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Monika TABAK[1] and Barbara FILIPEK-MAZUR[1]

CONTENT AND UPTAKE OF NITROGEN BY MAIZE FERTILIZED WITH ORGANIC MATERIALS DERIVED FROM WASTE

ZAWARTOŚĆ I POBRANIE AZOTU PRZEZ KUKURYDZĘ NAWOŻONĄ MATERIAŁAMI ORGANICZNYMI POCHODZENIA ODPADOWEGO

Abstract: The aim of the research was to determine influence of organic materials fertilization on amount of maize yield as well as on nitrogen content in plants and on amount of uptaken nitrogen. The three-year field experiment comprised 7 treatments: non-fertilized soil (control) and soil fertilized with mineral fertilizers: manure, compost from green waste, sewage sludge, compost from sewage sludge and wheat straw as well as with a mixture of sewage sludge and hard coal ash. Maize harvested for silage was the test plant. Nitrogen content in the maize top parts was assessed by Kjeldahl method.

The yield-forming effect of the compost from green waste and of the sewage sludge was more favorable than the effect of the compost from sludge and straw and the mixture of sludge and ash, and similar to the effect of the manure and the mineral fertilizers. The weighted mean nitrogen content in the fertilized maize was higher than in the control plants. The highest mean element content was assessed in the maize fertilized with the compost from sludge and straw and with the mixture of sludge and ash (as a result of nitrogen cumulation in a relatively small yield of the plants fertilized with those materials). In the 1st year of the research, the amount of nitrogen uptaken from the soil fertilized with the mineral fertilizers was the highest, while in the following years the amount of nitrogen uptaken from the soil fertilized with the manure and organic materials was higher. The total amount of nitrogen uptaken from the soil fertilized with the mineral fertilizers, the manure, the compost from green waste and the sewage sludge was the highest.

Keywords: nitrogen, organic materials, waste, compost, sewage sludge, maize

In order to properly supply plants with nutrients, in conditions of fertilization with organic material, it is not sufficient to introduce an adequate dose of elements, which is established on the basis of their total content in the material. Degree of availability of elements from soil, after fertilization, should also be taken into consideration. It will allow not only to satisfy nutrient requirements of plants but also to limit risk of

[1] Department of Agricultural and Environmental Chemistry, University of Agriculture in Krakow, al. A. Mickiewicza 21, 31–120 Kraków, Poland, phone: +48 12 662 43 47, fax: +48 12 662 43 41, email: Monika.Tabak@ur.krakow.pl

environmental pollution caused by leaching and volatilization of nutrients. Organic materials, depending on their origin, differ in content of element forms directly available for plants and in rate of converting from bound forms of nutrients to available forms [1].

The aim of the research was to determine influence of fertilization with organic materials derived from waste on amount of maize yield as well as on content of nitrogen in the maize and on amount of uptaken nitrogen. Moreover, the aim of the research was to establish value of coefficient of nitrogen utilization from organic materials.

Material and methods

The 3-year field experiment was set up in 2008 at an experimental station of the University of Agriculture in Krakow. The experiment was conducted on Eutric Cambisol, with grain-size distribution of light clay. The soil was characterized with acid reaction (pH_{KCl} = 5.40) and very high contents of available forms of phosphorus and potassium (respectively 94.9 mg and 219.2 mg $\cdot$ kg^{-1} d.m.). Content of organic carbon amounted to 9.88 g $\cdot$ kg^{-1} d.m. and content of total nitrogen amounted to 1.07 g $\cdot$ kg^{-1} d.m. The soil properties were suitable for agricultural use of sewage sludges [2]. Detailed information regarding the soil properties before establishing the field experiment can be found in the paper of Tabak and Filipek-Mazur [3].

The experiment comprised 7 treatments: a non-fertilized soil (control treatment) and a soil fertilized with mineral fertilizers, cattle manure, compost from green waste, sewage sludge, compost from sewage sludge and straw as well as with a mixture of sewage sludge and hard coal ash. Each treatment was carried out in 4 replications. The manure contained 28.49 gN, the compost from green waste contained 14.44 gN, the sewage sludge contained 20.19 gN, the compost from sludge and straw contained 24.48 gN and the mixture of sludge and ash contained 14.49 gN $\cdot$ kg^{-1} d.m. Content of trace elements in the organic materials used for fertilization did not exceeded the limit values established for agricultural use of sewage sludges [2]. Origin and properties of the organic materials used for fertilization were described in the paper of Tabak and Filipek-Mazur [3].

The doses of nutrient elements introduced in particular years to the soil of the fertilized treatments are shown in Table 1.

Table 1

Doses of the nutrient elements introduced to the soil in particular years [kg $\cdot$ ha^{-1}]

Year	N	P_2O_5	K_2O
1^{st} year	160	168	140
2^{nd} year	100	30	110
3^{rd} year	100	30	110

In the 1^{st} year of the research, to the soil fertilized with the manure and the organic materials, the whole nitrogen dose was introduced with the fertilizer and those materials. Ammonium nitrate, enriched superphosphate and potassium chloride were used to introduce the nutrient elements to the soil of the mineral treatment and also to even up the doses of phosphorus and potassium in the soil of the remaining fertilized treatments. The mentioned mineral fertilizers were also used to conduct fertilization in the 2nd and 3rd year of the field experiment.

The PR 39F58 maize (Pioneer) was the test plant in all years of the research and it was grown for silage. The mean temperature for the maize growing season was similar in all years and amounted to (16.2–16.3) ^{o}C (Table 2). That temperature was higher than the mean temperature sufficient for proper growth of maize, which amounts to about 15 ^{o}C [4]. However, in all years May and September were the cold months. In every year the sum of rainfall during the maize growing season exceeded the level of 300 mm (regarded as sufficient, with right distribution, for proper maize development [4]). However, the distribution and the amount of rainfall were not favorable. A water deficit occurred in May and June in the 1st year of the research, that deficit was replenished in July. In the 2nd year, in May and June an excess of rainfall occurred, whereas in the 3rd year of the experiment an excess of rainfall occurred during all months of maize growth.

Table 2

Mean monthly temperatures and monthly sums of rainfall

Parameter	Year	Month					
		V	VI	VII	VIII	IX	V–IX
Mean temperature [^{o}C]	1st year	13.6	18.4	18.7	18.2	12.6	16.3
	2nd year	13.6	16.0	19.9	18.6	12.9	16.2
	3rd year	12.8	17.6	20.5	18.5	12.3	16.3
Sum of rainfall [mm]	1st year	28.7	26.7	142.6	41.6	98.8	338.4
	2nd year	106.6	122.1	82.7	53.3	61.5	426.2
	3rd year	299.0	135.2	105.2	127.5	112.8	779.7

The maize was harvested at wax maturity stage of the grain (proper for harvesting for silage). After the harvest the amount of fresh matter yield of the maize top parts was determined. Then, after desiccating at 70 ^{o}C in a dryer with hot air flow, the content of dry matter in the maize top parts was determined. The amount of dry matter yield of the maize top parts harvested from a given object was calculated basing on the mean amount of the fresh matter yield obtained from that treatment and the mean content of dry matter in that yield.

The content of total nitrogen in dry and melted plant material was determined with Kjeldahl method [5], after reduction of nitric form to ammonium form. The assessment was conducted on Kjeltec 2300 (FOSS) apparatus. The mean nitrogen content in biomass was counted as a weighted mean.

The results were formulated statistically using Statistica 8.0 program. A univariate analysis of variation was carried out, and the significance of differences between the mean values was estimated using the Duncan test (α = 0.05).

Results and discussion

The used fertilization led to an increase of the total (from 3 years) yield of the maize (Table 3). The total fresh matter yield of the top parts of the maize fertilized with the organic materials was higher by 25.9–37.2 % than the control yield, and the total dry matter yield was higher by 31.5–51.9 %. The described beneficial yield-forming effect of the organic materials derived from waste is consistent with literature data [6–10]. However, some authors indicate a possibility of decreasing plant yield as a result of fertilization with organic materials [11].

Table 3

Total (from 3 years) yield of maize [$Mg \cdot ha^{-1}$]

Treatment	Total fresh matter yield of maize top parts	Total dry matter yield of maize top parts
No fertilization	140.91 a*	45.88
Mineral fertilizers	205.10 d	68.10
Manure	195.04 cd	68.96
Compost from green waste	191.79 c	69.69
Sewage sludge	193.29 c	67.17
Compost from sewage sludge and straw	178.32 b	60.32
Mixture of sewage sludge and ash	177.42 b	62.16

* Mean values in columns marked with the same letters do not differ statistically significantly at $\alpha = 0.05$, according to the Duncan test.

The compost from green waste and the sewage sludge were characterized with yield-forming effect similar to the manure, and – while analyzing the dry matter yield – also to the mineral fertilizers (Table 3). From among the examined fertilization types, the compost from sewage sludge and straw as well as the mixture of sewage sludge and ash had the weakest yield-forming effect. Contrary to the Authors' own research, Krzywy and Woloszyk [10] stated that yield-forming effect of sewage sludge and composts from sewage (with addition of straw, sawdust or leaves) was similar to effect of mineral fertilizers or better than that. Moreover, the yield-forming effect of using the composts was more favorable than the effect of using only the sludge or similar to it. Gondek et al [9] also established that yield of plants fertilized with sewage sludges as well as with mixtures of sewages and peat was usually higher than yield of plants fertilized with mineral salts. Adding peat to the sludge had a beneficial influence on the yield-forming effect of the organic material. However, Gondek and Filipek-Mazur [8] showed a weaker effect of organic material (compost from plant residues) than of mineral salts. In the cited research [8, 9] it was found that the organic materials were characterized with the yield-forming effect similar to manure or better than it. Those results were not always confirmed in the Authors' own research. Doses of nitrogen, phosphorus and potassium were balanced in fertilized treatments both in the Authors' own research and in the researches of Gondek and Filipek-Mazur [8], Gondek et al [9] as well as of Krzywy and Woloszyk [10]. Therefore, differences in the influence of

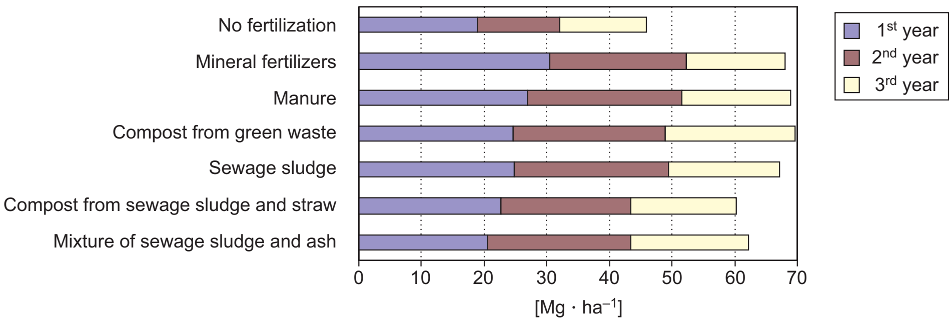

Fig. 1. Dry matter yield of maize top parts

particular types of fertilization on the amount of plants yield should not be explained by different doses of those elements, but rather by differentiated content of available forms in soil of particular treatments. More favorable effect of mineral fertilization in the 1st year of the investigations, stated in the Authors' own research (Fig. 1) and also by Gondek et al [9], can be explained by higher availability of the elements from the soil fertilized minerally than from the soil fertilized with organic matter. In the following years the difference between effects of mineral fertilizers and of organic materials diminished, in consequence of releasing elements from organic matter. Beneficial yield-forming effect of organic materials is also a result of introducing some nutrients present in those materials (elements other than nitrogen, phosphorus and potassium) to soil. Also Gondek et al [9] point that out.

In the 1st year of the field experiment, a statistically significant influence of the fertilization on the nitrogen content in the maize top parts was not stated, in comparison with the content determined in the non-fertilized maize (Table 4).

Table 4

Nitrogen content in the maize top parts [g · kg−1 d.m.]

Treatment	1st year	2nd year	3rd year	Mean content
No fertilization	11.64 ab*	8.18 a	10.82 ab	10.40
Mineral fertilizers	11.95 b	8.58 ab	11.32 b	10.73
Manure	11.14 a	9.96 c	10.54 a	10.57
Compost from green waste	11.04 a	9.17 b	12.47 c	10.81
Sewage sludge	11.70 ab	10.23 c	10.50 a	10.85
Compost from sewage sludge and straw	12.13 b	10.51 c	11.10 ab	11.28
Mixture of sewage sludge and ash	12.12 b	10.33 c	11.00 ab	11.12

* See Table 3.

However, Wieczorek and Gambus [11] indicate a possibility of increasing nitrogen content in plants already in the year of applying sludges. In the Authors' own research, the greatest influence of the fertilization on the nitrogen content in the test plants was noticed in the 2nd year of the research – statistically significantly higher nitrogen content was obtained in the maize fertilized with the manure and the organic materials than in the non-fertilized plants. The maize fertilized with the manure, the sewage sludge and the materials containing sludge contained 21.8–28.5% more nitrogen than the plants gathered from the control object; the maize fertilized with the compost from green waste contained 12.1 % more nitrogen. In the 3rd year of the research only the fertilization with the compost from green waste statistically significantly influenced the nitrogen content in the plants, in comparison with the content in the control maize (the content higher by 15.3 %). The weighted mean nitrogen content in the maize top parts was higher in the fertilized treatments (between 10.6 g · kg^{-1} d.m. and 11.3 g · kg^{-1} d.m.) than in the control (10.4 g · kg^{-1} d.m.) (Table 4). The highest mean nitrogen content was assessed in the maize fertilized with the compost from sewage sludge and straw as well as with the mixture of sewage sludge and ash. It was a result of nitrogen cumulation in a relatively small yield gathered from the treatments fertilized with those two materials (Table 3, Fig. 1). Gondek et al [9] also stated that fertilization with organic materials led to an increase in nitrogen content in maize top parts. However, the authors obtained higher nitrogen content in plants fertilized with mineral salts than with manure and organic materials.

The content of total protein in the plants fertilized with the organic materials was in the range (57.31; 77.96) g · kg^{-1} d.m. (the protein content was obtained by multiplying the total nitrogen content by 6.25). That content was lower than the proper value given in literature for maize for silage, which is about 80–90 g · kg^{-1} d.m. [4, 12]. The content of total protein in the non-fertilized maize as well as in the maize fertilized with the mineral fertilizers and with the manure also did not exceed 80 g · kg^{-1} d.m.

In the 1st year of the research, the highest maize yield was gathered from the object fertilized with the mineral fertilizers (Fig. 1). What is more, those plants were characterized with a relatively high nitrogen content (Table 4). As a result, in the 1st year of the research the amount of nitrogen uptaken from the soil fertilized with the mineral fertilizers was the highest (Table 5).

Table 5

Amount of nitrogen uptaken by maize [kg · ha^{-1}]

Treatment	1st year	2nd year	3rd year	Total uptake
No fertilization	220.3	107.4	149.4	477.2
Mineral fertilizers	365.0	186.2	179.4	730.6
Manure	300.7	245.7	182.3	728.7
Compost from green waste	271.9	222.6	259.1	753.7
Sewage sludge	291.1	251.0	186.4	728.5
Compost from sewage sludge and straw	276.2	216.9	187.5	680.6
Mixture of sewage sludge and ash	249.3	236.6	205.4	691.4

That indicates higher availability, in the 1st year of research, of nitrogen from that soil than from the soil fertilized with the manure and the organic materials. In the 2nd and 3rd years, the amount of nitrogen uptaken from the soil fertilized with the manure and with the organic materials was higher than the amount of nitrogen uptaken from the soil fertilized with mineral fertilizers. That indicates mobilization of nitrogen introduced to the soil in organic form. The total amount of uptaken nitrogen was the highest from the soil fertilized with the mineral fertilizers, the manure, the compost from green waste and the sewage sludge (it amounted to 152.7–157.9 % of the amount of nitrogen uptaken from the control soil).

Maize belongs to plants that well utilize nutrients from fertilizers containing organic matter [13]. In 1st year after manure application nitrogen utilization by maize amounts to about 25–40 %, whereas in the 2nd and 3rd – to about 35–40 % [13]. However, values obtained in researches concerning utilization of nitrogen from organic materials derived from waste were lower than the ones given above. Mackowiak argues that immediate nitrogen utilization from sewage sludges usually amounts to about 20 % and sequential utilization amounts to about 10 % [14]. Mazur et al [15] stated that nitrogen utilization in the year of applying composts from sewage sludge with different additives (sawdust, brown coal, slops) amounted to 12–19 %. With additional mineral nitrogen fertilization the utilization amounted to (33; 38) %. Czyzyk et al [7] obtained higher nitrogen utilization from composts from sewage sludge and straw when organic material was characterized with higher content of nitrate and ammonium nitrogen (therefore available forms). In the Authors' own research, the value of the coefficient of nitrogen utilization from the mineral fertilizers and the manure was the same and amounted to 70 %. The utilization of nitrogen from the compost from green waste was higher (77 %), from the sewage sludge it was the same (70 %), whereas from the materials prepared basing on the sludge it was lower (57; 59) % than the utilization from the mineral fertilizers and the manure. The level of nitrogen utilization from the organic materials was relatively high – it most probably resulted from the fact that the fertilization with the organic materials was combined with the mineral nitrogen fertilization.

Conclusions

1. Fertilization with organic materials derived from waste beneficially influenced the amount of the maize yield. Both the compost from green waste and the sewage sludge had more favorable yield-forming effect than the compost from sewage sludge and straw and the mixture of sewage sludge and ash. Moreover, the effect of the compost from green waste and of the sludge approximated the effect of the manure and the mineral fertilizers.

2. The greatest influence of the fertilization on the nitrogen content in the test plants was noticed in the 2nd year of the research. At that time, fertilization with the manure and the organic materials led to an increase of the nitrogen content in plants, in comparison with the control. Weighted mean nitrogen content in the maize top parts was higher in the fertilized treatments (between 10.57 $g \cdot kg^{-1}$ d.m. and 11.28 $g \cdot kg^{-1}$ d.m.) than in the control (10.40 $g \cdot kg^{-1}$ d.m.). The highest mean nitrogen content was found in the maize fertilized with the compost from sewage sludge and straw as well as with the mixture of sewage sludge and ash.

3. In the 1st year of the field experiment, the amount of nitrogen uptaken by the plants fertilized with the mineral fertilizers was the highest. In the following years, as a result of mineralization of organic nitrogen compounds, the amount of nitrogen uptaken from the soil fertilized with the manure and the organic materials was higher than the amount of nitrogen uptaken from the soil fertilized with the mineral fertilizers. Totally during 3 years, the amount of nitrogen uptaken by the plants fertilized with the mineral fertilizers, the manure, the sewage sludge and the compost from green waste was the highest (152.7; 157.9) % of the amount of nitrogen uptaken from the control soil).

4. The utilization of nitrogen from the compost from green waste and the sewage sludge was higher than the utilization of that element from the compost from sludge and straw and the mixture of sewage sludge and ash.

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ZAWARTOŚĆ I POBRANIE AZOTU PRZEZ KUKURYDZĘ NAWOŻONĄ MATERIAŁAMI ORGANICZNYMI POCHODZENIA ODPADOWEGO

Katedra Chemii Rolnej i Środowiskowej
Uniwersytet Rolniczy im. Hugona Kołłątaja w Krakowie

Abstrakt: Celem badań było określenie wpływu nawożenia materiałami organicznymi na wielkość plonu kukurydzy, zawartość azotu w roślinach oraz ilość pobranego azotu. Przeprowadzono trzyletnie doświadczenie polowe obejmujące 7 obiektów: glebę nienawożoną (kontrola) oraz glebę nawożoną nawozami mineralnymi, obornikiem, kompostem z odpadów zielonych, osadem ściekowym, kompostem z osadu ściekowego i słomy pszennej oraz mieszaniną osadu ściekowego i popiołu z węgla kamiennego. Rośliną testową była kukurydza uprawiana na kiszonkę. Zawartość azotu ogólnego w roślinach oznaczono metodą destylacyjną Kjeldahla.

Plonotwórcze działanie kompostu z odpadów zielonych i osadu ściekowego było korzystniejsze niż działanie kompostu z osadu i słomy oraz mieszaniny osadu i popiołu, a jednocześnie zbliżone do działania obornika i nawozów mineralnych. Średnia ważona zawartość azotu w częściach nadziemnych kukurydzy nawożonej była większa niż w roślinach kontrolnych. Największą średnią zawartość pierwiastka stwierdzono w kukurydzy nawożonej kompostem z osadu i słomy oraz mieszaniną osadu i popiołu (na skutek kumulacji azotu w stosunkowo małym plonie roślin nawożonych tymi materiałami). W pierwszym roku badań największa była ilość azotu pobranego z gleby nawożonej nawozami mineralnymi, natomiast w kolejnych latach większa była ilość azotu pobranego z gleby nawożonej obornikiem i materiałami organicznymi. Analizując dane sumaryczne stwierdzono, że największa była ilość azotu pobranego z gleby obiektów nawożonych nawozami mineralnymi, obornikiem, kompostem z odpadów zielonych i osadem ściekowym.

Słowa kluczowe: azot, materiały organiczne, odpady, kompost, osad ściekowy, kukurydza