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The utilization of phosphorus from purified municipal sewage by cultivated plants

ABSTRACT. The aim of this study was the agrochemical evaluation of purified municipal sewage as a source of phosphorus – one of the basic nutrients. The study was based on the chemical analysis of plant material obtained from a strict two-year pot experiment. The soil material used for the experiments was collected from the depositional layer of the peak-muck soil made of low moor peat (organic soil) and from podzolic soil with granulometric composition of light loamy sand (mineral soil). The test plants were spring barley, spring rape and sunflower. The application of purified municipal sewage influenced the increase of phosphorus content in the dry plant matter. The increase was more conspicuous in plants grown on the organic soil. This justifies the statement that sewage can be a source of phosphorus for plants, which is comparable with mineral fertilizers. The plants watered with sewage took a little less phosphorus than those fertilized with mineral salts. Also fertilization with sewage supplemented with salts in most cases affected the absorption of this component less effectively than fertilization with mineral salts in the optimum rate. When equivalent amounts of phosphorus were applied, the test plants utilized the analyzed component from mineral fertilizers to a greater extent than that from purified municipal sewage. Similarly, the application of sewage and supplementing it with mineral salts up to the level that was assumed as optimum contributed to the decrease of the degree in which phosphorus was utilized in comparison with that found in the treatments where mineral salts in the optimum rate were exclusively used. Among the tested species, spring rape is the most suitable for thorough sewage treatment.

KEY WORDS: phosphorus, utilization, sewage effluent, pot experiment

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Phosphorus is one of the basic ingredients that are indispensable for the life of all organisms. The physiological functions of this element, its participation in the metabolism of plants, as well as its influence on their development, cropping and crop quality, are commonly known [Johansson, Hylander 1998; Czuba 2001].

The concentration of phosphorus in sewage water is high. However, its presence in purified municipal sewage is undesirable, as it has vital effect on the water eutrofication process. The effective way of managing phosphorus contained in purified municipal sewage is using it for soil fertilization and cultivated plant nutrition [Czyżyk 1994; Kaczor, Kozłowska 1997a; Kaczor, Kozłowska 1997b; Bednarek, Lipiński 1998; Filipek, Olek 1999].

In periodical deficits of water or certain elements in the soil, sewage may be their significant supplement. Thus, the aim of this study was the agrochemical evaluation of purified municipal sewage as a source of phosphorus – one of the basic nutrients.

METHODS

The study was based on the chemical analysis of plant material obtained from strict two-year pot experiments. The soil material used for the experiment was collected from the depositional layer of the peat-muck soil made of low moor peat (organic soil) and from podzolic soil with granulometric composition of light loamy sand (mineral soil). The organic soil contained 33% organic matter, 1.62% N in total, and 668.5 mg N kg^{-1} – of the easily hydrolyzing nitrogen. It had a very high content of available phosphorus and a very low content of potassium and magnesium. In the mineral soil the total N content was 0.16 %, the content of easily hydrolyzing nitrogen – 84 mg N kg^{-1}. The content of available phosphorus was average, of potassium – low, and of magnesium – very low. Pots of 5 dm^3 cubic capacity were used for the experiment. They held 6 kg mineral soil, which contained 7.7% H_2O and 4.5 kg organic soil of 53.6% moisture.

The experiments were conducted in two series. In the first series the test plant was orchard grass, which was collected three times during its vegetation period. Then, the following year, spring barley was sown. It was gathered in the phase of its full ripeness. In the second series corn was grown, and mustard as aftercrop. After it had been harvested, the following year, spring rape was sown, and then – garden sunflower. The rape was harvested in full blossom, and the sunflower was gathered in the beginning of its blooming period. After the appropriate number of plants had sprouted up and had been left in the pot, they were watered with purified municipal sewage, in accordance with the experimental scheme, which comprised 8 fertilization treatments in 4 repetitions on mineral soil, and the same number of fertilization treatments on organic soil: 1. Control, without fertilization; 2. Watering plants with sewage water in the quantity of 100 cm^3 per pot a day; 3. Watering plants with sewage water in the quantity of 200 cm^3 per pot a day; 4. Mineral fertilization (N, P, K, Mg) in the quantity equivalent to 100 cm^3 per pot a day; 5. Mineral fertilization (N, P, K, Mg) in the quantity equivalent to 200 cm^3 per pot a day; 6. Mineral fertilization (N, P, K, Mg) in the optimum rate; 7. Sewage water in the rate of 100 cm^3 per pot a day + mineral fertilization up to the optimum level; 8. Sewage water in the rate of 200 cm^3 per pot a day + mineral fertilization up to the optimum level.

The biologically purified municipal sewage used in the experiment came from the municipal biological-mechanical treatment plant Hajdów in Lublin. On average, in 1 dm^3 of sewage, the following amounts of basic components were contained: soluble N – 30 mg, soluble PO_4-P 4 mg, total K – 30 mg, total Mg – 10 mg, SO_4-S – 80 mg. The amount of components introduced with the sewage during one vegetation period on g/pot at lower rate was: N – 0.36, P – 0.048, K – 0,36, Mg – 0.12, S – 0.96. At the higher rate of sewage these amounts were twice as high.

The mineral fertilizers were used in the form of soluble salts (NH_4NO_3, KH_2PO_4, KCl $MgSO_4$ $7H_2O$). The total rate of these components in g per pot, applied during one vegetation season in treatment 6 was: N – 2.4; P – 0.52; K – 1.41; Mg – 0.24. The mineral salts dissolved in distilled water were used in accordance with the assumed experimental scheme.

In all treatments the soil moisture was maintained by watering plants to fixed constant weight with distilled water, on the level of 60% of maximum water capacity.

In the plant material of the average treatment tests, after mineralizing in concentrated sulfuric acid with added H_2O_2, phosphorus was determined by means of the vanadium-molybdenum method. We calculated the uptake and utilization of this element by plants using the percentage of the analyzed component, plant yield [Kaczor, Kozłowska 1997a; Kaczor, Kozłowska 1997b] and the applied rate of phosphorus. The effect of the experimental factors on the uptake and utilization was calculated with the use of variance analysis with the application of Tukey confidence half-intervals.

RESULTS

The application of purified municipal sewage induced distinct changes in the content, uptake and utilization of phosphorus by cultivated plants (Tab 1, Tab. 2, Tab. 3). The range of these changes, like in the studies by other authors [Borowiec, Gajda 1993; Talik 1993; Czyżyk 1994; Kaczor, Kozłowska 1996; Kaczor, Brodowska 2001], depended on the species of the plant, rate of sewage, and type of soil.

Table 1. The effect of municipal sewage on the content of phosphorus in plants

Treat-ment*	Mineral soil				Organic soil				Mean
	Spring barley		Spring rape	Sun-flower	Spring barley		Spring rape	Sun-flower	
	grain	straw			grain	straw			
	%								
1	0.37	0.050	0.24	0.29	0.20	0.030	0.10	0.18	0.21
2	0.41	0.025	0.26	0.17	0.22	0.065	0.17	0.16	0.21
3	0.42	0.030	0.21	0.18	0.37	0.082	0.20	0.21	0.25
4	0.34	0.010	0.25	0.14	0.26	0.010	0.10	0.12	0.18
5	0.33	0.010	0.21	0.12	0.33	0.085	0.11	0.13	0.19
6	0.46	0.080	0.30	0.44	0.61	0.230	0.31	0.48	0.42
7	0.35	0.023	0.29	0.30	0.53	0.310	0.26	0.42	0.36
8	0.36	0.025	0.29	0.21	0.54	0.360	0.27	0.29	0.33
Mean	0.38	0.032	0.26	0.23	0.38	0.147	0.19	0.25	-
Mean	0.22				0.24				-

* Explanations like in methods

Table 2. The effect of municipal sewage on the uptake of phosphorus by plants

Treat-ment	Mineral soil			Organic soil			Mean
	Spring barley	Spring rape	Sun-flower	Spring barley	Spring rape	Sun-flower	
	mg P per pot						
1	26.8	25.7	13.3	11.9	14.1	6.7	16.42
2	50.9	43.4	19.4	40.2	36.2	10.2	33.38
3	45.1	43.0	26.3	62.5	49.6	16.8	40.55
4	54.5	50.7	23.2	40.8	32.1	9.5	35.13
5	75.1	63.0	27.1	73.5	61.2	16.4	52.72
6	146.2	168.3	139.9	170.9	254.5	71.0	158.46
7	109.5	172.8	122.4	190.7	254.5	67.2	152.85
8	109.3	179.5	90.9	209.1	234.4	59.7	147.15
Mean	77.18	93.30	57.81	99.95	117.08	32.19	-
Mean	76.1			83.07			-

LSD $_{(0.05)}$ treatment x plant 126.6, treatment x soil 92.1, plant x soil 45.2

Table 3. The effect of municipal sewage on the utilization of phosphorus by plants

Treat-ment	Mineral soil			Organic soil			Mean
	Spring barley	Spring rape	Sun-flower	Spring barley	Spring rape	Sun-flower	
	%						
1	-	-	-	-	-	-	-
2	50.2	36.9	12.7	59.0	46.0	7.3	35.35
3	19.1	18.0	13.5	52.7	37.0	10.5	25.13
4	57.7	52.1	20.6	60.2	37.5	5.8	38.98
5	50.3	38.9	14.4	64.2	49.1	10.1	37.83
6	23.0	27.4	24.3	30.6	46.2	12.4	27.31
7	15.9	28.3	21.0	34.4	46.2	11.6	26.23
8	15.9	29.6	14.9	37.9	42.4	10.2	25.15
Mean	33.16	33.03	17.34	48.42	43.48	9.7	-
Mean	27.84			33.87			-

$LSD_{(0.05)}$ treatment x plant 20.6, treatment x soil 15.5, plant x soil 8.3

The irrigation of sewage water influenced the increase of phosphorus content in dry matter of the tested plants (Tab. 1). It was more distinct in plants grown on the organic soil and was almost three times as large in spring barley straw compared with the values determined in plants from the control series.

The results of studies by other authors, concerning the influence of sewage on the amount of this element in the plant dry matter, are not as explicit. According to Majdowski [1968], Borowiec and Gajda [1993], as well as Bieniek et al. [2000], sewage water contributes to the increase of phosphorus content in plant dry matter. However, in other papers concerning green crops [Czyżyk 1968] and spring barley [Kutera 1969], no visible influence of sewage irrigation on the content of this component was revealed.

In the conditions of the performed experiments, after increasing the sewage rate from 100 to 200 cm^3 per pot a day, the content of phosphorus in the plant dry matter increased (by 24% on average). The spring rape, cultivated on the mineral soil was the exception. In this case the increase of sewage rate caused a slight decrease of the content of this component. The increase of phosphorus concentration under the influence of increasing sewage rates was also observed in experiments concerning meadow grasses [Kaczor, Kozłowska 1996; Kaczor, Brodowska 2001].

The comparison of the content of the analyzed component in plants watered with purified municipal sewage with the amount of phosphorus in plants watered with mineral salts was also interesting. All the tested plants, watered with sewage water, had higher concentrations of this element. The biggest, more than six-fold increase of phosphorus concentration occurred in spring barley straw. The barley was cultivated on the organic soil. The increase of phosphorus content in dry plant matter is an advantageous phenomenon, which raises the fodder value of the obtained feed.

The application of mixed fertilization (sewage + mineral salts) caused the decrease of the analyzed component concentration in comparison with the amount observed in the dry matter of plants which were fertilized exclusively with mineral salts in the optimum rate. This probably resulted from the fact that phosphorus occurs in purified sewage partly in its organic form, and therefore it is available to plants only after mineralization.

The influence of the purified municipal sewage was also distinctly marked in the amount of phosphorus taken by cultivated plants (Tab. 2). The introduction of sewage water contributed to the increase of the analyzed component uptake in comparison with its accumulation observed in the control. An especially distinct increase of absorption was found on the organic soil (2,5–fold in sunflower; 3.5–fold in spring rape, and 5–fold in spring barley). The results support the observations of other authors that purified municipal sewage are a good source of phosphorus for plants [Borowiec, Gajda 1993; Kaczor, Brodowska 2001].

However, it is interesting that spring barley, spring rape, and sunflower, that were watered with sewage water, took less phosphorus that the plants which were fertilized with mineral salts in equivalent rates. The causes of the decrease of the amount of the component taken up were lower yields obtained in the treatments where sewage were applied [Kaczor, Kozłowska 1997a; Kaczor, Kozłowska 1997b].

The influence of mixed fertilization (sewage + mineral salts) on the uptake of phosphorus depended on the plant species and type of soil. Generally, it can be stated that the mixed form of fertilization induced the decrease of the analyzed component uptake. Only the spring rape grown on the mineral soil and the spring barley cultivated on the organic soil took a little more phosphorus from the treatments where sewage was used and supplemented with mineral fertilizers.

The applied experimental factors (soil, fertilizer, plant) also significantly affected the utilization of phosphorus (Tab. 3). The spring barley and spring rape grown on the organic soil made better use of the analyzed component than the plants cultivated on the mineral soil. A different situation was observed in the case of the sunflower.

The influence of the increasing rates of sewage water on the utilization of phosphorus was dependent on the plant species. Both spring rape and spring barley, fertilized with a higher rate of purified municipal sewage, used the analyzed component to a much less extent than those watered with a lower rate of sewage water, whereas the sunflower, fertilized with 200 cm^3 of sewage per pot a day, made use of more phosphorus compared with the values reported in the treatments where 100 cm^3 of sewage per pot a day were used. The fact that the utilization of the analyzed element decreased with the increase of the sewage rate was also found by Talik and Pławiński [1995].

When we were comparing the utilization of the phosphorus from purified municipal sewage with the uptake of this element from mineral salts used in equivalent rates, we found that plants utilized this component better when it was applied in the form of mineral fertilizers. Most probably it was caused by the fact that a part of the phosphorus contained in purified municipal sewage occurs in the form of organic compounds.

The effect of mixed fertilization (sewage + mineral salts) on the utilization of the analyzed component depended on the plant species and type of soil. The spring rape cultivated on the mineral soil and spring barley cultivated on the organic soil utilized the phosphorus applied in a mixed form to a little greater extent than the phosphorus used in the form of mineral salts in the optimum rate. All the remaining test plants utilized the analyzed component better when it was applied exclusively in the form of mineral fertilizers.

The results of the conducted studies indicate that purified municipal sewage compared with mineral fertilizers was a comparable source of phosphorus for plants. The proof of this is especially the content of this component in the test plants. This results from the fact that watering plants with sewage water may also influence the improvement of phosphorus balance in soils [Szerszeń et al. 1996; Bednarek, Lipiński 1998]. It is significant because in many regions of Poland there are soils that have very low and low content of this component [Sapek 1998].

The results also indicate that the plants may be used for purification of sewage water from the basic element, which is phosphorus. Among the tested plants, due to high absorption of the analyzed ion, spring rape was most suitable for this purpose.

Conclusions

1. The application of purified municipal sewage influenced the increase of phosphorus content in the dry plant matter. The increase was more conspicuous in plants grown on the organic soil. This justifies the statement that sewage can be a source of phosphorus for plants, which is comparable with mineral fertilizers.

2. The plants watered with purified municipal sewage took a little less phosphorus than those fertilized with mineral salts. Also fertilization with sewage supplemented with salts in most cases affected the absorption of this component less effectively than fertilization with mineral salts in optimum rates.

3. When the equivalent amounts of phosphorus were applied, the test plants utilized the analyzed component from mineral fertilizers to a greater extent than that from purified municipal sewage. Similarly, the application of sewage and supplementing it with mineral salts up to the level that was assumed as optimum contributed to the decrease of the degree in which phosphorus was utilized in comparison with that found in the treatments where mineral salts in the optimum rate were exclusively used.

4. The spring rape and, to a smaller extent, sunflower and spring barley, may be used for eliminating phosphorus from sewage water.

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