Response of Maize (*Zea mays* L.) Grown for Grain After the Application of Sewage Sludge

Reakcja kukurydzy uprawianej na ziarno po zastosowaniu osadów ściekowych

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Abstract

The aim of this study was to assess the effects of the agricultural use of sewage sludge in corn for grain, in the year of application and follow up effect after one and two years after its application. The study was conducted on the variety PR39G12 on the field after the 5-year monoculture corn. Sewage sludge was used in accordance with the Directive of Minister of Environment allowing application of 10 t dry mater per ha-1 once every five years. Fertilization with sludge of maize grown for grain did not cause differences in the growth and development of plants, compared to mineral fertilized objects, as well as did not exceed the limit value for heavy metals content in above-ground plant parts. Maize grown using sewage sludge yielded higher than the objects fertilized with mineral, especially in conditions of extreme drought, which occurred in 2006. Beneficial effect of sewage sludge was maintained in the next two years after application and stabilized the grain yield of maize.

Keywords: maize, residual effect, sewage sludge, SPAD, yield

Abstrakt

Celem pracy była ocena efektów rolniczego wykorzystania komunalnych osadów ściekowych w uprawie kukurydzy na ziarno, w roku zastosowania oraz w kolejnych dwóch latach działania następczego. Badania przeprowadzono z wykorzystaniem odmiany PR39G12, na polu po 5-cio letniej monokulturze kukurydzy. Osad ściekowy stosowano zgodnie z ówczesnym rozporządzeniem Ministra Środowiska dopuszczającym aplikację w dawce 10 ton s.m.·ha^{-1} raz na 5 lat. Nawożenie osadem ściekowym kukurydzy, uprawianej z przeznaczeniem na ziarno, nie spowodowało różnic we wzroście i rozwoju roślin w porównaniu do obiektów nawożonych mineralnie, jak również nie powodowało przekroczenia dopuszczalnych zawartości metali ciężkich w nadziemnych częściach roślin. Kukurydza uprawiana z wykorzystaniem osadów ściekowych plonowała wyżej niż na obiektach nawożonych mineralnie, zwłaszcza w warunkach ekstremalnej suszy, jaka wystąpiła w 2006 roku. Korzystne oddziaływanie osadu ściekowego utrzymywało się w kolejnych dwóch latach od jego zastosowania oraz stabilizowało plon ziarna kukurydzy.

Keywords: kukurydza, następcze działanie, osad ściekowy, plon, SPAD

Introduction

The primary goal of agriculture is to achieve the optimum yields in terms of size and quality of crops, while maintaining fertility and productivity of soil. In order to meet these requirements it is necessary to use the latest achievements of genetics, proper agricultural technology, plant protection, and above all rational mineral and organic fertilization. Fertilizer commonly used in agriculture is manure, but due to the reduction of its production caused by decrease in animal populations, it began to look for alternative sources of organic matter, which can be incorporated into the soil.

Polish soils are generally poor in organic matter and the cultivation of intensive crops such as maize, cause decrease of humus and nutrients content. According to Szulc, at al. (2012) maize is characterized by a high yield potential and to exploit it, should be provided to the plants nutrients sufficient for normal growth and development. Sulewska and Koziara (2007) report that in Poland, the share of soil quality classes IV to VI, with a low content of organic matter and silt and clay fraction is about 74%. One way to improve its agricultural value may be sludge, which is becoming increasingly important as a source of enrichment of soil organic matter and nutrients for plants need (Nascimento, at.al., 2004). According to Singh and Agrawal (2008) municipal sewage sludge is highly abundant in the relevant components for soil fertilization and plant nutrition. These properties determine the advisability of sludge utilization as fertilizer, especially for the soils in Poland (Sulewska and Koziara, 2007; Szymańska, at al., 2013). The municipal sewage sludge C:N ratio is usually as 5.68–16.75:1, so its use should not block nitrogen availability for plants (Cuevas, at al., 2003). According to Singh and Agrawal (2008) and Vaca, et al., (2011) the use of sewage sludge as fertilizer is the most appropriate method of disposal. Theoretically, determination of sludge dose should not be a problem, given that it is subject to the provisions of the legislation (Directive, 2010). Agricultural condition of its use is to meet sanitary and hygienic norms and to meet acceptable amount of toxic compounds in the harvested crop plants (Reszel, at al., 2007). Singh and Agrawal (2010) also highlighted significant variations in the chemical composition of sewage sludge, which in the case of agricultural use requires constant analytical control.

The aim of this study was to evaluate the effects of application of municipal sewage sludge in corn for grain, in the year of application and follow up effect after one and two years after its application. The research hypothesis assumes that the use of municipal sewage sludge and follow up effects is beneficial for height and yield components of corn grown for grain.

Materials and Methods

The experiment was carried out in 2006–2008 in the fields of Experimental Station in Swadzim belonging to the Department of Agronomy at the Poznań University of Life Sciences. The object of this study was PR39G12 corn variety, grown for grain, on the field after the 5-year monoculture corn. One factor experiment with the cultivation of corn for grain was established in random block design with 4 replications as follows: control - mineral fertilizers; sewage sludge in the year of application; sludge in 1st year after application: the sludge is 2nd year after application. Effects of sewage sludge were evaluated against the control object fertilized with mineral doses: nitrogen (N) – 110 kg·ha^{-1}, phosphorus (P) – 35 kg·ha^{-1}, potassium (K) – 100 kg·ha^{-1}. Amount of organic matter was increased by 9–10 t·ha^{-1} of chopped straw after harvest of corn for grain.

Sewage sludge from sewage deposited plant in Szamotuły was used in accordance with Directive of Minister of Environment (2002) allowing application at a dose of 10 t·ha^{-1} dry mater (DM) once every 5 years. The soil where the experiment was established met the requirements of the content of heavy metals such as Cd, Cr, Cu, Hg, Ni, Pb and Zn required for sewage sludge used in agricultural (Directive of the Minister of Environment, 2002). Applied sewage sludge was covered with spring plowing. Sewage sludge used in the experiment was analyzed in terms of microbiological and heavy metal content in the laboratory of AQUANET in Koziegłowy. The chemical composition for ingredients content in sewage sludge was investigated by the following methods: dry matter content: PN-EN 12880:2004; N total: PN-EN 13342:2002; P: PB/PFO-11; Mg and Ca: PN-ISO 7980: 2002; Cr: PN-EN 1233:2000; Hg: PB/PFO-8; Zn, Cd, Cu, Ni, Pb: PN-ISO 8288: 2002; pH: PN-EN 12176:2004. The chemical composition of the applied sewage sludge and heavy metals limits set by standards (Directive of the Minister of Environment, 2002) are given in Table 1.

Table 1. The chemical composition and limits for ingredients content in sewage sludge applied

Specification	Sewage sludge	Content limits g·kg^{-1} DM
N total	5.6% D.M.	-
P	2.41% D.M.	-
K	4.53% D.M.	-
Ca	2.45% D.M.	-
Mg	0.57% D.M.	-
Cu	0.33 g·kg^{-1} D.M.	0.8
Zn	1 g·kg^{-1} D.M.	2.5
Cd	< 0.0025 g·kg^{-1} D.M.	0.01
Pb	0.043 g·kg^{-1} D.M.	0.5
Ni	0.022 g·kg^{-1} D.M.	0.1
Cr	0.026 g·kg^{-1} D.M.	0.5
Hg	0.00081 g·kg^{-1} D.M.	0.005
pH	7.3	-
Dry matter content	24%	-

According to Singh and Agrawal (2008) the chemical analyzes of sediments show, that they are substantial source of N, P, Ca and Mg for plants, and to a lesser extent concerning K. The same authors also observe that the beneficial use of sludge is associated with not only increased the basic content of macronutrients in the soil, but also an increase of soil pH and the saturation of the magnesium cations. According to Singh and Agrawal (2010), it should be noted, however, quite large differences in the content of individual components in the sediments, suggesting the need to analyze each batch of sludge destined for fertilization. The levels of heavy metals content in the sludge permitted by the (Directive of the Minister of Environmental, 2002) are presented in Table 2.

Table 2. Limits and heavy metal weight g·ha^{-1}·year applied with sewage sludge

	Specification						
	Cu	Zn	Cd	Pb	Ni	Cr	Hg
Brought g·ha^{-1}·year	660	2 000	5.0	86	44	52	1.62
Limit g·ha^{-1}·year	1 600	5 000	20	1 000	200	1 000	10

The results of the analysis indicate that they were safe in terms of sanitation. Heavy metals content was much lower than the limit for sediments in agricultural use. Consequently, at the doses used it was applied to the soil with sludge from a limit of 8.6% for lead and 41.2% for copper. Similar results were obtained by Krzywy, et al. (2008), as the results of the analysis showed, that none of the heavy metals did not exceed limits set up in the Directive of the Minister of Environment of Poland (2002). Soil classification of experimental fields, according to FAO, (2006) belongs to suvisoils, established from light loamy sand, shallow clay deposited. According to the soil classification, it is class IV, and by agricultural suitability, it is complex 5 (good rye). The soil acidity at which the experiment was conducted ranged from 6.1 in 2006 to 6.8 in 2008. Total phosphorus content ranged from 11.7 in 2008 to 15.3 mg·100 g^{-1} soil in 2006. The soil where the experiment was established did not contain heavy metals such as Cd, Cr, Cu, Hg, Ni, Pb and Zn.

Soil management was done in accordance with proper agricultural practice for grain maize. Applied sewage sludge was covered with spring plowing. Plot area was 22.4 m^2 of which only two middle rows were harvested. During the course of experiment, it were identified loses of plants during growing season, the number productive ears and plant size. Plant greenness index (SPAD), was determined at flowering stage of maize ears and tassels (BBCH 61–67), on a leaf below the ear, on a random plant of the plot, by Hydro N-Tester, in triplicate measurements. Just before harvest in full grain maturity stage (BBCH 89) samples of ears were collected to determine the yield components. Grain moisture at harvest was determined on a sample of 250 g of grains taken at random, using an automatic moisture meter Super Matic. Grain yield was converted to a constant humidity of 15%.

Contents of mineral and heavy metals in the aboveground parts of the plant form objects fertilized sewage sludge were analysed at the laboratory of the EgroEkspert company (Poland). The chemical composition for ingredients content in aboveground parts of the maize plants was investigated by the commonly used methods.

The results were collected in *MS Excel* spreadsheet. The effect of sewage sludge on the tested characters was analyzed by standard analysis of variance (*ANOVA*) for orthogonal factorial experiments (Elandt, 1964). The least significant difference (LSD) was verified by Tukey's test at the level P<0.05 and P<0.01. For the analysed traits the characteristics of variation were also determined, such as coefficient of variation, and minimum and maximum values. The significance of the Pearson linear correlation coefficients between the studied traits were assessed at the level of P< 0.05 (* significant difference) and P<0.01 (** highly significant difference). All data were analyzed using procedures in STATPAK software.

Results and Discussion

In the years 2006-2008, in which it was carried out field experiments, meteorological conditions, especially total precipitation and its distribution were characterized by high volatility. In 2006, there was an extreme drought, which began in May and lasted until the end of the growing season despite of one significant rainfall in August, from which, plants could not benefit after long time in drought stress. However, the years 2007-2008 proved to be very beneficial to the growth and development of maize plants, particularly in terms of the distribution of precipitation. Total precipitation in 2007 amounted 331.9 mm and 370.7 mm in next year. It should also be noted, that the highest soil moisture in these years occurred in the period of peak demand for water for maize plants.

In all the years of the study, both the number of plants after emergence and before harvest, after the application of sewage sludge did not differ significantly from those, which have been identified at control objects (Table 3).

Table 3. The quantitative status of maize plants after the application of sewage sludge

Treatment	Plants number after emergence pcs·m^2			Plants number before harvest pcs·m^2			Plants losses %		
	2006	2007	2008	2006	2007	2008	2006	2007	2008
Control	8.0	7.4	7.9	7.8	7.4	7.7	2.8	0.9	2.2
Sewage sludge in year of application	7.5	7.5	7.9	7.5	7.4	7.7	0.6	1.2	3.2
Residual effect in first year	-	7.4	7.0	-	7.5	6.9	-	0.0	1.9
Residual effect in second year	-	-	8.2	-	-	8.1	-	-	1.3
P<0.05	n.s.	n.s.	0.99*	n.s.	n.s.	0.97*	1.34*	n.s.	n.s.

*, ** – indicate statistical significance at the 5% and 1% levels of probability, respectively; n.s. – not significant

Significant differences in the values of these features occurred in the last year of the study. It should be noted that the practical density of plants gave an opportunity to obtain satisfactory yields on all experimental objects. In spite of the 2006 drought, which lasted until the end of the growing season, in the year of application of sewage sludge, it was observed a significantly lower percentage of maize plant outages compared to the control (Table 3). An inverse relationship was observed during favourable weather conditions (2007 and 2008), where plant outages, compared to the control, were higher, but not statistically confirmed. The follow up effect of application of sewage sludge decreased outages of maize plants, both in the first and second year after application. The use of sewage sludge improved the rate of greenness of corn leaf under the ear (Table 4).

Table 4. Below ear leaf greenness index in (SPAD) units after the application of sewage sludge

Treatment	Below ear leaf greenness index in SPAD units		
	2006	2007	2008
Control	540.0	571.0	391.5
Sewage sludge in year of application	618.7	742.9	398.7
Residual effect in first year	-	739.9	420.5
Residual effect in second year	-	-	392.5
P<0.05	n.s.	50.16**	n.s.

*, ** – indicate statistical significance at the 5% and 1% levels of probability, respectively; n.s. – not significant

This effect was statistically confirmed in a 2007. Application of sludge caused increase of greenness rate, compared to the control, by 171.9 units SPAD. A similar relationship has been found in the previous year of the study, and the smallest difference was observed in 2008. In that year, SPAD value of plants grown year after application of sewage sludge was higher by 29 units from the plant with the control treatment, and about by 25 units compared with the other objects. The results found in this study differ from those presented by Sulewska and Koziara (2007), who showed, that the use of the sludge causes the accumulation of N in the leaves. Similar results were also obtained by Gondek, (2010). The height of maize plants in the first two years of the study did not change significantly under the influence of sewage sludge (Table 5).

In the second year of the study, compared to the control, it was found only a trend to increase the height of maize plants, both in the year of application of sewage sludge or years after treatment. In favourable for the growth and development of the maize 2008, on the objects with sludge application, the height of maize plants was significantly lower than the control object. Similar correlation was also found with regard to the height of ear establishment (Table 5).

Table 5. The morphological characteristics of matured maize plants after the application of sewage sludge

Treatment	Plant height cm			Height of ear establishing cm		
	2006	2007	2008	2006	2007	2008
Control	243.7	270.2	182.1	110.9	117.8	54.9
Sewage sludge in year ofapplication	241.7	275.5	156.5	110.8	115.9	41.4
Residual effect in first year	-	275.5	168.6	-	114.1	48.5
Residual effect in second year	-	-	166.0	-	-	48.6
P<0.05	n.s.	n.s.	21,82*	n.s.	n.s.	7.16**

*, ** – indicate statistical significance at the 5% and 1% levels of probability, respectively; n.s. – not significant

Results of this study indicate a high dependence of maize yield on the weather conditions and high volatility in the grain yield (Table 6). The lowest, from the years of research, the grain yield has been found in extremely dry 2006. On the control object amounted to 37.6 $dt \cdot ha^{-1}$, while on the object in the year of application of sewage sludge, in these dry conditions, grain yields were higher by as much as 18.2 $dt \cdot ha^{-1}$. Reasons for the growth of maize grain yield, which was achieved in an extremely dry year, may be due to hygroscopic of sewage sludge (Singh and Agrawal, 2008).

Table 6. Grain yield of maize ($dt \cdot ha^{-1}$) 15% H_2O after the application of sewage sludge

Treatment	Years		
	2006	2007	2008
Control	37.6	95.5	49.2
Sewage sludge in year of application	55.8	103.5	54.0
Residual effect in first year	-	101.9	52.8
Residual effect in second year	-	-	55.9
P<0.05	14.57**	n.s.	4.93*

*, ** – indicate statistical significance at the 5% and 1% levels of probability, respectively; n.s. – not significant

In this way the sewage captures and collects water, thereby improving water retention in the soil. The positive effect of application of sewage sludge in corn silage studies have also shown Niewiadomska, et al. (2010). On objects after applying sewage sludge, the authors obtained a significantly higher yield of total plant fresh matter yield and a higher share of ears in fresh matter than maize fertilized with mineral nutrients. Statistical analysis for 2007 results showed no significant difference in the yield of maize between the control and object with the application of sewage sludge. Only the upward trend was observed in grain yield in the year of application of sewage sludge (8.4%) and one year after the application of sludge (6.7%). Similarly Sulewska and Koziara (2007), Mujacić, (2011) showed that the yield of maize fertilized with sewage sludge exceeded those with the mineral or organic fertilization. Similar results were also obtained by Vaca, et al. (2011). The positive effect of application of sewage sludge also was observed in the following year in maize monoculture. Application of sewage sludge resulted in a significant increase in grain yield. The objects with the application of sewage sludge showed higher yields compared to control by 4.8 $dt \cdot ha^{-1}$ (9.7%), while in the second year of sludge application grain yield was higher by 6.7 $dt \cdot ha^{-1}$ (13.6%). Kalembasa and Malinowska (2008) also found a positive follow up effect of sewage sludge in the cultivation of Miscanthusa sacchariflorus. These results were confirmed in a previous study conducted by Antonkiewicz, (2005) on the effects of sewage sludge on the yield of a mixture of grasses and legumes. It was found already in the first year of vegetation after the application of the sludge the fivefold increase in dry matter yield in comparison to control, and in the following year yields were 2-3 times higher. Similar correlations showed Gondek, (2010) in the study of maize. In other studies Gondek and Filipek-Mazur (2006) indicate that the efficiency of sewage sludge application in the autumn is higher than in spring time. The authors also indicate better performance of yield-forming caused by sediments from urban than industrial origin. The Reszel, et al. (2004), besed on the response of maize pot experiment to fertilization with limed sewage sludge noticed that most effective are sediments in the first year after application, and this is related to the amount of available nutrients, which was confirmed by our own experiments.

The use of sewage sludge in corn for grain, influenced on the level of yield and yield components (Table 7). The calculated coefficients of variation indicate that the use of sewage sludge stabilized grain yield and 1000 kernels weight (TKW) compared to the control fertilized with mineral nutrients. Although the use of sewage sludge caused that number of ears per area unit and the number of kernels in the ear were characterized by higher volatility than the control object, but fertilization with sewage sludge increased the minimum and maximum yield values, the number of kernels in the ear and TKW. The calculated correlation coefficients indicate that in the object fertilized with mineral nutrients, grain yield was most strongly correlated with the number of kernels in the ear, and the use of sewage sludge caused strong relationship between the number kernels in the ear and TKW, and yield of corn.

Extended statistical analysis of multiple regression equation calculation shows, that in the maize grown without sludge, grain yield depended mainly on the number of kernels in the ear and TKW (Table 8). In contrast, when sewage sludge is used, grain yield in 81% depend on all components of yield.

Table 7. Correlation coefficients and statistical characteristics of grain yield and yield components

Object	Specification	1	2	3	CV%	Values min–max
Control	Ears number (1)	1.000			10.8	6.0–8.3
	Grain number in ear (2)	0.724**	1.000		15.4	342–531
	TGW (3)	0.663*	0.364	1.000	13.8	198.9–332.7
	Grain yield	0.537	0.674*	0.335	44.9	22.7–103.2
Sewage sludge	Ears number (1)	1.000			14.7	5.0–8.3
	Grains number in ear (2)	0.782**	1.000		16.2	345–558
	TGW (3)	0.516	0.477	1.000	9.8	245.2–346.2
	Grain yield	0.558	0.838**	0.606*	34.6	41.3–106.8

P<0.05 (* significant difference), P<0.01 (** highly significant difference)

Table 8. The impact of yield components on grain yield of maize

Treatment	Regression equation	Coefficient of determination (R^2)
Control	y* = –0.726 + 0.257(lz)** + 0.711(m)***	46.4
Sewage sludge	y = –0.976 – 0.927(lk)**** + 0.328(lz) + 0.281(m)	81.0

* y is grain yield (dt·ha^{-1}), ** lz is the grains number in ear (pcs.·m^2), *** m is weight of 1000 grains (g), **** lk is the ear number (pcs.·m^2)

Table 9. Grain moisture [%] at harvest after the application of sewage sludge

Treatment	Years 2006	2007	2008
Control	27.0	26.8	24.4
Sewage sludge in year of application	29.9	27.5	25.2
Residual effect in first year	-	27.2	24.9
Residual effect in second year	-	-	25.4
P<0.05	0.61*	n.s.	0.75*

*, ** – indicate statistical significance at the 5% and 1% levels of probability, respectively; n.s. – not significant

In all years of research, after application of the sludge, grain moisture was higher than the control object, which indicates the elongation of the vegetation period of plants fertilized in this way (Table 9). In the first year of testing, grain moisture on these objects was higher by 2.9 point %, and in subsequent years the use of sewage sludge increased the average moisture content by about 0.8 point %. The increase in grain moisture on the objects fertilized with sewage sludge can be explained by hygroscopic properties of the deposits of which inform (Singh, Agrawal 2008). Similar observations reported Sulewska and Koziara (2007), who showed extending the growing season on objects fertilized with deposits as well as increased corn grain moisture at harvest.

As a result, the use of sludge tended to reduce the number of ears per area unit (Table 10). In the first two years of the study the number of ears in objects with sewage sludge was lower than in controls, but these differences are not statistically confirmed. In the last year of the study, the use of sewage sludge resulted in a reduction of about 0.4 ears·m^{-2}, which was statistically significant. However, the objects after the first year of sludge application, the number of ears decreased to 5.7 pcs·m^{-2}. The positive follow up effect of sludge was found in the second year after application, which was based on a significant increase in the number of ears per area unit (6.5 pcs·m^{-2}). This is supported by Reszel, et al. (2004), because their research shows that the use of limed sludge favored establishing of ears by maize plants. In case of the number of kernels in the ear and TKW, a follow up effect of sludge was probably dependent on the weather conditions during the test. In extremely dry 2006 season, application of sewage sludge resulted in a tendency to increase the number of kernels in the ear and TKW. The positive effect of the sewage sludge is maintained in the following years of research, which was particularly evident in the number of kernels in the ear. In the last year of the study application of sludge increased TKW by 24.1 g compared to the control. It was also noted the continuing positive effect of sewage sludge subsequent effect on TKW. Follow up effect of sewage sludge in the first and second year of its use has also resulted in increasing the number of kernels in the ear, but these differences are not statistically proven.

Table 10. Yield components of maize after application of sewage sludge

Treatment	Ear number pcs.·m^2			Grains number in ear pcs.			TKW g		
	2006	2007	2008	2006	2007	2008	2006	2007	2008
Control	7.1	7.7	6.5	401.0	498.0	418.2	305.4	313.0	242.0
Sewage sludge in year of application	6.8	7.5	6.1	403.2	529.0	414.7	307.9	320.4	266.1
Residual effect in first year	-	7.6	5.7	-	513.2	413.7	-	328.1	254.5
Residual effect in second year	-	-	6.5	-	-	422.0	-	-	260.0
P<0.05	n.s.	n.s.	0.35*	n.s.	24.4*	n.s.	n.s.	n.s.	16.41*

*, ** – indicate statistical significance at the 5% and 1% levels of probability, respectively; n.s. – not significant

In all the years of research, the use of sewage sludge did not result in significant morphological diversity of maize as compared to the control (Table 11). It was observed only a slight tendency to increase the length of the ears.

Table 11. The morphological characteristics of maize ears after application of sewage sludge

Treatment	Length of ears cm			Width of ear cm		
	2006	2007	2008	2006	2007	2008
Control	15.7	17.4	16.0	3.7	4.0	3.7
Sewage sludge in year of application	16.1	17.6	15.9	3.7	4.0	3.7
Residual effect in first year	-	17.9	15.9	-	4.0	3.6
Residual effect in second year	-	-	16.6	-	-	3.7
$P<0.05$	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

*, ** – indicate statistical significance at the 5% and 1% levels of probability, respectively; n.s. – not significant

In the studies there was also performed analysis of plant material originating only from objects fertilized with sewage sludge. Their aim was to assess the possible content of heavy metals and other elements in different parts of the plant. The content of these components in the aboveground parts of the plant is presented in Table 12. Differentiation of individual plant components, among others, have expressed in, that the grain is characterized by a higher content of N and P than other parts of plants. Analyzing the differences in the contents of individual minerals in plants, Mazur, et al. (2009) found a higher content of P and K in corn ears fertilized with sewage sludge composts than magnesium and calcium. Our findings indicate that the maize stalks contain more K and leaves more calcium and magnesium. Influence of sewage sludge on the chemical composition was also tested for other agricultural plant species. Krzywy, et al. (2008), after examining the seeds of spring oilseed rape, oats, triticale, found that composts from municipal sewage sludge in the first year after application influenced the increase of calcium, magnesium and sulphur, and the follow up effect has not been confirmed in next years of the study. Gondek and Filipek-Mazur (2006) reported that the K content in the biomass of maize was significantly influenced by term of fertilization with sewage sludge. They found that crops grown on objects fertilized in the spring contain more K. Antonkiewicz, (2005) examining the effects of sewage sludge on N content in the mixture of grasses and legumes, reports, that the highest content of this component was found on the objects fertilized only with sludge. It should be noted that in those studies it was used much higher doses of sludge. The author adds that the utilization of N in plants dependent on sludge doses applied. Gondek and Filipek-Mazur (2006) showed that fertilization with sewage sludge retained N content in the biomass of corn and white mustard at a level similar to the content of the crops grown on manure.

Table 12. Average values of mineral and trace elements content (objects with sewage sludge) in the aboveground parts of the plant

Specification	Grain	Leaves	Stalks
Macroelements % DM			
N – total	1.50	1.02	0.76
P	0.344	0.196	0.165
K	0.381	0.547	1.626
Ca	0.028	0.779	0.300
Mg	0.132	0.211	0.126
Trace elements mg·kg^{-1} DM			
Pb	0.60	0.61	0.39
Cd	0.05	0.12	0.06
Ni	0.50	0.39	0.72
Hg	<0.001	0.008	<0.001
Zn	25	31	17.2
Cu	1.90	3.75	1.05
Cr	0.54	0.61	1.37

Comparison of the above ground parts of the plant, in terms of heavy metals content, confirmed the opinion of the lower concentration of these elements in the generative organs. The positive results came out for grain, which contained significantly fewer heavy metals (except lead) than the leaves and stems. Corn stalks accumulated more nickel and chromium than the seed and leaves. Also Czyżyk, (2009) described Cu and Cr content in the biomass of maize as low and did not see a clear correlation between the applied dose of sludge compost and their contents. The other analyzed heavy metals were accumulated mainly in the leaves of maize. Kalembasa and Malinowska (2009) in two-year studies of sewage sludge influence on heavy metal content in the biomass of Miscanthusa sacchariflorus, showed the higher concentration of heavy metals (except for zinc) in the leaves than in the stems of the grass. While Czyżyk, (2009) in fertilization of grass with sludge compost, demonstrated that in particular high doses of sludge resulted in increased bioaccumulation of heavy metals.

According to the annex to Directive of Committee, (2006), setting maximum levels for certain contaminants in foodstuffs, the maximum allowable level of contamination of cereals and legumes in lead is 0.2 mg Pb·kg^{-1} FM, and cadmium in cereals excluding bran, germ, wheat and rice is 0.1 mg Cd·kg^{-1} FM. Identified in our study level of lead content exceeded the standards set out in Commission Regulation (EC) (2006). Limit the lead content in plants proposed by Kabata-Pendias and Pendias (1999) allowed for plant consumption amounts not more than 1.0 mg Pb·kg^{-1} DM, while Gorlach, (1991) given by the content of 0.1-1.0 mg Pb·kg^{-1} DM, is considered to be safe in animal feed. According to the standards given by above mentioned authors, the lead content in the plant material from our research was not exceeded. Also content of cadmium found in the above-ground parts of maize plants, was within the range of values suggested by Kabata-Pendias and Pendias (1999) and specified in the Regulation of the EU Commission (2006). In addition, in our study, the average concentration of nickel and cadmium in aboveground parts of maize plants was lower than in the biomass of Miscanthusa sacchariflorus fertilized at the same dose as maize plants. Kalembasa and Malinowska (2009) also showed that Miscanthus biomass harvested from objects fertilized with NPK contains more Ni than the biomass of the objects fertilized with sludge, which was not confirmed statistically. Kalembasa and Godlewska (2008) consider that application of sewage sludge significantly increased the content of Mn and Ni in annual ryegrass, but the total content of these metals did not exceed the levels considered to be toxic.

Conclusions

1. Fertilization with sewage sludge of maize grown for grain did not cause differences in the growth and development of plants, compared to mineral fertilized objects.
2. Maize grown with the use of sewage sludge yielded higher than the control objects, especially under extreme conditions of drought. Beneficial effect of sludge was maintained in the next two years after application.
3. Sewage sludge in the year application, and its follow up effect in next two years, compared to the control, caused a better nutrition of maize plants, expressed in SPAD units.
4. Fertilization with sewage sludge fertilization did not result in exceeding the limit values for heavy metals in the above ground parts of the plant.
5. Municipal sewage sludge can be safely disposed in corn contributing to the increase of yields.

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