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Franciszek CZYŻYK[1] and Agnieszka RAJMUND[1]

LEACHING OF BIOGENIC ELEMENTS (NPK) FROM FERTILIZED LIGHT SOIL

WYMYWANIE PIERWIASTKÓW BIOGENNYCH (NPK) Z NAWOŻONEJ GLEBY LEKKIEJ

Abstract: This review presents results of investigation from 6 years studies of an annual light soil fertilization with mineral fertilizer influence on quantity amount of nitrogen (N), phosphorus (P) and potassium (K) penetration to water environment. The studies were done in lysimeters filled with light-clayey sand. In this studies two variants of compost fertilization (K1 - 10 and K2 - 15 g N · m^{-2}) were used. Additionally two variants of NPK with equivalent doses of nitrogen as an ammonium nitrate supplemented with PK as a superphosphate and potassium salt were applied. The results showed the increase of concentrations of nitrogen in the soil leachates, with increasing doses of fertilizer. During the time of fertilization there was observed intense increase of quantity of nitrogen eluted from the soil, which indicated on the presence of this element in the soil. The total quantity of nitrogen drained in leachates from soil were 14.9-17.3 $g \cdot m^{-2}$ of the total quantity of nitrogen supplied to the soil in the variants with compost fertilization, and 19.6-27.3 $g \cdot m^{-2}$ in the variants with mineral fertilization. Content of the phosphorus in the leachate from the soil, in contrast to the nitrogen, were relatively small and did not show depending on the type and dose of fertilizer, or the passage of time from the application of fertilizer. Leaching P were negligible 0.11-0.14 $g \cdot m^{-2}$ and independent of the type of fertilizer used. Loss of K as well as N were higher in variants with mineral fertilizers (28.4-31.7 $g \cdot m^{-2}$) than in the case of the use of compost (21.4-23.9 $g \cdot m^{-2}$).

Keywords: fertilization, biogenic components, leachate from the soil, lysimeters

Introduction

In recent years, growth in crop production caused a significant increase in the consumption of fertilizers [1, 2]. Crop production is seen as one of the main sources of pollutants leaching into groundwater [3]. In the current agricultural practice annual fertilization is used, and doses of fertilizers are usually determined according to the nutritional requirements of plants. Soil richness in digestible nutrients is not taken into account [4]. Fertilization currently used in agriculture - intensive crop production often deviates from accepted agricultural practices. Doses of fertilizers, especially nitrogen, often exceed the recommended level for sustainable agriculture [5]. This creates an excess of soluble components of fertilizers in the soil as well as their leaching and pollution of the water environment [6]. It concerns light soils, characterized by good permeability and generally low sorption properties [7]. Fertilizers used in agriculture are not fully utilized by the plants and are not discharged from the crop. Significant parts of component of fertilizers, both organic and mineral, are rinsed from the soil. The nutrients supplied to the soil in the mineral fertilizers are easily soluble and easily available to plants [8]. Nitrogen (N) supplied to the soil in mineral fertilizers, especially nitrate, is easily leached from the soil into the groundwater. Under anaerobic conditions it undergoes a process of denitrification which is associated with the formation of gaseous forms of NO, N_2O and N_2,

[1] Institute of Technology and Life Sciences - Lower Silesia Research Centre in Wrocław, ul. Z. Berlinga 7, 51-209 Wrocław, Poland, phone/fax +48 71 367 80 92, email: f.czyzyk@itep.edu.pl, agnieszka_rajmund@o2.pl
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which afterwards are oxidized to the atmosphere [9, 10]. Annual fertilization with phosphorus (P) may cause accumulation of P in the soil [11], and then its release into the water in an uncontrolled manner. Szara et al [12] write that P in mineral fertilizers used by the plant in about 20%. The remaining part of P in the soil undergoes changes into forms with different availability to plants [13]. Depending on soil conditions (pH, humidity), some of them may transform into inedible compounds and is locked. The use of potassium fertilizers (K) is necessary in sustainable fertilization of plants. The interaction between K and N is important. Unequal fertilization N/K leads to an increase in the concentration of nitrate in plant tissue. Potassium in mineral fertilizers is an element quite easily eluted from the soil, especially light soil [14]. The compost from sewage sludge used as a fertilizer is rich in organic matter and nutrients, which are released gradually over a longer period of time [8]. Organic nitrogen supplied to the soil undergoes complex and dynamic changes in which the nutrients are released in the forms of available for plants. Biogenic components, which will not be taken up by the plant are usually leached into the groundwater [15]. The scale of the threat depends on the size of the doses of compost, but is much smaller than at fertilization equivalent doses of mineral fertilizers.

In this paper presents the results of six-year study showing the degree of fertilizers components leaching from sandy soil annually fertilized by moderate doses of compost and mineral fertilizers.

Conditions and methods

The studies were conducted in 2002-2007 in lysimeters filled with clayey sand containing *ca* 14% of the earthy particles (fraction < 0.02), 0.7% organic carbon and 0.1% of the total nitrogen. Conditions in the lysimeters are similar to the natural field conditions. Lysimeters with a diameter of 100 cm and a depth of 130 cm are completely submerged in the ground. Every year the soil was fertilized by compost made from sewage sludge rural and vegetable waste, containing *ca* 2.5% total nitrogen, 20% organic carbon and 63% organic matter. Compost mixed with the top layer of soil. Each year, before the spring application of compost to fertilize, it was determined the content of the major components of fertilizers. Two variants of compost fertilization (K1 - 10 and K2 - 15 g $N \cdot m^{-2}$) were used. Additionally two variants of NPK with equivalent doses of nitrogen as an ammonium nitrate supplemented with PK as a superphosphate and potassium salt were applied (NPK1 - 10 g $N \cdot m^{-2}$ + 2.5 g $P \cdot m^{-2}$ + 6 g $K \cdot m^{-2}$ + 4 g $P \cdot m^{-2}$ + 9 g $K \cdot m^{-2}$). All variants were used in three replications. In the following years of research lysimeters were sown by: a mixture of grasses, corn, sugar beets, white mustard (to seeds), triticale and canola. Systematically there were investigated the volume of precipitation and leachates as well as the samples of water for laboratory analysis were collected. Chemical analyzes were performed according to the method currently in force and widely used [16, 17].

Results and discussion

Individual years of research considerably differ in terms of the amount of precipitation (Table 1). Leachate volume in the lysimeters was also varied and mainly depending on the amount of precipitation and to a lesser extent on the variants of fertilization and the type of fertilizer (Table 2). Leachate from the lysimeters occurred mainly during the late autumn and winter. In growing season the volume of leachate was much smaller and they only occurred after heavy precipitation, *eg* in May and July 2005 and August 2006. Depending on the moisture of the content of the soil, the leachate typically occurs after a period from several hours to two days after the onset of intense precipitation.

Precipitation in the growing seasons in different years were significantly higher than in the autumn-winter period and accounted for 60-70% of annual precipitation. The volume of leachate from the soil during vegetation season was significantly lower than in the autumn and winter periods. Of the total five-year amount of leachate, in particular variants of fertilization, only 24-29% occurred on vegetation seasons, and 71-76% for the autumn-winter period.

Table 1

Atmospheric precipitation at research station of the Lower Silesian Research Centre in Kamieniec Wroclawski in the years 2002-2007

Year	**Precipitation in months**											
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**
2002	23.8	59.2	15.7	32.9	37.1	68.2	49.5	78.7	52.2	61.2	52.3	16.2
2003	40.0	2.8	18.7	11.9	80.5	24.3	58.8	55.3	42.4	51.5	27.8	47.3
2004	31.2	60.6	56.6	24.5	35.2	40.5	88.5	50.8	21.8	45.6	81.4	15.4
2005	46.2	51.2	11.5	27.0	150.8	46.8	122.6	54.4	24.9	6.7	31.0	106.4
2006	28.9	43.7	26.1	54.2	21.9	56.6	12.0	179.3	20.3	68.4	65.6	36.7
2007	64.6	53.3	55.5	3.6	57.6	79.5	124.1	42.0	51.6	26.5	56.0	27.9

Source: own studies

Table 2

Annual amount of precipitation and volume of leachates [dm^3] from particular fertilization variants in the period of IV 2002 - VII 2007

Year	**Annual amount of precipitation [mm]**	**Volume of leachates from particular variants**			
		K1	**K2**	**NPK1**	**NPK2**
2002	547.0	37.1[1)]	28.9[1)]	41.7[1)]	45.2[1)]
2003	461.3	66.0	64.3	64.5	54.6
2004	552.1	97.1	94.3	101.1	108.0
2005	679.5	112.1	123.2	119.7	122.6
2006	613.7	95.1	88.0	109.4	105.5
2007	642.2	64.8[2)]	62.0[2)]	69.7[2)]	64.4[2)]

[1)] 1 IV - 31 XII 2002 [2)] 1 I - 30 VI 2007

Explanations: K1, K2 - variants of soils fertilized with compost 10 and 15 $g N \cdot m^{-2}$, respectively;
NPK1 - 10 $g N \cdot m^{-2}$ + 2.5 $g P \cdot m^{-2}$ + 6 $g K \cdot m^{-2}$; NPK2 - 15 $g N \cdot m^{-2}$ + 4 $g P \cdot m^{-2}$ + 9 $g K \cdot m^{-2}$.

Source: own studies

The tested leachates from the soil are characterized by varying concentration of the NPK components (Table 3). In the leachates from all variants of fertilization, the largest there were concentrations of potassium and smallest of phosphorus. The variability of the concentrations of individual elements was at the average level (Table 4). Variation of concentrations of potassium, was lower than in the case of nitrogen and phosphorus.

Average nitrogen concentrations in the leachate from the lysimeters varied and depending on the variants of fertilization. These concentrations were calculated as the weighted average of the volume of leachate and content of analyzed components (NPK).

The concentrations of nitrogen in the leachate from the soil fertilized by compost were significantly lower than in the leachate from the soil fertilized with an equivalent dose of N as an ammonium nitrate [18].The concentration of N in the leachate from the soil increased with increasing doses of fertilizers, and also significantly increased over the years of use of fertilizer. This indicates the formation of excess N in the soil as a result of the use of annual fertilization, and thus increasing the water pollution with that component.

Table 3

Average annual concentrations of N, P and K in leachates from different variants of fertilization in IV 2002-VI 2007 [$mg \cdot dm^{-3}$]

Year	**K1**			**K2**			**NPK1**			**NPK2**		
	N	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**
2002[1)]	5.7	0.19	38.4	6.3	0.19	40.9	8.2	0.22	45.5	17.9	0.20	49.8
2003	13.8	0.19	38.7	16.8	0.23	41.5	18.4	0.20	47.0	24.4	0.27	49.5
2004	25.5	0.19	37.5	27.2	0.22	41.6	28.3	0.18	46.7	38.1	0.21	50.4
2005	26.3	0.24	37.1	29.0	0.26	43.2	33.4	0.26	44.7	42.1	0.27	48.6
2006	31.3	0.17	37.9	38.3	0.17	37.4	37.3	0.19	41.3	45.9	0.17	49.8
2007[2)]	33.9	0.10	36.5	45.3	0.10	38.0	41.9	0.10	41.4	55.1	0.14	51.2

[1)] 1 IV - 31 XII 2002 [2)] 1 I - 30 VI 2007

Explanations: K1, K2 - variants of soils fertilized with compost 10 and 15 $g\ N \cdot m^{-2}$, respectively;
NPK1 - 10 $g\ N \cdot m^{-2}$ + 2.5 $g\ P \cdot m^{-2}$ + 6 $g\ K \cdot m^{-2}$; NPK2 - 15 $g\ N \cdot m^{-2}$ + 4 $g\ P \cdot m^{-2}$ + 9 $g\ K \cdot m^{-2}$.

Source: own studies

Table 4

Average multiannual concentration and coefficient of variation of N, P and K in the leachate samples collected in 2002-2007 [$mg \cdot dm^{-3}$]

Components	**Concentration of nutrients in different versions**							
	K1		**K2**		**NPK1**		**NPK2**	
	***n* = 45**		***n* = 46**		***n* = 45**		***n* = 51**	
	x	***V%***	***x***	***V%***	***x***	***V%***	***x***	***V%***
N	22.9	52.9	27.7	39.1	27.3	51.0	36.5	42.5
P	0.22	52.4	0.20	57.3	0.21	42.6	0.22	46.0
K	42.9	44.4	43.3	29.6	49.5	33.2	51.6	39.2

Explanations: *n* - number of samples, *x* - mean concentration, *V%* - variability coefficient.

Source: own studies

Effluent of the nitrogen into groundwater can be reduced by precise determination of doses of fertilizers. It is important to consider not only the nutritional needs of plants, but also the content of mineral nitrogen in the soil [4]. It is also necessary to maintain optimum pH of the soil for plants and control conditions of the water in soil. These factors provide a greater use of fertilizers by plants. One of the most effective ways to reduce nitrogen leaching from soil is the use of aftercrops. They reduce the leaching of soil nitrogen 36-62% [19].

Content of the P in the leachate from the soil (Table 3), in contrast to the N, were relatively small and did not show depending on the type and dose of fertilizer, or the passage of time from the application of fertilizer. Movement of phosphorus in the soil is very small and usually remains in the layer of soil, which has been introduced [20, 21].

Phosphorus is mainly kept in the subsurface, the biologically active layer of the soil profile. Penetration of P into the deeper layers of the soil and groundwater is generally low. Significant leaching of P by precipitation can occur in the case of very light and highly acidic soils [22]. The potassium concentration in the leachate from the soil, as well as the concentration of N was dependent mainly on variants of fertilization and increased with increasing doses of fertilizers. However it was not increased over the years the use of fertilizer. It indicates that the part of the delivered doses of K that is not used by plants is annually eluted by rain water.

Tables 5 and 6 shows the total amounts of N, P and K supplied in fertilizers and precipitation to the soil and discharged from the leachate during the entire period of study. The amount of N in the soil brought from the rain was an average 3.4 $g \cdot m^{-2}$ per year [23]. The amount of K was significantly lower and was annually 0.82 $g \cdot m^{-2}$. [24] The amount of P in precipitation was trace and did not take into account in the calculation. The amount of N discharged from the leachate was significantly higher in variants with mineral fertilization than fertilizer with equivalent doses of N in compost. The loss of N, in the 6-year study, caused by the leaching to groundwater, were on average 14.9-17.3 $g \cdot m^{-2}$ in compost and 19.6-27.3 $g \cdot m^{-2}$ for the fertilizer with equivalent doses of ammonium nitrate. P losses were however negligible 0.11-0.14 $g \cdot m^{-2}$, and independent of the type of fertilizer used K was most significantly leached. Its amount leached from the soil increased depending on the size of rainfall, volume of leachate and increasing doses of fertilizers. K and N losses, were higher in the variants with mineral fertilizers (28.4-31.7 $g \cdot m^{-2}$) than in the case of the use of compost (21.4-23.9 $g \cdot m^{-2}$).

Table 5

Amounts of nitrogen and phosphorus drained from leachate during the period of IV 2002 - VII 2007

Year	**The amounts of individual variants of fertilization [$mg \cdot m^{-2}$]**											
	K1			**K2**			**NPK1**			**NPK2**		
	N	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**
2002[1)]	269	9	1815	232	8	1505	436	12	2417	1031	12	2867
2003	1160	16	3254	1376	19	3400	1512	16	3862	2080	19	3442
2004	3154	24	3639	3268	26	4998	3645	24	6015	5944	29	6934
2005	3756	34	5098	4551	41	6780	5093	40	6816	6857	42	7593
2006	3792	21	4592	4294	19	4193	5199	27	5756	6868	23	6691
2007[2)]	2799	8	3013	3578	8	3001	3721	9	3540	4521	12	4200
Sum	14930	112	21411	17299	121	23877	19606	128	28406	27301	137	31727

[1)] 1 IV - 31 XII 2002 [2)] 1 I - 30 VI 2007

Explanations: K1, K2 - variants of soils fertilized with compost 10 and 15 $g N \cdot m^{-2}$, respectively;
NPK1 - 10 $g N \cdot m^{-2}$ + 2.5 $g P \cdot m^{-2}$ + 6 $g K \cdot m^{-2}$; NPK2 - 15 $g N \cdot m^{-2}$ + 4 $g P \cdot m^{-2}$ + 9 $g K \cdot m^{-2}$.
Source: own studies

Table 6

Amounts of nitrogen and phosphorus supplied to the soil and drained from leachate during the period of IV 2002 - VII 2007 [$g \cdot m^{-2}$]

The amounts of N P K	**K1**			**K2**			**NPK1**			**NPK2**		
	N	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**
in fertilizers	60.0	15.0	32.1	90.0	21.6	48.2	60.0	15.0	36.0	90.0	24.0	54.0
of precipitation	20.5	-	4.9	20.5	-	4.9	20.5	-	4.9	20.5	-	4.9
total	80.5	15.0	37.0	110.5	21.6	53.1	80.5	15.0	40.9	110.5	24.0	58.9
leachate discharged from	14.9	0.11	21.4	17.3	0.12	23.9	19.6	0.13	28.4	27.3	0.14	31.7

Conclusions

1. Annual fertilization of the soil, both by the compost and mineral fertilizers, in doses determined only by the nutritional needs of the plants cause a systematic increase of contamination of the water environment by nitrogen. Concentrations of total nitrogen in the leachate from the soil fertilized by compost were significantly lower than in the leachate from the soil fertilized by equivalent doses of nitrogen in the form of ammonium nitrate.
2. Loss of nitrogen and its penetration into the water environment are smaller in the case of using organic fertilizer in the form of compost, than in the case of a mineral fertilizer. This is due to the mineralization process of organic matter in the soil and gradual supply of available forms of nitrogen to the plants.
3. The concentrations of nitrogen in the leachate from the soil are increased with increasing doses of fertilizers, as well as their use over the years. This indicates the formation of an excess of nitrogen in the soil due to application of fertilizer annually, and thereby increasing the pollution of environment by the soluble forms of this component.
4. The concentration of phosphorus in the leachate from the soil were relatively small and do not show depending on the type of fertilizer, the dose and over the years the application of fertilizer. Losses of phosphorus and the amount of leaching into groundwater does not exceed 0.11-0.14 $g \cdot m^{-2}$ of the applied doses.
5. Potassium concentrations in the leachate from the soil are much higher than concentrations of nitrogen and phosphorus. The total amount of potassium leached from the fertilized soil depends mostly on the size of precipitation and volume of doses of fertilizer.

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WYMYWANIE PIERWIASTKÓW BIOGENNYCH (NPK) Z NAWOŻONEJ GLEBY LEKKIEJ

Instytut Technologiczno-Przyrodniczy, Dolnośląski Ośrodek Badawczy, Wrocław

Abstrakt: Przedstawiono wyniki 6-letnich badań wpływu corocznego nawożenia gleby lekkiej nawozami mineralnymi i kompostem na ilości azotu (N), fosforu (P) i potasu (K) przenikających do środowiska wodnego. Badania prowadzono w lizymetrach wypełnionych piaskiem słabo gliniastym. W badaniach zastosowano dwa warianty nawożenia kompostem (K1 - 10 g N·m^{-2} i K2 - 15 g N·m^{-2}). Dodatkowo zastosowano dwa warianty nawożenia mineralnego (NPK) z równorzędnymi dawkami azotu w postaci saletry amonowej z uzupełnieniem PK w postaci superfosfatu i soli potasowej. Badania wykazały zwiększanie się stężenia azotu w odciekach z gleby wraz ze zwiększeniem dawek nawozu. Stężenia N w odciekach z gleby nawożonej kompostem były zdecydowanie mniejsze niż w odciekach z gleby nawożonej równorzędnymi dawkami N w postaci saletry. Wystąpiło też zdecydowane zwiększenie się ilości wymywanego z gleby N wraz z upływem lat stosowania nawozów, co wskazuje na tworzenie się coraz większych jego nadmiarów w glebie. Łączne ilości azotu odprowadzone w odciekach z gleby wynosiły 14,9-17,3 g·m^{-2} ogólnej ilości azotu dostarczonej do gleby w wariantach z nawożeniem kompostem i około 19,6-27,3 g·m^{-2} w wariantach z nawożeniem mineralnym. Zawartości P w odciekach z gleby w przeciwieństwie do N były stosunkowo małe i nie wykazywały zależności od rodzaju nawozów i ich dawek ani też od upływu lat stosowania nawożenia. Wymywanie P było znikome, wynosiło 0,11-0,14 g·m^{-2} niezależne od rodzaju stosowanych nawozów. Straty zarówno K, jak i N były większe w wariantach z zastosowaniem nawozów mineralnych (28,4-31,7 g·m^{-2}) niż w przypadku stosowania kompostu (21,4-23,9 g·m^{-2}).

Słowa kluczowe: nawożenie, składniki biogenne, wymywanie z gleby, lizymetry