ECOLOGICAL CHEMISTRY AND ENGINEERING A

Vol. 18, No. 9–10 2011

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

FORMATION OF MAIZE YIELD AS A RESULT OF FERTILIZATION WITH ORGANIC MATERIALS

KSZTAŁTOWANIE PLONU KUKURYDZY W EFEKCIE NAWOŻENIA MATERIAŁAMI ORGANICZNYMI

Abstract: The research aimed at determining the influence of organic materials fertilization on the amount of the maize yield. During 2 years of the field study direct and consequent effects of the materials used in fertilizing were determined. The research comprised 7 objects: non-fertilized soil and soil fertilized with mineral fertilizers, cattle manure, compost from green waste, sewage sludge, compost from sewage sludge and straw as well as with a mix of sewage sludge and hard coal ash. Pioneer 'PR 39F58' maize cv. harvested for silage was the test plant in both years of the experiment.

Fertilization with organic materials usually resulted in increasing the yield of both fresh matter of the maize top parts and fresh matter of the maize cobs. It was not stated that the examined organic materials affected the yield amount more favorably than mineral fertilizers or manure. From among the analyzed materials, the compost from green waste had the strongest yield-forming effect, whereas the mixture of sewage sludge and hard coal ash had the weakest effect.

Keywords: compost, sewage sludge, organic materials, maize

The presently stated diminution in production of natural fertilizers, and consequently in using those fertilizers in soil fertilization, forces necessity of seeking alternative materials, which could be a source of nutrient elements and organic matter. Emphasized is fertilizing usability of composts from green waste, agri-food industry waste, sewage sludge and composts containing sludge [1, 2]. Used materials, especially sewage sludge, are enriched with various additions (straw, tree leaves, sawdust, bark, peat, brown coal, furnace-ash, calcium oxide) and composted to improve their physical and chemical qualities [1, 3]. Fertilization with organic materials, apart from increasing richness of soil in nutrients and humus, plays a role in limiting deposition of waste.

[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

Evaluation of organic materials usability in fertilization consists in an analysis of their chemical composition. Moreover, this evaluation focuses on an amount and quality of plants yield as well as on soil properties.

The aim of this research was to determine the impact of the fertilization with selected organic materials on the amount and structure of the maize yield within two years of the field experiment.

Material and methods

The field experiment was set up in 2008 at the Experimental Station of the University of Agriculture in Krakow. The experiment was carried out on Eutric Cambisol containing, on the humus horizon, 25 % of mechanical fraction of diameter below 0.02 mm. The soil properties are shown in Table 1. The heavy metals content in soil and the pH value of soil allowed the fertilization with sewage sludge [4].

The experiment comprised 7 treatments: a non-fertilized soil (A) and a soil fertilized with mineral fertilizers (B), cattle manure (C), compost from green waste (D), sewage sludge (E), compost from sewage sludge and wheat straw (F) as well as with a mixture of sewage sludge and hard coal ash (G). Each treatment was conducted in 4 replications.

Table 1

Selected properties of soil before setting up the experiment

Parameter	Unit	Value
pH_{H_2O}	[-]	6.29
pH_{KCl}		5.40
Hh	[mmol (+) · kg^{-1} d.m.]	18.8
S		126.5
T		145.2
V	[%]	87
$N_{tot.}$	[g · kg^{-1} d.m.]	1.07
$C_{org.}$		9.88
Available P	[mg P_2O_5 · kg^{-1} d.m.]	217.5
Available K	[mg K_2O · kg^{-1} d.m.]	264.1
Cr	[mg · kg^{-1} d.m.]	2.19
Zn		70.7
Pb		26.5
Cu		9.93
Cd		0.55
Ni		5.00
Mn		268
Fe		4 675

Chemical composition of the organic materials used for fertilization is presented in Table 2.

Table 2

Chemical composition of the materials used in fertilization

Parameter	Unit	Material				
		manure	compost from green waste	sewage sludge	compost from sludge and straw	mixture of sludge and ash
Dry matter	[%]	18.5	47.7	35.1	30.8	44.7
$N_{tot.}$	$[g \cdot kg^{-1}$ d.m.]	28.5	14.4	20.2	24.5	14.5
$C_{org.}$		418	202	245	309	152
S		3.46	2.04	10.50	7.30	5.33
P		6.02	1.95	8.22	9.97	6.66
K		13.58	4.47	0.65	4.54	0.75
Mg		4.88	4.70	5.65	6.20	7.55
Ca		11.57	35.88	38.32	31.35	27.38
Na		1.63	0.43	0.17	0.45	0.34
Fe		1.30	6.11	8.75	7.81	8.34
Cr	$[mg \cdot kg^{-1}$ d.m.]	4.31	19.17	17.83	17.93	19.27
Zn		223	285	855	716	520
Pb		5.59	61.33	73.50	59.50	38.73
Cu		23.5	52.8	103.7	99.2	82.8
Cd		1.35	0.88	2.70	2.59	1.48
Ni		4.49	8.59	13.17	11.64	15.43
Mn		141	442	169	198	235

Heavy metals content in all the materials used for fertilization did not exceed acceptable amounts for sludge used in agriculture [4]. The compost used in the experiment was obtained from a container green waste compost facility Barycz, operating under Kneer technology and belonging to Miejskie Przedsiebiorstwo Oczyszczania Sp. z o.o. in Krakow. The sewage sludge (after one year of stabilization) came from a mechanical-biological treatment plant of municipal sewage belonging to Wodociagi i Kanalizacja Krzeszowice Sp. z o.o. The ash from hard coal was obtained from Elektrocieplownia "KRAKOW" S.A. The description of the way of preparing the compost from sludge and straw as well as the mixture of sludge and ash, along with changes in chemical composition of those materials during the composting process, are presented in Tabak's [5] article.

In each year of the experiment the fertilization was carried out before sowing time in spring. In the 1st year of the experiment (2008) the following doses of nutrient elements were used: 160 kg N, 168 kg P_2O_5 and 140 kg $K_2O \cdot ha^{-1}$. Doses of nitrogen and potassium were determined basing on the nutritional requirements of maize, whereas the dose of phosphorus was equalized to the highest dose introduced with one of the organic materials. In the **C-G** treatments the whole nitrogen dose was introduced to the soil in the organic materials used for fertilization. Ammonium nitrate (34 % N), enriched with superphosphate (40 % P_2O_5) and potassium chloride (60 % K_2O) were used to introduce the nutrient elements to the soil of the mineral treatment and also to equalize the doses of phosphorus and potassium in the soils of the remaining treatments. In the 2nd year of the experiment (2009) the following were used: 100 kg N, 30 kg P_2O_5 and 110 kg $K_2O \cdot ha^{-1}$, the fertilization was carried out using the previously mentioned mineral fertilizers.

The Pioneer 'PR 39F58' maize cv. was the test plant in both years of the research and it was harvested at the wax maturity stage of the grain, in other words at a proper stage to harvest maize for silage. Thermal and rainfall conditions during the growth period of the maize are presented in Table 3.

Table 3

Mean monthly temperatures and monthly sums of rainfall

Parameter	Year	Month					
		V	VI	VII	VIII	IX	V–IX
Mean temperature [°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
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

From 1st May to 30th September mean temperature should be approximately 15 °C [6], which is favorable for proper growth of maize. The mean air temperatures during the period of the experiment were slightly higher and amounted to 16.3 °C in the 1st year of the research and 16.2 °C in the 2nd year. May and September were the cold months in both years of the research. With right distribution, rainfall of 300 mm ensures proper maize development in vegetation season [6]. The amount of rainfall reached the mentioned level in both years. However, the rainfall distribution in the 1st year of the experiment was different than in the 2nd year. A water deficit occurred in May and June in the 1st year (the deficit was replenished in July), whereas in the 2nd year an excess of rainfall occurred in this period.

In the 1st year of conducting the field experiment the maize sowing took place on 9th May 2008, whereas the harvest took place on 4–5th September 2008. In the 2nd year of the experiment the dates were respectively 8th May and 15–16th September 2009. The area of one plot in the experiment was 35 m^2, while the harvest was conducted from an area of 6 m^2. The yield of fresh matter of the maize top parts and the yield of fresh matter of the maize cobs with covering leaves were determined after the harvest. The dry matter content of the maize top parts was determined after drying at 70 °C in a dryer with hot air flow. Values presented in the paper are mean arithmetic values from 4 replications. The results were verified statistically using Statistica 8.0. A univariate analysis of variation was carried out, and the significance of the differences between the mean values for particular fertilizing treatments (within a given year of the experiment or for given total data) was estimated using the Duncan test ($p < 0.05$).

Results and discussion

In the 1st year of the experiment the fertilization with organic materials (except for the sludge and ash mixture) led to an increase in the fresh matter yield of the maize top parts (Table 4).

Table 4

Yield of fresh matter of the maize top parts as well as dry matter content in the top parts

Treatment*	Fresh matter yield of the maize top parts [$Mg \cdot ha^{-1}$]			Dry matter [%]	
	1st year	2nd year	1st year + 2nd year	1st year	2nd year
A	58.87 a**	41.76 a	100.63 a	32.16	31.46
B	98.63 c	59.46 bc	158.09 e	30.96	36.52
C	80.45 b	65.96 c	146.41 d	33.55	37.39
D	75.42 b	63.32 bc	138.74 cd	32.67	38.34
E	80.70 b	63.98 bc	144.68 d	30.83	38.35
F	75.51 b	57.28 b	132.79 bc	30.16	36.04
G	63.93 a	61.00 bc	124.92 b	32.18	37.56

* See "Material and methods"; ** mean values in columns marked with the same letters do not differ statistically significantly at $p < 0.05$, according to the Duncan test.

The effect of the used materials was weaker than of the mineral fertilizers. In the 2nd year of the experiment the organic materials affected the amount of fresh matter yield of the maize similarly to mineral fertilizers (Table 4). It indicates an after-effect of those materials. The highest total yield of fresh matter of the maize top parts was obtained from the mineral treatment, where each type of fertilization produced a statistically significantly higher yield than the yield stated for the non-fertilized object (Table 4). While analyzing the total yield, it was found that the compost from green waste and the sewage sludge affected the yield amount similarly to the manure (hence the most favorably from among the examined organic materials). In compliance with literature data, maize for silage should contain from 28 % to 35 % of dry matter [7]. Such content of dry matter ensures proper course of biochemical processes during silaging. The later the time of harvest, the higher the content of dry matter in plants and the more precise the biomass fragmentation must be (to ensure proper silaging and full eating-up of the silage by animals) [7, 8]. In the 1st year of the experiment the content of the dry matter in top parts of the plants was proper for the maize harvested for silage. In the 2nd year the maize gathered from the fertilized objects was characterized by the content of the dry matter slightly higher than 35% (Table 4).

The influence of the fertilization on the yield amount of the maize cobs fresh matter became apparent in the 2nd year of the experiment (Table 5).

The highest total yield of the cobs fresh matter was obtained from the objects fertilized: minerally, with manure and with the compost from green waste. Yield amount of cobs, more precisely share of cobs in yield of maize top parts, is responsible

Table 5

Fresh matter yield of the maize cobs with covering leaves as well as share of this yield in the fresh matter yield of the top parts

Treatment*	Fresh matter yield of the maize cobs [$Mg \cdot ha^{-1}$]			Share of the cobs yield in the top parts yield [%]		
	1st year	2nd year	1st year + 2nd year	1st year	2nd year	1st year + 2nd year
A	27.00 ab**	12.48 a	39.49 a	45.89	30.14	39.38
B	32.28 b	22.31 b	54.59 c	32.73	38.06	34.58
C	28.21 ab	21.26 b	49.47 bc	35.05	32.25	33.79
D	27.11 ab	21.85 b	48.96 bc	35.88	34.54	35.30
E	26.12 a	21.30 b	47.42 b	32.27	33.27	32.76
F	26.93 ab	19.67 b	46.60 b	35.60	34.44	35.04
G	23.58 a	20.34 b	43.92 ab	37.15	33.35	35.20

* See "Material and methods"; ** see Table 4.

for energy value of a material. Because degradation (which takes place in the rumen) of starch found in maize grain is slower than degradation of starch from other fodders, the digestive process is stable [8]. What is more, the final degradation of starch takes place thanks to enzymes in the small intestine (obtained glucose is absorbed) – in consequence, feeding with fodder containing starch contributes to diminution of energy deficit which can take place in cattle of high productivity [8]. The share of the cobs yield in the fresh matter yield of maize intended for silaging should amount at least to 30 %, preferably over 40 % (according to some sources even over 50 %) [7, 9]. In the Authors' own research, that share always reached the level of 30 %, however it usually did not exceed 40 % (Table 5).

An increase in yield formation of the maize in the effect of fertilization with organic materials was stated in the Authors' own research (the yield-forming effect of those materials was not stronger than the effect of mineral fertilizers and manure). The analysis of other authors' findings shows that impact of organic materials on yield amount depends on properties of organic materials, soils and plants as well as on conditions for conducting experiments. Literature data indicate both a yield-forming effect of sewage sludge and composts with sewage sludge as well as composts from organic municipal waste [10–13] and lack of a favorable impact of those materials on maize yield amount [14]. Also in the case of other plants, organic materials showed generally a favorable impact on the yield amount [10, 11, 15–18]. In some cases the organic materials revealed a weaker yield-forming effect than mineral fertilization [11, 13], especially in the cases where the consequent effect of the used materials was not analyzed.

A weak yield-forming effect of the organic materials most often results from their inappropriate properties. Using unstable and immature materials (of non-uniform structure, of considerable content of organic matter which is vulnerable to decomposition or materials characterized with a presence of pathogenic microbes) can result in worsening of soil properties (with a change in soil bioactivity, with biological immobilization of nitrogen), and in the effect in the limitation of plants yield formation. Because the biochemical processes during composting of the sewage sludge and the hard coal ash were not advanced [5], it might be the reason of the weak fertilization effect of the sewage and ash mixture. The lack of a significant yield-forming effect of the organic materials can be attributed to too low (compared with alimentary needs of plants) content of nutritional elements in those materials, such as too low potassium content in sewage sludge, or to a small assimilability of those elements [13]. A presence of considerable amounts of heavy metals in the organic materials can also be the reason of the weak yield-forming effect of those materials.

Conclusions

1. Fertilization with the organic materials (compost from green waste, sewage sludge, compost from sewage sludge and wheat straw, mixture of sewage sludge and hard coal ash) usually resulted in increasing the yield of both fresh matter of the maize top parts and fresh matter of the maize cobs.

2. Within two years of the research, the organic materials used in fertilization were not found to have a more favorable effect on the maize yield amount than mineral fertilizers and manure.

3. From among the analyzed materials, the compost from green waste had the strongest yield-forming effect. Fertilization with the mixture of sewage sludge and hard coal ash had the least favorable effect on yield formation of the maize.

References

[1] Krzywy E., Wołoszyk Cz. and Iżewska A.: [in:] Diagnostyka gleb i roślin w rolnictwie zrównoważonym, S. Kalembasa (ed.), Wyd. Akademii Podlaskiej, Siedlce 2004, p. 98–109.
[2] Maćkowiak Cz.: Nawozy Nawoż. 2000, **4**(5), 131–143.
[3] Kalembasa S.: [in:] Substancje humusowe w glebach i nawozach. Problemy badań, B. Dębska, S.S. Gonet (eds.), Polskie Towarzystwo Substancji Humusowych, Wrocław 2003, p. 63–74.
[4] Rozporządzenie Ministra Środowiska z dnia 1 sierpnia 2002 r. w sprawie komunalnych osadów ściekowych. DzU 2002, nr 134, poz. 1140.
[5] Tabak M.: [in:] Wielokierunkowość badań w rolnictwie i leśnictwie. Monografia, B. Wiśniowska-Kielian (ed.), Wyd. Uniwersytetu Rolniczego w Krakowie, Kraków 2009, **1**, 401–407.
[6] Dubas A.: Kukurydza w gospodarstwie wielkoobszarowym. PWRiL, Warszawa 1981.
[7] Kowalik I.: [in:] Profesjonalna uprawa kukurydzy, M. Dreczka (ed.), Polskie Wydawnictwo Rolnicze, Poznań 2001, p. 88–91.
[8] Księżak J., Machul M., Brzóska F., Rola H., Kęsik K., Górski T., Hołubowicz-Kliza G., Siódmiak J. and Madej M.: Uprawa kukurydzy na kiszonkę z całych roślin. Wyd. IUNG, Puławy 2009, 86 p.
[9] Michalski T.: Farmer 2007, **16**, 32–34.
[10] Ailincăi C., Jităreanu G., Ailincăi D. and Balan A.: Cercetări Agronomice în Moldova 2010, **43**(1[141]), 5–16.
[11] Czyżyk F., Kozdraś M. and Sieradzki T.: Zesz. Probl. Post. Nauk Roln. 2002, **484**, 117–124.
[12] Gondek K. and Filipek-Mazur B.: Acta Agrophys. 2008, **11**(3), 633–646.
[13] Jadczyszyn T. and Stachyra A.: Zesz. Probl. Post. Nauk Roln. 2005, **505**, 145–151.
[14] Wieczorek J. and Gambuś F.: Zesz. Probl. Post. Nauk Roln. 2007, **520**, 407–415.
[15] Akdeniz H., Yilmaz I., Bozkurt M. A. and Keskin B.: Polish J. Environ. Stud. 2006, **15**(1), 19–26.
[16] Gondek K., Filipek-Mazur B. and Mazur K.: [in:] Zanieczyszczenia środowiska azotem. Materiały pokonferencyjne, S. Nowel (ed.), Wyd. Wszechnicy Mazurskiej, Olecko 2005, p. 183–194.

[17] Krzywy E. and Wołoszyk Cz.: Zesz. Probl. Post. Nauk Roln. 1997, **448**b, 149–155.
[18] Singh R.P. and Agrawal M.: Ecol. Eng. 2010, **36**(7), 969–972.

KSZTAŁTOWANIE PLONU KUKURYDZY W EFEKCIE NAWOŻENIA MATERIAŁAMI ORGANICZNYMI

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

Abstrakt: Celem badań było określenie wpływu nawożenia materiałami organicznymi na ilość plonu kukurydzy. W dwuletnim doświadczeniu polowym oceniono bezpośrednie oraz następcze działanie zastosowanych do nawożenia materiałów. Doświadczenie obejmowało 7 obiektów: glebę nienawożoną oraz glebę nawożoną nawozami mineralnymi, obornikiem bydlęcym, kompostem z odpadów zielonych, osadem ściekowym, kompostem z osadu ściekowego i słomy oraz mieszaniną osadu ściekowego i popiołu z węgla kamiennego. Rośliną testową w obu latach była kukurydza odmiany 'PR 39F58' firmy Pioneer, zbierana z przeznaczeniem na kiszonkę.

Nawożenie materiałami organicznymi zazwyczaj skutkowało zwiększeniem plonu świeżej masy części nadziemnych oraz świeżej masy kolb kukurydzy. Nie stwierdzono, by badane materiały organiczne oddziaływały na ilość plonu korzystniej niż nawozy mineralne i obornik. Spośród analizowanych materiałów, najsilniejszym działaniem plonotwórczym cechował się kompost z odpadów zielonych, natomiast najsłabszym – mieszanina osadu ściekowego i popiołu z węgla kamiennego.

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