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EFFECT OF FERTILIZATION WITH FARMYARD MANURE, MUNICIPAL SEWAGE SLUDGE AND COMPOST FROM BIODEGRADABLE WASTE ON YIELD AND MINERAL COMPOSITION OF SPRING WHEAT GRAIN

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Abstract

Both deficiency and excess of mineral components in cereal grain may impair its biological value, later interfering with the metabolic processes occurring in animal and human organisms. Potential accumulation of undesirable components in biomass should be taken into consideration since such compounds occur in large amounts in waste material. Therefore, it is necessary to assess the effect of waste-based fertilizers on both the amount of generated biomass and its chemical composition. The present investigations were conducted to determine the effect of fertilization with farmyard manure, municipal sewage sludge and compost from biodegradable materials on the yield and mineral composition of spring wheat grain. The field investigations ran for three years. Nitrogen in wheat grain was assessed using Kjeldahl's method, phosphorus by colorimetry, sulphur, copper, manganese and zinc by the ICP-AES method, and potassium, magnesium and sodium by flame photogrammetry. In the first year, organic fertilizers were observed to be less stimulating to yield formation than mineral fertilizers. Although the uptake of N, P and K from the applied organic fertilizers was impeded, their deficiency in wheat grain was preventable by balancing doses of these components. Despite different amounts of magnesium, sodium and sulphur applied to the soil with the fertilizers, the concentrations of these elements in grain were considerably stable in the years of the investigations. Copper and manganese concentrations in wheat grain were deficient, which significantly depressed grain fodder value and might indirectly determine the crop yield.

Key words: fertilization, sewage sludge, compost, mineral composition, spring wheat.

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WPŁYW NAWOŻENIA OBORNIKIEM, KOMUNALNYM OSADEM ŚCIEKOWYM I KOMPOSTEM Z BIODEGRADOWALNYCH MATERIAŁÓW NA PLONOWANIE I SKŁAD MINERALNY ZIARNA PSZENICY JAREJ

Abstrakt

Zarówno niedobór, jak i nadmiar składników mineralnych w ziarnie roślin zbożowych może obniżyć ich wartość biologiczną, co może niekorzystnie wpływać na procesy metaboliczne u zwierząt i ludzi. Należy brać pod uwagę możliwość akumulacji niepożądanych składników w biomasie, gdyż takie związki mogą występować w dużych ilościach w odpadach wykorzystywanych do nawożenia. Stąd też konieczna jest ocena wpływu nawozów wytwarzanych na bazie odpadów zarówno na ilość wytworzonej biomasy, jak i na jej skład chemiczny. Trzyletnie doświadczenie polowe wykonano w celu określenia wpływu nawożenia obornikiem, komunalnym osadem ściekowym oraz kompostem wyprodukowanych z materiałów biodegradowalnych na plonowanie i skład mineralny ziarna pszenicy jarej. Zawartość azotu w ziarnie pszenicy oszacowano metodą Kjedahla, fosfor kolorymetrycznie, siarkę, miedź, mangan i cynk za pomocą metody ICP-AES, natomiast potas, magnez i sód z użyciem fotogrametrii płomieniowej. W pierwszym roku stwierdzono, że nawozy organiczne miały słabszy wpływ plonotwórczy niż nawozy mineralne. Pomimo ograniczonego poboru N, P i K z zastosowanych nawozów organicznych, można było zapobiegać niedoborom tych pierwiastków w ziarnie przez bilansowanie dawek tych składników. Mimo zróżnicowanych ilości magnezu, sodu i siarki wprowadzonych do gleby wraz z nawozami, zawartość tych pierwiastków w ziarnie była znacząco stabilna w ciągu kolejnych lat badań. Zawartość miedzi i manganu w ziarnie pszenicy była niewystarczająca, co znacząco obniżyło wartość paszową ziarna pszenicy i mogło mieć pośredni wpływ na plonowanie.

Słowa kluczowe: nawożenie, osad ściekowy, kompost, skład mineralny, pszenica jara.

INTRODUCTION

Apart from the crop yield, another crucial aspect in the assessment of the value of cereal grain used as animal fodder is its content of macro- and microelements, which are an important source of mineral substances for animals. Concentrations of individual elements in cereal grain are highly varied depending on a cereal species and its form, soil abundance in nutrients, the weather conditions, plant protection and cultivation measures, including fertilization (Šramkova et al. 2009, Gondek, Gondek 2010). Fertilization may have direct or indirect influence on yielding and mineral content in grain by affecting speciation of elements in soil and the soil properties (Mijangos et al. 2006, Głąb, Gondek 2008, Rutkowska et al. 2009). Balanced application of natural and mineral fertilizers improves crop yields and poses no threat to the quality of biomass. The risk of adverse changes in yielding and chemical composition of crops may arise from soil fertilization with waste organic material whose chemical composition is not stable (Gasco, Lobo 2007).

Both deficiency and excess of mineral components in cereal grain may lead to its inferior biological value, thus disturbing the metabolic processes in an animal fed such grain. Potential accumulation of undesirable components in biomass should be taken into consideration, since they may occur in large quantities in waste material. Therefore, it is necessary to assess the effect of these substances not only on the amount of biomass but also on its chemical composition (Kalembasa, Malinowska 2009).

With high quantities of plant nutrients in natural and organic fertilizers and waste organic material, fertilization with these substances on crop yields and their chemical composition can be expected to produce beneficial effects. This research was conducted to determine the effect of fertilization with farmyard manure, municipal sewage sludge and compost from biodegradable materials on the yield and mineral composition of spring wheat grain.

MATERIAL AND METHODS

The investigations were conducted as a field experiment set up 10 km west of Krakow (49°59' N; 19°41' E) under moderate climate. The data obtained from a meteorological station are presented in Tables 1 and 2. The soil under the experimental field was classified as Stagnic Gleysoils (Fao 1998). Table 3 shows selected properties of the soil prior to the experiment.

The experiment was set up according to the randomized block method. The plot area was 30 m^2. The experimental design comprised 5 treatments in four replications: without fertilization (0), NPK mineral fertilization (M) [110 kg N ha^{-1}, 58.6 kg P ha^{-1} and 120 kg K ha^{-1}]; swine FYM (SF) [14.30 t ha^{-1} of fresh mass], municipal sewage sludge from a mechanical-biological treatment plant (SS) [14.15 t ha^{-1} of fresh mass] and compost made from plant and other biodegradable waste (C) [6.46 t ha^{-1} of fresh mass]. Selected properties of the manure, municipal sewage sludge and compost are presented in Table 4.

Before the experiment (autumn 2004), the field was limed according to half the value of hydrolytic acidity (962.0 kg CaO ha^{-1}).

In the spring of the following year, after basic cultivation measures, the plots were evenly covered with farmyard manure, sewage sludge or compost and ploughed. Two weeks later, supplementary mineral fertilization was conducted and the fertilizer was mixed with the soil using a cultivator and harrow aggregate. The nitrogen dose supplied with the organic materials was 110.0 kg N ha^{-1}. Phosphorus and potassium were supplemented in mineral fertilizers to the equal level introduced with fertilizers in all the treatments (except the control), [phosphorus to 58.6 kg P ha^{-1} as single superphosphate and potassium to 120.0 kg K ha^{-1} as 60% potassium salt]. In the second and third year, doses of these elements were identical as in the first year but were introduced only in the form of mineral fertilizers, applied in order to supplement nutrients (nitrogen, phosphorus and potassium) removed with wheat yield.

Table 1

Monthly and periodic precipitation totals during the experiment (mm)

Year	Month												Σ Mar – – Aug
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2005	66.4	32.6	20.7	49.1	61.3	40.6	113.4	102.6	26.5	7.7	29.9	46.7	387.7
2006	57.5	48.5	60.1	56.5	51.9	89.1	14.1	104.1	17.2	31.9	20.9	16.1	375.8
2007	100.6	42.2	61.1	15.4	51.7	72.1	71.0	76.4	179.8	48.3	90.4	21.4	347.7
1961-1999	34.0	32.0	34.0	48.0	83.0	97.0	85.0	87.0	54.0	46.0	45.0	41.0	434.0

Table 2

Mean daily air temperature during the experiment (^{o}C)

Year	Month												Mean Mar – – Aug
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2005	-1.2	-4.3	-0.2	6.8	11.4	14.4	17.6	15.4	12.5	7.1	3.9	-0.7	10.9
2006	-2.4	-3.0	0.2	5.6	10.9	15.0	18.6	15.6	13.4	9.1	6.3	0.9	11.0
2007	3.2	1.2	6.0	8.5	15.2	18.4	19.4	19.0	12.4	7.7	0.8	-1.1	14.4
1961-1999	-3.3	-1.6	2.4	7.9	13.1	16.2	17.5	16.9	13.1	8.3	3.2	-1.0	12.3

Table 3

Physical and chemical properties of the soil before experiment (0-20 cm layer)

Determination	Unit	Value
pH (KCl)	–	5.60
Organic C	g kg^{-1}	15.3
Total N	g kg^{-1}	1.59
Total S	g kg^{-1}	0.41
Total Cu	mg kg^{-1}	15.8
Total Zn	mg kg^{-1}	132.8
Total Mn	mg kg^{-1}	2230
P available	mg kg^{-1}	71.8
K available	mg kg^{-1}	297.5
Mg available	mg kg^{-1}	367.7
Bulk density	g cm^{-3}	1.52
Total porosity	cm^3 cm^{-3}	0.41
Fraction < 0.02 mm	g kg^{-1}	520

The test plant was cv. Jagna spring wheat. In the first year, wheat was sown on 7 April 2005, then on 10 April 2006 and finally on 28 March 2007. The plant density was 485 plants per 1 m^2. During vegetation, chemical preparations were applied to protect wheat from weeds (spraying with 1 dm^3 ha^{-1} of Puma Universal herbicide, manufactured by Bayer CropScience, and 1 dm^3 ha^{-1} of Aminopielik Gold, manufactured by Makhteshim Agan Agro Poland S.A.) and from fungal diseases (spraying with 1 dm^3 ha^{-1} of Alert 375 S.C. fungicide, manufactured by Du Pont). The duration of the wheat growth period in each year depended on the weather conditions. Wheat was harvested at grain full maturity on 13 August 2005, on 3 August 2006 and on 31 July 2007. In order to determine grain yield, wheat was gathered from an area of 4 m^2, separately from each plot.

Sewage sludge used for the experiment originated from a municipal mechanical and biological sewage treatment plant located in Malopolska. Compost was produced from plant and other biodegradable waste in a composting plant located in Krakow, using the MUT-Kyberferm technology. The types and shares of waste in the composted biomass were: 25% grass, 20% wood pellets; 20% leaves; 10% market waste; 5% tobacco waste and 20% coffee production waste. Swine FYM was stored for 6 months on a manure plate.

The following were determined in the fresh samples of sewage sludge, compost and manure: dry mass by drying at 105°C for 12 hrs, pH by potentiometery, conductivity with a conductometer and total nitrogen content after sample mineralization in concentrated sulphuric acid with Kjeldahl's method. Dried and ground material samples were used to determine the content of organic matter through annealing and the content of minerals after sample mineralization in a chamber furnace (at 450°C for 5 hrs) and dissolution of the ash in diluted (1:2) v/v nitric acid. The phosphorus concentration was assessed by colorimetry on a Backamn DU 640 spectrophotometer and potassium was determined by flame photometry on a Philips PU 9100X apparatus. Heavy metal concentrations were determined using the ICP-AES method on a JY 238 Ultrace apparatus. The analyses were conducted according to the methodology described by BARAN and TURSKI (1996) and KRZYWY (1999) and the results are given in Table 4.

Wheat grain was crushed in a laboratory mill. Afterwards, crushed wheat grain samples were mineralized in concentrated sulphuric acid and nitrogen was determined with Kjeldahl's method. Sulphur was determined after mineralization of the material in concentrated nitric acid by with the ICP-AES method. The remaining elements were determined after sample mineraliza-

Table 4

Physical and chemical properties of the organic materials

Determination	Unit	Pig FYM (PF)	Sewage sludge (SS)	Compost (K)
Total N	g kg^{-1} d.m.[b]	34.0	26.2	38.9
P	g kg^{-1} d.m.	12.8	8.2	5.8
K	g kg^{-1} d.m.	21.8	1.9	29.9
S	g kg^{-1} d.m.	4.76	9.66	3.61
Cu	mg kg^{-1} d.m.	156	103	33
Zn	mg kg^{-1} d.m.	284	1146	194
Mn	mg kg^{-1} d.m.	355	194	280
Cr	mg kg^{-1} d.m.	2.8	23.4	15.0
Pb	mg kg^{-1} d.m.	1.2	55.7	9.3
Cd	mg kg^{-1} d.m.	0.80	3.97	1.42
Ni	mg kg^{-1} d.m.	10.1	21.1	10.4
EC[a]	mS cm^{-1}	2.89	1.69	2.62
pH (H_2O)	–	8.23	6.23	7.31
Organic matter	g kg^{-1} d.m.	831	414	531
Water content	g kg^{-1} f.m.[c]	774	703	563
Ash	g kg^{-1} d.m.	169	586	469

a – EC = electrical conductivity
b – data are based on 105°C dry matter weight
c – f.m. = fresh matter

tion in a chamber furnace (at 450°C for 5 hrs) and dissolving the residue in diluted (1:2) nitric acid. Phosphorus was determined by colorimetry on a Backman DU 640 spectrophotometer, whereas the concentrations of potassium, magnesium and sodium were determined by flame photometry on a Philips PU 9100X apparatus. The concentrations of copper, manganese and zinc were determined using the ICP-AES method on a JY 238 Ultrace apparatus. The analyses were conducted according to the methodology described by OSTROWSKA et al. (1991).

Chemical analyses of the plant material were carried out in four replications, and the initial material (manure, sewage sludge, compost and soil) was analyzed in two replications. A plant reference sample NCS DC733448 (China National Analysis Center for Iron &Steel) or a soil reference sample AG-2 (*Agro*MAT) was assigned to each analyzed series and the result was regarded reliable if the estimated determination error did not exceed 5%.

The results were verified statistically using two-way ANOVA (factors: fertilization and years of the experiment) in a totally randomized design using f-Fisher test. Significance of differences between arithmetic means was verified on the basis of homogenous groups determined by Duncan's test at the significance level α<0.05. All calculations were made using Statistica software (STANISZ 1998).

RESULTS AND DISCUSSION

The average spring wheat grain yield in the first year of the experiment from the treatments with organic fertilization was lower, between 0.30 t and 1.06 t of dry mass ha^{-1}, than the yield from the treatments where mineral NPK (M) fertilizers had been applied (Table 5). With respect to organic fertilization treatments, the lowest grain yield was harvested after the application of compost (C). In the third year, significantly the lowest yield of spring wheat grain dry mass was obtained from the treatment where only mineral fertilizers (M) had been used. An increase in wheat grain yield after the application of swine FYM (SF), sewage sludge (SS) and compost (C) in relation to the yield from the treatment where only mineral fertilizers (M) were used was 25%, 9% and 26%, respectively.

Fertilization with organic material usually has a weaker effect on the growth and development of plants than application of mineral fertilizers. The so-called residual effect is frequently missing because a considerable amount of nutrients from fertilizers is removed with harvest in the first year. The present study demonstrates a weaker effect of organic fertilizers than mineral ones in stimulating better yields. However, in the third year, organic fertilizers proved to be more effective. These results do not completely coincide with the research by IŻEWSKA (2009), who demonstrated that

Table 5

Yields of grain spring wheat (t ha^{-1} ± SD)

Objects	1^{st} year	Relative	3^{rd} year	Relative
No fertilization (0)	2.53 ± 0.15*a*	61	2.55 ± 0.12*a*	59
Mineral fertilization NPK (M)	4.13 ± 0.54*d*	100	4.30 ± 0.04*de*	100
Swine FYM (SF)	3.36 ± 0.19*bc*	81	5.39 ± 0.36*f*	125
Sewage sludge (SS)	3.83 ± 0.32*cd*	92	4.70 ± 0.41*e*	109
Compost (K)	3.07 ± 0.71*ab*	74	5.42 ± 0.13*f*	126

Means marked by the same letters did not differ significantly at $\alpha < 0.05$ according to Duncan's test.

higher doses of municipal sewage sludge significantly increased yields of spring rapeseed and winter triticale grain in comparison with the yield from plots receiving mineral fertilizers. Such a result did not occur when composted sewage sludge had been applied. However, it should be emphasized that under controlled conditions (pot experiment) plants have optimal moisture conditions, which may stimulate biochemical processes accelerating mineralization of organic matter supplied with the tested materials. Also JAMIL et al. (2004) and KHAN et al. (2007) reported a beneficial effect of fertilization with sewage sludge on wheat yielding. IBRAHIM et al. (2008), who investigated compost fertilization on wheat yield, point to the fact that amounts of nutrients supplied with fertilizers need to be balanced.

Concentrations of macroelements wheat grain dry mass from the treatments where fertilization had been applied were as follows: nitrogen 19.0 g - - 9.5 g kg^{-1}, phosphorus 4.61 g - 5.01 g kg^{-1}, potassium 3.97-5.32 g kg^{-1}, magnesium 0.83-1.13 g kg^{-1}, sodium 0.02-0.06 g kg^{-1}, sulphur 1.19-1.60 g kg^{-1} (Tables 6,7). Concentrations of nitrogen, potassium, magnesium and sulphur were significantly varied between the years of the experiment. Higher concentrations of these elements were detected in the grain from the third year of the research. The phosphorus and sodium concentrations in grain did not differ significantly between the years.

The nitrogen concentration in the first year was markedly the highest in wheat grain fertilized with mineral fertilizers, whereas in the third year much larger quantities of this element were assessed in wheat grain from the treatments where manure, sewage sludge or compost fertilization had been applied in the first year (Table 6). However, the statistical analysis of arithmetic means of the concentrations of this element in grain did not confirm the significance of differences.

Concentrations of phosphorus in wheat grain were relatively stable, irrespective of the year or applied fertilization (Table 6). Despite the lack of significant differences, there was a tendency towards increasing levels of this element in grain from the treatment where only mineral NPK ferti-

Table 6

Nitrogen, phosphorus and potassium content (g kg^{-1} d.m. ± SD) in grain of spring wheat

Treatments*	N		P		K	
	1st year	3rd year	1st year	3rd year	1st year	3rd year
(0)	20.1 ± 1.0*ab*	26.1 ± 0.3*cd*	5.00 ± 0.21*a*	4.99 ± 0.14*a*	4.54 ± 0.28*b*	5.27 ± 0.16*c*
(M)	24.6 ± 0.9*c*	27.7 ± 0.7*de*	4.68 ± 0.46*a*	5.01 ± 0.19*a*	3.97 ± 0.54*a*	5.32 ± 0.35*d*
(SF)	21.5 ± 2.1*b*	28.2 ± 1.8*e*	4.61 ± 0.24*a*	4.83 ± 0.25*a*	4.06 ± 0.13*a*	5.15 ± 0.23*c*
(SS)	20.5 ± 1.3*ab*	29.5 ± 0.5*e*	4.82 ± 0.18*a*	4.82 ± 0.15*a*	4.30 ± 0.17*b*	5.21 ± 0.12*c*
(K)	19.0 ± 1.2*a*	27.9 ± 1.0*e*	4.63 ± 0.17*a*	4.70 ± 0.23*a*	4.33 ± 0.18*b*	5.08 ± 0.15*c*

*see Table 5

Means marked by the same letters did not differ significantly at $\alpha < 0.05$ according to Duncan's test.

lizers (M) were used. The increase in P in wheat grain from this treatment in the third year was over 7%. In the treatments where manure (SF) and compost (C) fertilization was applied, the increase in P concentrations in wheat grain in the third year versus the first one did not exceed 3.5%. According to the Danish feeding standards for cattle, the phosphorus concentrations in grain determined in our study were satisfactory (MŘLLER et al. 2000).

Potassium concentrations in spring wheat grain in the first year of the experiment were significantly the lowest following the application of mineral fertilizers (M) and manure (SF) – Table 6. Wheat grain fertilized with sewage sludge (SS) and compost (C) contained 8% and 9% more potassium, respectively, than the grain from the treatment where mineral fertilizers (M) were used. In the third year of the experiment, the highest concentrations of potassium were detected in wheat grain gathered from the treatment where mineral NPK fertilizers (M) were applied. Assessment of the fodder value of the analyzed material shows a deficient potassium concentration in grain from the first year of the research (MŘLLER et al. 2000).

Magnesium in grain from both the first and the third year of the investigations was on a similar level, independently of the applied fertilization (Table 7). On average, the Mg content from all fertilized treatments in the first year was 0.86 g kg^{-1} and in the third year – 1.09 g kg^{-1} of grain. Considering the fodder value, the magnesium concentration in grain from the first year was deficient, irrespectively of the applied fertilization (MŘLLER et al. 2000).

Our results demonstrate a relatively high increase in the sodium content in wheat grain harvested in the third year in comparison to the first year. Despite a considerable increase in this element, it continued to be deficient in respect the fodder value (MŘLLER et al. 2000). The applied fertilization did not differentiate the Na content in grain (Table 7).

The content of sulphur, like magnesium and sodium, was on a relatively low level (Table 7), independently of the fertilizers used. However, it was adequate considering the fodder value (MŘLLER et al. 2000). Nonetheless, it should be emphasized that an increased content of this element in wheat grain (from 7% to 27%) was observed in the third year, particularly after the application of sewage sludge (SS) and compost (C).

Beside the crop yield, plant chemical composition is conditioned by many factor s and their interactions. On the one hand, availability of nutrients is limited by the soil properties. On the other hand, their uptake is determined by the plant's genetic traits. Despite impeded absorption of nitrogen, phosphorus or potassium from organic fertilizers, by balancing their doses introduced to soil it was possible to diminish differences in concentrations of these components in wheat grain. Also, despite various amounts of magnesium, sodium or sulphur brought to soil with fertilizers, their levels in grain proved considerably stable in the years of the experiment, which was mainly because the wheat plants uptake of these elements was not excessive. A study by BOWSZYS et al. (2006) shows that concentrations of macronutrients are conditioned by the type of applied organic material and duration of its activity. As the above authors claimed, nitrogen concentrations in barley grain from treatments where composts were applied were higher only than in grain from an unfertilized treatment. Mineral fertilizers affected most strongly the concentration of this element. Fertilization with composts produced from municipal waste had no significant effect on concentrations of phosphorus or magnesium in barley grain. Analogously, in the present experiment (in the first year) the potassium content in spring wheat grain was higher following the application of sewage sludge and compost than in grain from the treatment receiving mineral fertilizers.

Zinc is important in plants, mainly because it co-activates many enzymes. In the first year of the experiment, the highest zinc concentrations were found in wheat grain fertilized with mineral fertilizers NPK (M) and compost (C) – Table 8. These concentrations differed significantly from the ones in wheat grain fertilized with manure (SF) and sewage sludge (SS). In the third year, the concentration of zinc content in grain increased markedly after the application of mineral fertilizers (M), manure (SF) and sewage sludge (SS) (the increases were 12.7%, 42.5% and 28.7%, respectively). With respect to the fodder value, zinc concentrations were optimal (GORLACH 1991).

Copper also belongs essential elements in plants, as it is a component of enzymes and proteins participating in many metabolic processes. The average copper concentration in wheat grain harvested in the first and third year of the experiment was 4.39 mg kg^{-1} of grain dry mass (Table 8), irrespectively of the applied fertilization. A significant increase in this element in wheat grain between the first and the third year was observed after manure (SF) application. The lowest copper concentration in the third year was found in grain from the treatment where only mineral fertilization has been applied (Table 8). Considering the fodder value, copper content was low (GORLACH 1991).

Table 7

Magnesium, sodium and sulphur content (g kg^{-1} d.m. ± SD) in grain of spring wheat

Treatments*	Mg		Na		S	
	1st year	3rd year	1st year	3rd year	1st year	3rd year
(0)	0.88 ± 0.03*ab*	1.20 ± 0.04*e*	0.02 ± <0.01*a*	0.06 ± <0.01*a*	1.19 ± 0.07*a*	1.43 ± 0.04*bc*
(M)	0.89 ± 0.01*ab*	1.13 ± 0.04*d*	0.02 ± <0.01*a*	0.06 ± <0.01*a*	1.43 ± 0.05*bc*	1.54 ± 0.11*cd*
(SF)	0.83 ± 0.03*a*	1.07 ± 0.05*c*	0.02 ± <0.01*a*	0.06 ± <0.01*a*	1.36 ± 0.07*b*	1.54 ± 0.16*cd*
(SS)	0.87 ± 0.03*ab*	1.11 ± 0.01*cd*	0.02 ± <0.01*a*	0.06 ± <0.01*a*	1.37 ± 0.06*b*	1.60 ± 0.03*d*
(K)	0.87 ± 0.03*ab*	1.07 ± 0.02*c*	0.02 ± <0.01*a*	0.06 ± <0.01*a*	1.19 ± 0.11*a*	1.52 ± 0.04*cd*

*see Table 5

Means marked by the same letters did not differ significantly at $\alpha < 0.05$ according to Duncan's test.

Table 8

Zinc, copper and manganese content (mg kg^{-1} d.m. ± SD) in grain of spring wheat

Treatments*	Zn		Cu		Mn	
	1st year	3rd year	1st year	3rd year	1st year	3rd year
(0)	41.1 ± 1.7*b*	51.3 ± 2.1*e*	4.78 ± 0.62*d*	2.58 ± 0.30*a*	31.5 ± 2.2*f*	17.8 ± 1.1*ab*
(M)	47.1 ± 3.7*d*	53.1 ± 2.0*ef*	4.54 ± 0.44*cd*	3.57 ± 0.19*b*	28.8 ± 2.0*f*	23.4 ± 1.5*cd*
(SF)	32.2 ± 0.9*a*	45.9 ± 2.4*cd*	4.11 ± 0.16*c*	4.76 ± 0.32*d*	25.1 ± 3.9*de*	16.1 ± 3.9*a*
(SS)	43.2 ± 1.9bc	55.6 ± 2.5*f*	4.62 ± 0.27*cd*	4.62 ± 0.16*cd*	31.8 ± 3.2*f*	28.5 ± 3.3*bcd*
(K)	47.5 ± 1.8*d*	47.5 ± 2.5*d*	4.29 ± 0.13*cd*	4.63 ± 0.31*cd*	32.1 ± 3.9*f*	32.1 ± 1.8*f*

*see Table 5

Means marked by the same letters did not differ significantly at $\alpha < 0.05$ according to Duncan's test.

Manganese is equally important for good fodder value. Mn content in the analyzed grain was low (Gorlach 1991). Fertilization with sewage sludge (SS) and compost (C) favourably affected concentrations of this element. In the third year, the Mn content decreased in comparison with the first year, except the treatment where compost (C) had been applied. An average decline in the grain manganese concentrations was 4.43 mg kg^{-1} of dry mass.

According to Gorlach (1991), both excess and deficiency of micronutrients in fodders is dangerous to animals. The content and bioavailability of micronutrients in soil are modified by many factors, such as soil pH, organic matter content, soil sorption capacity. But they also depend on the plant's ability for their absorption and on fertilization. A study by Ruszkowska et al. (1996) demonstrated that producing long-term production of high yields requires control over the plant supply with micronutrient, a conclusion which supports the purposefulness of the present experiment.

The concentrations of all the analyzed micronutrients, except zinc, in wheat grain were deficient, which evidently depresses the grain's fodder value and may also indirectly affect the crop yield, especially that manganese or copper are part of enzymes and proteins which participate in specific metabolic processes (Rüegsegger et al. 1990, Prasad 1995, Yeruela 2005). Much of these elements is arrested in the root system, which strongly inhibits their transport to biomass, a source of animal feed (Gondek, Filipek-mazur 2003). Limited bioavailability of these elements might have resulted from the soil properties, particularly its sorptive characteristics. Lower copper content in crop yields from highly productive fields was also pointed out by Czuba (1986). Our results demonstrated stronger influence of the applied organic materials than that of manure on the content of the analyzed micronutrients in wheat grain.

Right proportions of the nutrients are crucial for assessment of biomass fodder value. In the analyzed wheat grain, the of K : Mg ratio was relatively stable and, independently of the year, ranged from 4.46 to 4.99 (Table 9).

The N:S ratio is important for the proper nitrogen economy in plant. In the present investigations, values of this parameter in wheat grain harvested in the first year from the treatments fertilized with manure (SF) and sewage sludge (SS) were 15.8 and 15.0 respectively (Table 9). A higher value of this parameter was demonstrated for wheat grain fertilized with mineral materials (M) and compost (C). In the third year, the value of this ratio increased significantly in wheat grain from all fertilized treatments, which resulted from the increase in nitrogen in grain. The highest increase in the N:S value between the first and third year (by 23%) appeared in wheat grain fertilized with sewage sludge (SS).

Significant diversification, both in the impact of the applied fertilization and between the years of the research, was observed for the P:Zn ratio (Table 9). In the first year, the highest value of this ratio was in wheat grain fertilized with manure (SF) and compost (C). The lowest value was

Table 9

Value of select ratio of quantitative elements in grain of spring wheat

Treatments*	K : Mg		N : S		P : Zn	
	1st year	3rd year	1st year	3rd year	1st year	3rd year
(0)	5.14 ± 0.35*d*	4.39 ± 0.06*a*	16.9 ± 0.49*bc*	18.0 ± 0.33*c*	121.5 ± 1.8*e*	97.2 ± 3.3*bc*
(M)	4.46 ± 0.44*ab*	4.72 ± 0.21*abc*	17.3 ± 0.90*bc*	18.0 ± 0.97*c*	100.1 ± 5.5*bc*	94.4 ± 1.3*ab*
(SF)	4.81 ± 0.18*cd*	4.79 ± 0.13*bcd*	15.8 ± 1.63*ab*	18.4 ± 0.79*c*	135.0 ± 8.2*f*	105.4 ± 2.8*cd*
(SS)	4.93 ± 0.26*cd*	4.71 ± 0.10*abc*	15.0 ± 0.93*a*	18.5 ± 0.15*c*	111.7 ± 7.9*d*	86.8 ± 3.9*a*
(K)	4.99 ± 0.07*cd*	4.76 ± 0.05*bc*	16.0 ± 2.09*ab*	18.3 ± 0.79*c*	126.0 ± 4.4*ef*	98.8 ± 4.2*bc*

*see Table 5

Means marked by the same letters did not differ significantly at $\alpha < 0.05$ according to Duncan's test.

observed in wheat grain receiving mineral fertilizers. In the third year, the value of P:Zn ratio declined in grain from all the treatments. Statistically significant differences were computed for all the treatments except the one enriched exclusively with mineral NPK fertilizers (M).

CONCLUSIONS

1. In the first year of the experiment, organic materials were less effective than mineral fertilizers in stimulating higher yields. A superior yield forming effect of organic materials compared with mineral fertilization was obtained in the third year.

2. Balancing N, P and K dose, despite worse uptake of these components from organic materials, minimizes the differences in their concentrations in wheat grain.

3. Despite various quantities of magnesium, sodium and sulphur in organic materials, the content of these elements in grain remained considerably stable in the years of the experiment.

4. The content of all micronutrients except zinc in wheat grain was deficient, which evidently depressed the grain fodder value. It may have also indirectly determined the crop yield.

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