8 mg P kg^{-1}. The significant increase in this fraction was primarily attributable to the type of fertilizer applied, which is well soluble in water, its relatively high rate, the relatively lower uptake of this nutrient by the increasingly higher yield of timothy grass, and the lack of movement (leaching) of phosphorus to the lower genetic soil horizons.

Fertilization with increasing rates of nitrogen (relative to PK) in the form of ammonium nitrate practically did not cause any significant differences in the easily soluble phosphate fraction content in soil. Under the influence of the single dose of this nutrient (N_1), the content of the fraction in question was 10.6 mg P kg^{-1}, after the double dose (N_2) – 10.2 mg P kg^{-1}, while after the triple dose (N_3) – 10.5 mg P kg^{-1}. The reduction in the content of this fraction in the N_2 treatment, statistically proven, could have been mainly caused by local soil variation, which is difficult to avoid when a field experiment is conducted on a relatively large area (more than one hectare). Essentially, the fact that fertilization with increasingly higher nitrogen rates was not found to affect the soil content of the more labile fraction of easily soluble phosphates may be evidence that it met the fertilization requirements of the increasing timothy grass yield at least at an optimal level, regardless of the nitrogen fertilization rate (Bednarek 2011).

Table 1. Easily soluble phosphate fraction content in soil after timothy grass harvest, mg P kg^{-1}

Fertilization	P_1			P_2			P_3			N Average
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3	
N_1	4.72	5.37	5.68	8.00	10.72	10.82	15.15	20.25	14.53	10.58
N_2	4.33	4.88	4.60	8.68	12.02	11.85	5.47	14.15	15.35	10.15
N_3	4.28	4.57	5.08	9.90	11.43	12.08	15.58	13.83	17.72	10.50
PK Average	4.44	4.94	5.12	8.86	11.39	11.58	15.40	16.08	15.87	10.41
P Average		4.83			10.61			15.78		
K Average				9.57	10.80	10.86				

$LSD_{0.05}$: N, P, K – 0.4; NP, NK, PK – 1.0; NPK – 2.0

Fertilization with potassium as potassium salt 47.3% K (relative to NP) caused a significant increase in the soil content of the phosphorus fraction evaluated, but only between the single and double doses as well as between the single and triple doses. Under the influence of the single dose of potassium (K_1), the easily soluble phosphate fraction content in soil was 9.6 mg P kg^{-1}, in the case of the double dose (K_2) – 10.8 mg P kg^{-1}, while for the triple dose (K_3) – 10.9 mg P kg^{-1}. This may be evidence that supplemental potassium fertilization, up to a certain level, contributes to a significant stabilising increase in the soil content of the phosphorus fraction in question.

It should be stressed that mineral fertilization significantly affected the easily soluble phosphate fraction content in soil. Phosphorus fertilization caused the highest increase, while this increase was lower in the case of potassium and nitrogen fertilization.

Conducting microplot experiments on spring wheat, Chmielewska *et al.* (1980) found a significant increase in the content of this fraction under the influence of high phosphorus rates used (140 and 280 kg P ha^{-1}). In pot and field experiments in which different rates and forms of phosphorus fertilizers were used, Moskal and Dełczewa-Walewa (1969), Bednarek 1991, Bednarek 1992 as well as Bednarek and Dechnik (1991) also found a significant increase in the content of the fraction analysed. It was relatively prone to migrate to the 20-40 cm soil layer under the influence of acid rain (Bednarek, Kaczor 1994) and also relatively easily taken up by plants (Smith 1969, Kęsik and Pietrasz-Kęsik 1981, Bednarek and Dechnik 1991, Amaizah *et al.* 2012).

Mineral fertilization, primarily with phosphorus and to a lesser degree with nitrogen and potassium, after timothy grass harvest significantly affected the aluminium phosphate fraction content in soil (Tab. 2). This is a fraction that can be a certain source of phosphorus for crop plants in a relatively short time from precipitation, especially in soils with a slightly acidic, neutral or basic reaction. As a result of fertilization with the single dose of phosphorus (P_1), relative to NK, the content of the fraction analysed was 109.2 mg P kg^{-1}, for the double dose (P_2) – 155.2 mg P kg^{-1}, whereas in the case of the triple dose (P_3) – 215.4 mg P kg^{-1}. Fertilization with increasing rates of phosphorus as granulated triple superphosphate resulted in a significant increase in the aluminium phosphate fraction content under the effect of the double and triple doses, compared to the single dose, as well as in the case of the triple dose compared to the double dose.

Table 2. Aluminium phosphate fraction content in soil after timothy grass harvest, mg P kg^{-1}

Fertilization	P_1			P_2			P_3			N
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3	Average
N_1	88.8	119.7	118.7	144.7	155.7	144.8	202.2	226.2	204.2	156.1
N_2	100.5	103.7	116.5	137.8	147.7	163.8	202.7	224.0	214.7	156.8
N_3	101.8	113.3	120.0	148.7	170.3	183.3	224.7	207.3	232.8	166.9
PK Average	97.0	112.2	118.4	143.7	157.9	164.0	209.8	219.2	217.2	159.9
P Average		109.2			155.2			215.4		
K Average				150.2	163.1	166.5				

$LSD_{0.05}$: N, P, K – 4.2; NP, NK, PK – 9.7; NPK – 19.4

Fertilization with increasing rates of nitrogen in the form of ammonium nitrate resulted in a significant increase in the aluminium phosphate fraction content in soil. This increase was statistically proven to be higher only in the plot fertilized with the triple dose of nitrogen compared to the single and double doses. After the application of the single dose (N_1), relative to PK fertilization, the soil content of the phosphorus fraction in question was 156.1 mg P kg^{-1}, for the double dose 156.8 mg P kg^{-1}, while for the triple dose – 166.9 mg P kg^{-1}. The significant increase in the content of this phosphorus fraction in soil could have been caused by the application of a high rate of nitrogen and an increase in H^+ concentration in the soil solution [pH_{KCl} – 4.7 (N_1) decreased to pH_{KCl} – 4.2 (N_3)].

Phosphorus fertilization caused a significant increase in the aluminium phosphate fraction content in soil in the treatments with the double dose and with the triple dose, respectively, compared to the single dose. As a result of the application of the single potassium dose (K_1), relative to NP fertilization, the content of the fraction in question was 150.2 mg P kg^{-1}, after the double dose (K_2) – 163.1 mg P kg^{-1}, while after the triple dose (K_3) – 166.5 mg P kg^{-1}. At the same time, this analysis shows unambiguously that especially the double dose of potassium resulted in an increase in the soil content of the phosphorus fraction analysed. Compared to the double dose, the application of the triple dose of potassium did not cause any significant increase in the aluminium phosphate fraction content in soil.

To sum up, it should be concluded that mineral fertilization applied after timothy grass harvest in the present experiment had a significant effect on the aluminium phosphate fraction content in soil. This conclusion applies to all the nutrients used for fertilization, *i.e.* nitrogen, phosphorus, and potassium.

Chmielewska *et al.* (1980) found that brown loess soil was enriched with the aluminium phosphate fraction, in proportion to the rate applied, but this was best seen in treatments with very high rates of phosphorus (140 and 280 kg P ha^{-1}). Apart from the rate, the increase in the content of this fraction was also dependent to a certain degree on the form of phosphorus fertilizer (Bednarek 1991, Bednarek and Dechnik 1991), but also on the type of soil and its properties as well as on the crop plant (Moskal and Dełczewa-Walewa 1969). At the same time, this fraction had a relatively high proportion in available phosphorus, as determined by different methods (Alexander and Robertson 1968). The occurrence of the aluminium phosphate fraction in the soil could have been dependent to some degree on its uptake by the plants, among others by annual ryegrass and spring barley or other plants (Smith 1969, Kęsik and Pietrasz-Kęsik 1981, Bednarek and Dechnik 1991, Amaizah *et al.* 2012).

Table 3. Iron phosphate fraction content in soil after timothy grass harvest, mg P kg^{-1}

Fertilization	P_1			P_2			P_3			N
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3	Average
N_1	257.0	254.8	272.5	283.2	278.0	241.8	245.7	258.3	239.5	259.0
N_2	255.7	250.8	265.2	255.3	275.0	261.0	246.3	239.3	243.8	254.7
N_3	276.8	265.5	269.3	275.2	270.2	259.7	236.0	241.8	240.7	259.5
PK Average	263.2	257.0	269.0	271.2	274.4	254.2	242.7	246.5	241.3	257.7
P Average		263.1			266.6			243.5		
K Average				259.0	259.3	254.8				

$LSD_{0.05}$: P – 6.8; PK – 15.7; NPK – 31.4

Fertilization with increasing rates of mineral fertilizers after timothy grass harvest essentially did not cause any significant changes in the iron phosphate fraction content in soil (Tab. 3). As a result of fertilization with increasing rates of phosphorus in the form of granulated triple superphosphate, in the soils in the treatment fertilized with the single dose (P_1), relative to NK, the content of the fraction in question was 263.1 mg P kg^{-1}, in the case of the double dose (P_2) – 266.6 mg P kg^{-1}, while for the triple dose (P_3) – 243.5 mg P kg^{-1}. No significant difference was found in the content of this fraction in the soils in the plots fertilized with the single and double doses of phosphorus; however, the amount of this fraction was significantly lower in the soils in the treatment fertilized with the triple dose (P_3) compared to the other two doses (P_1 and P_2). This can be explained by local soil variation and phosphorus uptake by timothy grass. Nevertheless, one should be aware that the iron phosphate fraction is a worse source of phosphorus for plants than the other two fractions discussed earlier (in the first place, the easily soluble phosphate fraction and to a lesser degree the aluminium phosphate fraction). More attention should be devoted to this issue in subsequent studies.

Fertilization with increasing rates of nitrogen as ammonium nitrate did not have any significant effect on the iron phosphate fraction content in soil. After the application of the single dose of nitrogen (N_1), relative to PK, the content of this fraction was 259.0 mg P kg^{-1}, after the double dose (N_2) – 254.7 mg P kg^{-1}, while after the triple dose (N_3) – 259.5 mg P kg^{-1}.

Fertilization with increasing rates of potassium after timothy grass harvest also did not cause any significant changes in the soil content of the phosphorus fraction evaluated. After the application of the single dose of this nutrient (K_1), the iron phosphate fraction content was 259.0 mg P kg^{-1}, after the double dose (K_2) – 259.3 mg P kg^{-1}, while in the case of the triple dose (K_3) – 254.8 mg P kg^{-1}. Evaluating the soil content of this fraction, it can be concluded that it was the most stable fraction and that mineral fertilization at increasing NPK rates essentially did not have any statistically proven effect on its occurrence.

Chmielewska *et al.* (1980) found that the iron phosphate fraction content increased only under the influence of the highest rate of phosphorus (280 kg P ha^{-1}); thus, it was much higher than the rate applied in the present experiment and the increase was associated with a significant decrease in soil pH. It was also dependent on the type of soil and its properties (Moskal and Dełczewa-Walewa 1969). In an experiment on loess-derived brown soil, Bednarek (1991) found that the soil content of the fraction in question significantly increased as affected by increasing rates of phosphorus. Fertilization with increasing rates of nitrogen and potassium did not have any statistically proven effect. This is also a fraction that showed much looser relationships with phosphorus available to plants than the fractions of easily soluble phosphates and aluminium phosphates (Kęsik and Pietrasz-Kęsik 1981, Bednarek 1991). Other authors have also drawn attention to the greater role of the iron phosphate fraction in available phosphorus, as determined by different methods (Alexander and Robertson 1968). At the same time, Bednarek and Kaczor (1994) report that under the influence of acid rain it significantly increased in the soil, but only in the 0-20 cm layer. The plants took up phosphorus mainly from the fractions of easily soluble phosphates and aluminium phosphates and at much lower amounts from the iron phosphate fraction (Kęsik and Pietrasz-Kęsik 1981, Bednarek and Dechnik 1991, Adhami *et al.* 2012).

Mineral fertilization after timothy grass harvest significantly affected the calcium fraction content in soil (Tab. 4). Fertilization with increasing rates of phosphorus (relative to NK) resulted in a significant, but non-systematic increase in the content of the fraction in question. Under the influence of the single dose (P_1), it was 129.9 mg P kg^{-1}, after the double dose (P_2) – 125.0 mg P kg^{-1}, while in the case of the triple dose (P_3) – 146.2 mg P kg^{-1}. The lower content of this fraction in the soil in the plots fertilized with the double dose of phosphorus could have been caused by local soil variation and a change in the availability of this nutrient, which unfortunately cannot be excluded in field experiments. It can therefore be presumed that the increase in the content of the fraction analysed as affected by phosphorus fertilization was higher than the uptake by timothy grass.

Table 4. Calcium phosphate fraction content in soil after timothy grass harvest, mg P kg^{-1}

Fertilization	P_1			P_2			P_3			N
	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3	Average
N_1	126.5	138.0	133.3	124.8	129.3	118.0	141.8	143.5	155.3	134.5
N_2	123.8	124.7	134.7	125.0	126.2	121.8	145.3	147.5	156.0	133.9
N_3	130.3	126.3	131.3	128.7	121.3	130.0	133.0	141.7	151.5	132.7
PK Average	126.9	129.7	133.1	126.2	125.6	123.3	140.0	144.2	154.3	133.7
P Average		129.9			125.0			146.2		
K Average				131.0	133.2	136.9				

$LSD_{0.05}$: P, K – 2.7; NP, NK, PK – 6.2; NPK – 12.4

As a result of the application of increasing rates of nitrogen (relative to PK), after its single dose (N_1) the content was 134.5 mg P kg^{-1}, in the case of the double dose (N_2) – 133.9 mg P kg^{-1}, whereas for the triple dose (N_3) – 132.7 mg P kg^{-1}. It can be noticed that with increasing nitrogen rate the soil content of the fraction in question systematically decreased. The reason could have been its uptake by the increasingly higher yield of timothy grass (Bednarek 2011). It should also be noted that the differences in the soil content of the fraction analysed due to nitrogen fertilization were too small to be considered statistically significant.

Fertilization with potassium as potassium salt 47.3% K resulted in a significant increase in the calcium phosphate fraction content in soil. After the application of the single dose of this nutrient (K_1), the content of the fraction in question was 131.0 mg P kg^{-1}, after the double dose (K_2) – 133.2 mg P kg^{-1}, whereas in the case of the triple dose (K_3) – 136.9 mg P kg^{-1}. Between the first and second rates, no significant difference was found in the content of this fraction in soil; however, in the soil fertilized with the triple dose this content was significantly higher than in the soils in the treatments fertilized with the two lower rates (K_1 and K_2). The statistically proven increase in the calcium phosphate fraction content in the soil fertilized with the triple dose of potassium could have resulted from its higher increase compared to the ability of timothy grass to take up this nutrient.

To sum up, it can be concluded that among the three fertilizer nutrients applied phosphorus and potassium fertilization after timothy grass harvest showed a significant and positive effect on the calcium phosphate fraction content in soil, while no such effect was found after the application of nitrogen.

Chmielewska *et al.* (1980) found than in brown loess soil with a slightly acidic reaction phosphorus not taken up by the plants was partially transformed into the fraction of relatively well soluble calcium phosphates, at an amount not dependent on pH and the phosphorus rates applied. In an experiment conducted on a similar type of soil, Bednarek (1991) observed that the soil content of this fraction of phosphates significantly increased under the influence of increasing phosphorus rates. Moskal and Dełczewa-Walewa (1969) found the largest amount of this fraction in rendzinas, while in chernozems or black earths no phosphorus fraction was distinctly predominant. In soil fertilized with Florida phosphorite, the calcium phosphate fraction had a certain proportion in the content of phosphorus available to plants. Plants (oats, white mustard – 1st year, maize, yellow lupine – 2nd year, and buckwheat – 3rd year of the experiment) took up and used phosphorus in the form of the calcium phosphate fraction in relatively large amounts, in particular in very acidic soil fertilized with Florida phosphorite and to a smaller extent in soil fertilized with Florida phosphorite ground with ammonium sulphate and Florida phosphorite ground with urea phosphate (Bednarek 1991). Minhas and Kick (1977) as well as Kęsik and Pietrasz-Kęsik (1981) noted that this fraction is taken up by plants in relatively small amounts. On the other hand, Smith (1969) found that wheat and clover fertilized with various fertilizers, among others phosphorite and basic slag, took up phosphorus mainly in the form of the aluminium and calcium phosphate fractions.

Table 5. Total mineral phosphate fraction content in soil after timothy grass harvest, the average for three years, mg P kg^{-1}

Fertilization	P1			P2			P3			N
	K1	K2	K3	K1	K2	K3	K1	K2	K3	Average
N1	469.5	508.6	476.6	496.9	549.0	505.4	676.1	682.1	677.2	560.2
N2	462.4	493.4	505.5	487.5	501.2	511.6	671.1	675.3	692.1	555.6
N3	487.6	499.8	511.8	513.8	524.2	538.6	683.3	663.6	703.1	569.6
PK Average	491.5	503.9	525.6	550.0	569.3	553.0	607.9	626.0	628.7	561.8
P Average		507.0			557.4			620.9		
K Average				549.8	566.4	569.1				

$LSD_{0.05}$: N, P, K – 9.9; NP, NK, PK – 22.9; NPK – 45.7

Mineral fertilization had a significant effect on the soil content of the total mineral phosphate fractions (*i.e.* the easily soluble, aluminium, iron and calcium phosphate fractions) (Tab. 5). This content is a resultant of the presence of the above analysed fractions in the soil. Phosphorus fertilization (relative to NK) resulted in the total phosphate fraction content in soil at the following levels: single dose (P_1) – 507.0 mg P kg^{-1}, double dose (P_2) – 557.4 mg P kg^{-1}, and triple dose (P_3) – 620.9 mg P kg^{-1}. Under the influence of the next phosphorus dose, this increase was statistically significant; this is not an untypical situation if we take into account the quantity of the doses of the nutrient applied.

Nitrogen fertilization (relative to PK) also had a significant effect on the total phosphorus fraction content in soil after timothy grass harvest. However, this effect was not systematic and was probably caused by local (relating only to a part of the experimental area) soil variation and the related availability of the above determined mineral phosphorus fractions. After the application of the single dose of nitrogen (N_1), the total phosphorus fraction content was 560.2 mg P kg^{-1}, after the double dose (N_2) – 555.6 mg P kg^{-1}, while after the triple dose (N_3) – 569.6 mg P kg^{-1}. No significant difference was found in the total fraction content between the single and triple doses, and its significant decrease in the soil fertilized with the double dose could have been due to the above-mentioned reasons.

The study found a systematic and significant effect of potassium fertilization (relative to NP) on the total phosphorus fraction content in soil. As affected by the single dose (K_1), this content was 549.8 mg P kg^{-1}, in the case of the double dose (K_2) – 566.4 mg P kg^{-1}, while for the triple dose (K_3) – 569.1 mg P kg^{-1}. There was a significant difference only between the single dose in relation to the double and triple doses; no statistically proven difference in the total phosphorus fraction content was found between the double and triple doses.

To sum up, it can be concluded that mineral NPK fertilization after timothy grass harvest significantly affected the total phosphorus fraction content in soil. A systematic increase in the total fraction analysed was primarily found under the influence of phosphorus and potassium fertilization.

If we take into account that the soil contained large amounts of total phosphorus, *i.e.* 1.5 g P kg^{-1}, this means that the mineral fractions of this nutrient determined in the present experiment only make up a small portion of it: easily soluble phosphate fraction 0.7%, aluminium phosphate fraction – 10.7%, iron phosphate fraction – 17.2%, calcium phosphate fraction – 8.9%, and total fraction – 37.5%. Organic compounds of this nutrient constitute a major percentage of total phosphorus (62.5%).

CONCLUSIONS

1. Mineral nitrogen, phosphorus and potassium fertilization after timothy grass harvest significantly affected the easily soluble phosphate fraction content in soil. Phosphorus fertilization caused the highest increase, while this increase was lower in the case of potassium and nitrogen fertilization.

2. Mineral fertilization (with nitrogen, phosphorus, and potassium) applied in the experiment significantly impacted the growth of contents of aluminium phosphate fractions in soil.

3. Evaluating the iron phosphate fraction content in soil, it can be concluded that it was the most stable fraction and that mineral fertilization at increasing NPK rates essentially did not have any statistically proven effect on its occurrence.

4. Among the three fertilizer nutrients applied (NPK), phosphorus and potassium fertilization after timothy grass harvest had a significant effect on increasing the calcium phosphate fraction content in soil. The application of nitrogen was not found to have such an effect.

5. Mineral NPK fertilization after timothy grass harvest significantly affected the total mineral phosphorus fraction content in soil. A systematic increase in the total fraction analysed was found primarily under the influence of phosphorus and potassium fertilization.

6. Phosphorus applied as granulated triple superphosphate was primarily transformed in the soil into fractions of iron and aluminium phosphates, to a lower extent into calcium phosphate fraction, and – to the lowest extent – into easily soluble phosphates fraction.

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WPŁYW NAWOŻENIA NPK NA ZAWARTOŚĆ MINERALNYCH FRAKCJI FOSFORU W GLEBIE

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S t r e s z c z e n i e. W doświadczeniu polowym przeprowadzonym na glebie płowej wytworzonej z lessu oceniano wpływ intensywnego, zróżnicowanego, nawożenia azotem, fosforem i potasem na zawartość mineralnych frakcji fosforu w glebie, które stanowią podstawowe, ale różniące się, źródło tego składnika dla uprawianych roślin. Przed założeniem eksperymentu gleba zawierała 77,2 mg P·kg^{-1}, 187 mg K·kg^{-1}, 44 mg Mg·kg^{-1}, 1,18% próchnicy oraz pH_{KCl} – 4,9. Doświadczenie obejmowało dwadzieścia siedem obiektów nawozowych – na tle trzech, wzrastających poziomów nawożenia fosforem, rozlosowano dziewięć kombinacji azotowo-potasowych, w czterech powtórzeniach każda. Frakcje fosforu oznaczono zmodyfikowaną metodą Changa-Jacksona. Nawożenie mineralne azotem, fosforem i potasem, po zbiorze tymotki łąkowej, w istotny sposób wpływało na zawartość frakcji fosforanów łatwo rozpuszczalnych w glebie. Największy przyrost powodowało nawożenie fosforem, mniejszy potasem oraz azotem. Zastosowane w eksperymencie nawożenie mineralne (azotem, fosforem i potasem) istotnie wpływało na przyrost zawartości frakcji fosforanów glinowych w glebie. Oceniając zawartość frakcji fosforanów żelazowych w glebie, można stwierdzić, że była ona najbardziej stabilną frakcją i, że nawożenie mineralne wzrastającymi dawkami NPK w zasadzie nie miało wpływu udowodnionego statystycznie na jej występowanie. Spośród trzech zastosowanych składników nawozowych (NPK), nawożenie fosforem oraz potasem wpływało istotnie na przyrost zawartość frakcji fosforanów wapniowych w glebie. Takiego wpływu nie odnotowano po zastosowaniu azotu. Nawożenie mineralne NPK wpłynęło istotnie na zawartość sumy mineralnych frakcji fosforu w glebie. Systematyczny przyrost ocenianej sumy frakcji odnotowano przede wszystkim pod wpływem nawożenia fosforem oraz potasem. Fosfor zastosowany w postaci superfosfatu potrójnego granulowanego przechodził w glebie przede wszystkim we frakcję fosforanów żelazowych i glinowych, w mniejszych ilościach – frakcję fosforanów wapniowych oraz w najmniejszych – frakcję fosforanów łatwo rozpuszczalnych.

Słowa kluczowe: nawożenie NPK, frakcje fosforu mineralnego, gleba