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YIELD AND SELECTED INDICES OF GRAIN QUALITY IN SPRING WHEAT (*TRITICUM AESTIVUM* L.) DEPENDING ON FERTILIZATION

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Abstract

The aim of the research was to determine the effect of fertilization with manure, compost from biodegradable waste and municipal sewage sludge on the yield and certain indices of grain quality in spring wheat in comparison to fertilization with mineral fertilizers. The research was conducted as a three-year field experiment. The limited access of plants to nutrients (mainly nitrogen) introduced with waste organic materials and with manure strongly affected the crop yield and its quality, particularly in the first year of the research. A much better residual of fertilization with pig manure and compost from biodegradable waste on the spring wheat grain yield was observed in comparison to fertilization with municipal sewage sludge. Fertilization with waste organic materials, in doses based on plant requirements for nutrients, did not lead to a decrease in the biological value of yield. Irrespective of the applied fertilization, copper and manganese were the microelements that limited the fodder value of spring wheat grain, whereas the quality of protein was determined by the content of lysine.

Keywords: spring wheat, microelements, exogenous amino acids.

PLON I WYBRANE WSKAŹNIKI JAKOŚCI ZIARNA PSZENICY JAREJ (*TRITICUM AESTIVUM* L.) W ZALEŻNOŚCI OD NAWOŻENIA

Abstrakt

Celem badań było określenie wpływu nawożenia obornikiem, kompostem z odpadów biodegradowalnych oraz komunalnym osadem ściekowym na plon i niektóre wskaźniki jakości ziarna pszenicy jarej, w porównaniu z nawożeniem nawozami mineralnymi. Badania prowadzono w warunkach doświadczenia polowego przez 3 lata. Ograniczony dostęp roślin do składników pokarmowych (głównie do azotu) wprowadzonych z materiałami organicznymi pochodzenia odpadowego oraz z obornikiem w znacznym stopniu determinował wielkość i jakość plonów, zwłaszcza w pierwszym roku badań. Stwierdzono istotnie lepszy, następczy wpływ nawożenia

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obornikiem od trzody chlewnej oraz kompostem z odpadów biodegradowalnych na plon ziarna pszenicy jarej w porównaniu z nawożeniem komunalnym osadem ściekowym. Nawożenie materiałami organicznymi pochodzenia odpadowego, w dawkach zgodnych z zapotrzebowaniem roślin na składniki pokarmowe, nie spowodowało pogorszenia wartości biologicznej plonu. Niezależnie od zastosowanego nawożenia, mikroelementami ograniczającymi wartość paszową ziarna pszenicy jarej były miedź i mangan, natomiast jakość białka była determinowana zawartością lizyny.

Słowa kluczowe: pszenica jara, mikroelementy, aminokwasy egzogenne.

INTRODUCTION

Wheat plays an important role in human nutrition and has a high yielding potential, which makes it one of the most popular crops not only in Poland, but also worldwide. Globally, about 60% of grain production is used for nutrition. The technological value of wheat grain is, to the greatest extent, conditioned by genetics. However, environmental and agro-technical conditions are also significantly important (SIELING et al. 2005, CIU et al. 2006).

When analyzing the abundance of Polish soils in nutrients and humus, and in respect of acidification, signs of degradation of these soils are increasingly more frequent. It is mainly the result of insufficient amounts of applied natural and organic fertilizers as well as inadequate liming. The annual outflow of biogenic components with plant yields and losses of these components make it necessary to perform fertilization, which regulates levels of nutrients necessary for plants.

The delivery of adequate amounts of nutrients supplied to crops, while ensuring optimal soil conditions, is the main factor conditioning the expected yield characterized by a proper biological and technological value; and at the same time it may be a determinant for dosing manure, compost or sewage sludge.

Cereal grain has a diverse content of mineral components such as microelements, and organic components, including amino acids. In respect of nutrition, not all microelements or amino acids are equally important. Most often, the biological value of cereal grain is limited by the content of zinc, copper or manganese, and by the content of such amino acids as lysine and sulfur amino acids. The levels of these elements and compounds may be conditioned, for example, by fertilization (FLAETE et al. 2005).

The aim of the research was to determine the effect of fertilization with manure, compost from biodegradable waste and municipal sewage sludge on the yield and certain indices of grain quality in spring wheat in comparison to fertilization with mineral fertilizers.

MATERIAL AND METHODS

The research was conducted as a field experiment located 10 km west of Krakow (49°59' N; 19°41' E). Data from the meteorological station are presented in Table 1. Soil from the experimental site was classified to Stagnic Gleysol (IUSS Working Group WRB 2006). Table 2 presents selected soil properties prior to the commencement of the research.

Table 1

Monthly rainfall and average daily temperature at the site during 2005-2007 and long-term mean (1961-1999)

Month	Sum of monthly precipitation (mm)				Monthly average temperature (°C)			
	2005	2006	2007	mean 1961 - -1999	2005	2006	2007	mean 1961 - -1999
January	66	58	101	34	–1.2	–2.4	3.2	–3.3
February	33	49	42	32	–4.3	–3.0	1.2	–1.6
March	21	60	61	34	–0.2	0.2	6.0	2.4
April	49	57	15	48	6.8	5.6	8.5	7.9
May	61	52	52	83	11.4	10.9	15.2	13.1
June	41	89	72	97	14.4	15.0	18.4	16.2
July	113	14	71	85	17.6	18.6	19.4	17.5
August	103	104	76	87	15.4	15.6	19.0	16.9
September	27	17	180	54	12.5	13.4	12.4	13.1
October	8	32	48	46	7.1	9.1	7.7	8.3
November	30	21	90	45	3.9	6.3	0.8	3.2
December	47	16	21	41	–0.7	0.9	–1.1	–1.0

Table 2

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} d.m.	15.3
Total N	g kg^{-1} d.m.	1.59
Total Cu	mg kg^{-1} d.m.	15.8
Total Zn	mg kg^{-1} d.m.	132.8
Total Mn	mg kg^{-1} d.m.	2230
P available	mg kg^{-1} d.m.	71.8
K available	mg kg^{-1} d.m.	297.5
Mg available	mg kg^{-1} d.m.	367.7
Bulk density	g cm^{-3}	1.52
Total porosity	cm^3 cm^{-3}	0.41
Fraction < 0.02 mm	g kg^{-1} d.m.	520

The experiment was set up with the randomized blocks method. The plot area was 30 m^2. The experimental design comprised 5 treatments in four replications: without fertilization (0), fertilization with mineral fertilizers (MF) [110.0 kg N ha^{-1}, 58,6 kg P ha^{-1} and 120.0 kg K ha^{-1}], fertilization with pig manure (PM) [dose of 3.23 t ha^{-1} d.m.], fertilization with compost from biodegradable waste (C) [dose of 2.83 t ha^{-1} d.m.], and fertilization with municipal sewage sludge (SS) [dose of 2.65 t ha^{-1} d.m.].

The field was limed before setting up the experiment (autumn 2004). The measure was conducted according to ˝ hydrolytic acidity value (962.0 kg CaO ha^{-1}) In the spring of the following year, after basic cultivation measures, manure, compost and sewage sludge were evenly distributed on surfaces of the plots and ploughed in. Two weeks later, supplementary mineral fertilization was applied; the fertilizers were mixed with the soil using a cultivator/harrow aggregate. The nitrogen dose supplied with organic materials was 110.0 kg N ha^{-1}. Phosphorus and potassium were supplemented with mineral fertilizers to an equal level in all 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 of the experiment, the same doses of components as in the first year were used, but only in the form of mineral fertilizers.

The experiment was performed on cv, Jagna spring wheat. The assumed sowing density was 485 plants per 1 m^2. Chemical measures were carried out during the vegetative growth to protect the plantation against weeds and fungal diseases.

The duration of a wheat vegetative period in individual years was weather-dependent. Wheat was harvested at grain maturity: on 13 August 2005 in the first year of the research, on 3 August 2006 in the second year, and on 31 July 2007 in the third year. In order to determine the wheat yield in field conditions, the plants were harvested from an area of 4 m^2, separately from each plot.

The swine manure used in the research had been stored in a manure heap for 6 months. The compost was made with the Mut-Kyberferm technology from plant waste and other biodegradable waste in the following proportions: 25% grass, 20% wood chips, 20% leaves, 10% organic waste from market squares, 5% tobacco dust, and 20% waste from coffee production. The compost came from a composting plant located in the city of Krakow. The stabilized sewage sludge (SS) originated from a municipal biological sewage treatment plant located in the Czernichów commune (Malopolska region).

The following assessments were made on fresh samples of manure, compost and sewage sludge: dry mass content (at 105°C for 12 h), pH by potentiometery, electrolytic conductivity with a conductometer, total nitrogen content by the Kjeldahl's method. The content of organic matter and ash was determined in dried and ground material after sample mineralization

Table 3

Physical and chemical properties of the organic materials

Determination	Unit	Pig manure (PM)	Compost (C)	Sewage sludge (SS)
N_{tot}	g kg^{-1} d.m.**	34.0	38.9	41.6
P_{tot}	g kg^{-1} d.m.	12.8	5.9	22.3
K_{tot}	g kg^{-1} d.m.	21.8	29.9	1.2
Cu_{tot}	mg kg^{-1} d.m.	156	34	80
Zn_{tot}	mg kg^{-1} d.m.	284	194	950
Mn_{tot}	mg kg^{-1} d.m.	355	280	112
EC*	mS cm^{-1}	2.89	2.62	0.47
pH (H_2O)		8.23	7.31	6.57
Organic matter	g kg^{-1} d.m.	831	531	726
Water content	g kg^{-1} f.m.***	774	563	742
Ash	g kg^{-1} d.m.	169	469	244

* EC – electrical conductivity, ** data are based on 105°C dry matter weight, *** f.m. – fresh matter

in a chamber furnace (at 450°C for 5 h). The phosphorus content was determined by colorimetry in a Beckman DU 640 spectrophotometer, and the potassium content was assessed by flame emission spectroscopy (FES) in a Philips PU 9100X apparatus. The content of copper, zinc and manganese was determined by the ICP-AES method in a JY 238 Ultrace apparatus. The analyses were performed according to the methodology described by Baran and Turski (1996), and Krzywy (1999), and the analytical results are presented in Table 3.

The content of selected microelements was determined in dried and ground wheat grain after sample mineralization in a chamber furnace (450°C, 5 h) (Ostrowska et al. 1991) by the ICP-AES method in a JY 238 Ultrace apparatus.

Concentrations of selected amino acids were assessed on an AAA-400 (Ingos) analyzer following protein hydrolysis in 6 mol dm^{-3} HCl (110°C, 24 h). The methionine content was determined after oxidation with formic acid.

On the basis of the results, the index of limiting amino acid CS (Chemical Score) was computed. It was introduced by Block and Mitchell (Bęza 1967) and consists of the ratio of an exogenous limiting amino acid in the analyzed protein to the content of the same amino acid in a standard protein. Two standards were used for the calculations: mature human protein (MH) and whole egg protein (WE) (FAO/WHO 1991).

The analysis of the plant material was conducted in four replications.

Table 4

Amounts (mean ± SD) of metals released for material NCS DC733448, as well as data for analytical precision and accuracy

Metal	The value obtained in current study (mg kg^{-1} d.m.)	Recommended value (mg kg^{-1} d.m.)	Accuracy	Accuracy
Zn	21.4±1.0	20.6±2.2	4.71	3.88
Cu	5.3±0.1	5.2±0.5	1.88	1.92
Mn	55±1	58±6	1.82	5.45

The accuracy of Zn, Cu and Mn determinations was assessed with reference material NCS DC733448 (China National Analysis Center for Iron & Steel). Data on the accuracy of performed determinations are presented in Table 4 (Fuentes et al. 2004).

A two-way analysis of variance (factors: fertilization x years) was conducted for spring wheat grain yield, and a one-way analysis of variance (factor: fertilization) in an entirely randomized design using f-Fisher test was conducted for weighted mean (from 3 years) content of the analyzed microelements, protein and of exogenous amino acids. The significance of differences between arithmetic means was verified on the basis of homogenous groups determined by the Duncan's test at the significance level $p < 0.05$. All statistical computations were conducted using a Statistica PL package (Stanisz 1998).

RESULTS

Grain yields

On treatments where pig manure (PF), compost from biodegradable waste (C), and municipal sewage sludge (SS) were applied, spring wheat grain yields in the first year of the research were smaller by 0.95 t, 1.23 t, and

Table 5

Dry-matter yields of grain spring wheat for different year of experiment

Year	Treatments				
	0	MF	PM	C	SS
	(t d.m. ha^{-1})				
2005	2.53^{b} ± 0.13	4.30^{ef} ± 0.23	3.35^{c} ± 0.16	3.07^{bc} ± 0.31	3.74^{c} ± 0.25
2006	2.00^{a} ± 0.18	4.97^{hi} ± 0.26	4.44^{efg} ± 0.27	4.31^{ef} ± 0.30	4.86^{gh} ± 0.30
2007	2.54^{b} ± 0.10	4.30^{ef} ± 0.35	5.39^{i} ± 0.31	5.41^{i} ± 0.11	4.42^{efg} ± 0.11

Means ± standard error. Different letters indicate significant differences ($\sum < 0.05$, Duncan's multiple range test).

0.56 t d.m. ha^{-1}, respectively, in comparison to the yield from the treatment fertilized with mineral fertilizers (MF) – Table 5. The statistical analysis of the results confirmed significance of the differences between arithmetic means from individual treatments.

In the second year, much smaller differences in wheat grain yields were found. The difference between the lowest grain yield, obtained after the application of compost from biodegradable waste (C), and the highest grain yield, obtained after fertilization with mineral fertilizers (MF), was 0.66 t d.m. ha^{-1}.

In the third year, higher spring wheat grain yields were gathered from the treatments where pig manure (PF), compost (C) and municipal sewage sludge (SS) were applied in the first year than from the one where wheat was fertilized exclusively with mineral fertilizers (MF). The results indicate a much better residual effect of fertilization with pig manure (PM) and compost from biodegradable waste (C) on the spring wheat grain yield in comparison to fertilization with municipal sewage sludge (SS).

Content of microelements in grain

The zinc content in spring wheat grain was varied, depending on the applied fertilization (Table 6). The lowest content of this element was obtained in wheat grain from the treatment fertilized with pig manure (SM), whereas

Table 6

Content of zinc, copper and manganese in grain of spring wheat

Treatments		(mg kg^{-1} d.m.)		
Fertilizer	Year	Zn	Cu	Mn
0	1st	41.1	4.56	30.7
	3rd	51.3	2.58	17.7
	average*	$49.7^{b} \pm 4.02$	$3.61^{a} \pm 0.51$	$27.9^{a} \pm 4.60$
MF	1st	48.4	4.68	28.1
	3rd	53.0	3.57	23.4
	average*	$51.7^{b} \pm 1.68$	$3.37^{a} \pm 0.72$	$28.3^{a} \pm 2.49$
PM	1st	34.1	4.11	23.9
	3rd	45.8	4.76	16.0
	average*	$43.1^{a} \pm 3.99$	$3.35^{a} \pm 0.96$	$24.9^{a} \pm 4.73$
C	1st	36.8	4.28	32.1
	3rd	47,5	4.63	18.1
	average*	$45.9^{ab} \pm 4.59$	$3.57^{a} \pm 0.77$	$27.2^{a} \pm 4.59$
SS	1st	35.1	3.92	27.4
	3rd	52.3	4.16	14.9
	average*	$46.0^{ab} \pm 4.81$	$3.26^{a} \pm 0.71$	$24.7^{a} \pm 4.37$

* Average of three years ± standard error. Different letters in columns indicate significant differences ($\sum < 0.05$, Duncan's multiple range test).

Table 7

Content and selected indicators of the quality of grain protein of spring wheat

Treatments		Total protein (g kg^{-1} d.m.)	$\sum$ EAA (g 100 g^{-1} protein)	CS (WE)$_{Lys}$	CS (MH)$_{Lys}$
Fertilizer	year				
0	1st	125.9	25.60	35.94	50.32
	3rd	162.9	22.12	40.22	56.31
	average*	142.8^{a} ± 9.38	25.2^{a} ± 1.34	31.3^{bc} ± 1.67	39.8^{bc} ± 2.13
MF	1st	153.7	26.33	42.63	59.68
	3rd	173.3	24.27	45.56	63.78
	average*	159.6^{b} ± 6.1	26.2^{a} ± 1.03	31.6^{c} ± 0.99	40.2^{c} ± 1.53
PM	1st	129.8	26.37	37.92	53.09
	3rd	176.0	22.26	43.42	60.79
	average*	154.6^{b} ± 11.7	25.1^{a} ± 1.28	31.1^{b} ± 1.58	39.6^{b} ± 2.02
C	1st	118.5	37.64	46.80	65.50
	3rd	174.3	23.35	42.11	59.00
	average*	149.6^{ab} ± 14.4	27.6^{b} ± 1.21	32.3^{c} ± 1.65	41.1^{c} ± 1.91
SS	1st	130.8	25.66	37.08	51.91
	3rd	184.3	20.72	41.40	57.95
	average*	157.8^{b} ± 13.5	24.0^{a} ± 1.44	29.3^{a} ± 1.75	37.3^{a} ± 2.23

CS – chemical score of limiting amino acid; WE – whole egg protein standards; MH – mature human;

* Average of three years ± standard error. Different letters in columns indicate significant differences ($\sum < 0.05$, Duncan's multiple range test).

the highest amount of zinc was found in wheat grain from the treatment where only mineral fertilizers were used (MF).

No significant differences in the content of copper in spring wheat grain after fertilization were found (Table 6). The weighted mean content of Cu was within the range of 3.26 mg kg^{-1} d.m. (grain from the treatment where municipal sewage sludge was used) to 3.61 mg kg^{-1} d.m. (grain from the unfertilized treatment).

Among the fertilized treatments, the highest content of manganese, was determined in grain of wheat fertilized with mineral fertilizers (MF) and after the application of compost from biodegradable waste (C) – Table 6.

Content of protein and exogenous amino acids in grain

The total protein content was significantly higher in wheat grain from fertilized treatments in comparison to the protein content in unfertilized wheat grain (Table 7). The highest weighted mean content of total protein was found in grain of wheat fertilized with mineral fertilizers (MF).

The highest weighted mean content of exogenous amino acids ($\sum$ EAA) occurred in wheat grain from the treatment where fertilization with compost from biodegradable waste was applied (27.6 g 100 g^{-1} of protein) – Table 7. On treatments fertilized with pig manure (PM), municipal sewage sludge

Table 8

Composition of selected exogenous amino acids in protein of grain protein of spring wheat

Treatments		(g 100 g^{-1} protein)								
Fertilizer	year	Thr	Val	Ile	Leu	Phe	Lys	Met	His	Arg
0	1st	2.10	3.51	2.53	5.00	3.20	2.21	1.06	2.04	3.95
	3rd	1.87	2.87	2.06	4.31	2.76	1.90	0.61	1.71	3.52
	average*	$2.14^{ab} \pm 0.15$	$3.30^{a} \pm 0.19$	$2.37^{ab} \pm 0.14$	$4.96^{ab} \pm 0.31$	$3.17^{ab} \pm 0.20$	$2.19^{a} \pm 0.14$	$0.71^{a} \pm 0.16$	$2.14^{a} \pm 0.05$	$4.04^{ab} \pm 0.29$
MF	1st	2.07	3.42	2.71	5.11	3.47	2.13	1.01	2.04	4.37
	3rd	2.01	3.10	2.34	4.76	3.17	2.03	0.66	1.88	4.09
	average*	$2.19^{b} \pm 0.14$	$3.37^{a} \pm 0.14$	$2.55^{ab} \pm 0.10$	$5.18^{b} \pm 0.23$	$3.45^{b} \pm 0.15$	$2.21^{a} \pm 0.12$	$0.72^{a} \pm 0.13$	$2.12^{a} \pm 0.05$	$4.45^{b} \pm 0.23$
PM	1st	2.24	3.49	2.67	5.13	3.28	2.25	1.10	1.97	4.22
	3rd	1.89	2.89	2.32	3.69	2.90	1.91	0.65	1.71	3.70
	average*	$2.17^{ab} \pm 0.13$	$3.32^{a} \pm 0.29$	$2.66^{b} \pm 0.17$	$4.27^{a} \pm 0.47$	$3.31^{ab} \pm 0.22$	$2.18^{a} \pm 0.13$	$0.76^{ab} \pm 0.15$	$2.15^{a} \pm 0.09$	$4.23^{ab} \pm 0.29$
C	1st	4.12	6.13	4.43	8.35	5.69	3.61	1.27	3.28	7.56
	3rd	3.57	5.30	3.86	7.63	5.10	3.24	1.10	2.92	6.56
	average*	$2.49^{c} \pm 0.43$	$3.70^{b} \pm 0.65$	$2.69^{b} \pm 0.46$	$5.29^{b} \pm 0.77$	$3.55^{b} \pm 0.55$	$2.26^{a} \pm 0.35$	$0.76^{ab} \pm 0.13$	$2.30^{b} \pm 0.29$	$4.58^{b} \pm 0.79$
SS	1st	2.03	3.42	2.60	5.16	3.23	2.19	1.03	2.02	4.00
	3rd	1.71	2.57	1.91	4.01	2.64	1.73	0.60	1.58	3.32
	average*	$2.01^{a} \pm 0.15$	$3.05^{a} \pm 0.22$	$2.27^{a} \pm 0.18$	$4.75^{ab} \pm 0.32$	$3.12^{a} \pm 0.22$	$2.05^{a} \pm 0.14$	$0.72^{a} \pm 0.13$	$2.09^{a} \pm 0.07$	$3.91^{a} \pm 0.29$

* Average of three years ± standard error. Different letters in columns indicate significant differences ($\sum < 0.05$, Duncan's multiple range test).

(SS), and mineral fertilizers (MF), the weighted mean content of amino acids was significantly lower, respectively by 9.1%, 13.1%, and 5.1%.

The content of amino acids in wheat protein was much lower than in standard protein (Hidvégi, Békés 1984, FAO/WHO 1991). Lysine, methionine and threonine are amino acids which are highly deficient in fodders. Fertilization with compost from biodegradable waste generally increased the content of the assayed exogenous amino acids to the highest degree (except for methionine). In comparison to the amino acid composition of mature, human protein or hen egg protein, it was stated that lysine was the amino acid limiting the quality of spring wheat grain (Table 8).

DISCUSSION

Numerous research results indicate a possibility of using organic waste material for biomass production (Jamil et al. 2006, Carbonell et al. 2011). The dynamics of biochemical processes occurring in soil, additionally intensified by environmental factors, may significantly affect the yield-forming efficiency of applied fertilization (Stewart, Hash 1982, Bonde et al. 1988) and chemical composition of plants, including the content of microelements and exogenous amino acids (Mallarino et al. 1999). In the first year of the research, the significantly lower wheat grain yield on treatments fertilized with organic materials resulted from limited possibilities of nutrient uptake by plants, particularly in the case of nitrogen, whose availability from organic materials is a result of weather conditions during the vegetative season, dose of applied materials and the value of carbon to nitrogen ratio (Barbarika et al. 1985, Agehara, Warncke 2004). Fertilization with organic material makes it difficult to synchronize the amounts of N released from organic substances with plant requirements for this component (Mikkelsen, Harrtz 2008). The present research results clearly indicate that the regress in wheat grain yield in the first year of the research might have been dictated by the spring term of organic materials application.

With time, the residual effect of applied organic materials becomes distinguishable, resulting in an increase in yield, which has been confirmed by a three-year scientific research. A beneficial effect of fertilization with sewage sludge and composted biodegradable waste on wheat biomass yield was shown by Tamrabet et al. (2009), Jamil et al. (2004), and Barzegar et al. (2002). However, Ibrahim et al. (2008), while studying the effect of compost fertilization on wheat yield, drew attention to the necessity of balancing the amounts of nutrients supplied with fertilization.

The microelement content in plant biomass is a result of the content of their assimilable forms in the soil, which is strongly modified by soil pH, organic matter content, soil sorptive capacity, and also by the cultivated plant species and fertilization (Kopeć, Przetaczek-Kaczmarczyk 2006). An insufficient copper content, in terms of fodder value, was found in the author's own research. The low copper content may have caused a decrease in the fodder value of grain, but also limited the amount and quality of yield, particularly as copper is included in the composition of enzymes and proteins participating in specific metabolic processes (Prasad 1995, Yruela 2005). Soil reaction and content of organic matter to which copper shows high affinity are the factors limiting the availability of this element. According to Gondek and Kopeć (2004), the formation of permanent bonds between humus and copper may be responsible for a low efficiency of soil fertilization with this element. The manure used in the research contained the largest amount of copper (among the applied organic materials), but despite this the content of this element in spring wheat grain did not increase markedly. The results imply no significant effect of compost from biodegradable waste or municipal sewage sludge on the zinc and manganese content in spring wheat grain in comparison to plants from the treatment fertilized with manure. It might have resulted from a relatively low content of these elements in the organic materials. The zinc content in grain was within the range considered optimal for animal nutrition, whereas the manganese content was deficient, regardless of the applied fertilization (Moller et al. 2000).

While using composts and municipal sewage sludge for fertilization one may expect their beneficial effect on plant yield, but also on its biological value. Taking into consideration the chemical composition, which determines the fodder nutritional value, it may be said that cereal grain is a carbohydrate fodder with a low or medium content of total protein (Brand et al. 2003). According to Dubetz and Gardiner (1980), the content of protein and amino acids in wheat grain changes considerably under the influence of increasing doses of nitrogen. In the own research, the nitrogen dose in all treatments (except the control) was the same, and the use of a dose of this element in compliance with the wheat nutritional requirements, both in the form of mineral fertilizers and organic materials (manure, compost, sewage sludge), did not cause any significant changes in the content of the analyzed amino acids in the protein of spring wheat grain. Also, according to Jasiewicz and Baran (2011), mineral fertilization diversifies the content of amino acids in plant biomass more than fertilization with organic materials. Cereal grain usually has a low content of lysine. Also in the own research, lysine was the amino acid limiting protein quality in grain with reference to both the whole egg protein standard (WE) and the mature human protein standard (MH), regardless of the applied fertilization. Sherry (2007) obtained similar results in his research. The current research results are not reflected in the report of Jasiewicz and Baran (2011), who found that methionine was the amino acid limiting the protein quality in maize. The differences in the research results may be attributed to the applied fertilization (type of organic material), the size of nitrogen dose and the cultivated plant species. It is crucial to maintain a proper balance of amino acids in the composition in feeds, matching the nutrient supply with animal requirements. Firstly, it enables animals to use most effectively one of the most valuable food ingredients, i.e. fodder protein. Secondly, it has an environmental aspect because of the decrease in nitrogen excreted with urine by avoiding excess of amino acids in relation to animal needs.

CONCLUSIONS

1. The limited access of plants to mineral components (mainly nitrogen) introduced with waste organic material and with manure determined the crop yield, particularly in the first year of the research.

2. A better residual effect of fertilization with pig manure and compost from biodegradable waste on the spring wheat grain yield was observed in comparison to fertilization with municipal sewage sludge.

3. Waste organic material used in moderate doses, based on plant requirements for nutrients, did not lead to a decrease in the biological value of yield.

4. Irrespective of the applied fertilization, copper and manganese were the microelements that limited the fodder value of spring wheat grain, whereas the quality of protein was determined by the content of lysine.

REFERENCES

Agehara S., Warncke D.D. 2005. *Soil moisture and temperature effect on nitrogen release from organic nitrogen sources*. Soil Sci. Soc. Am. J., 69(6): 1844-1855. Doi:10.2136/sssaj2004.0361

AOAC 1990. *Official methods of analysis*. 15th Edition Association of Official Analytical Chemists. Arlington, VA.

Baran S., Turski R. 1996. *Specialist exercises on waste and sewage disposal*. Wyd. AR w Lublinie. (in Polish)

Barbarika A., Sikora L.J., Colacicco D. 1985. *Factors affecting the mineralization of nitrogen in sewage sludge applied to soil*. Am. J. Soil Sci., 49: 1403-1406. Doi: 10.2136/sssaj1985.03615995004900060014x

Barzegar A.R., Yousefi A., Daryashenas A. 2002. *The effect of addition different amounts and types of organic materials on soil physical properties and yield of wheat.* Plant and Soil, 247 (2): 295-301. Doi: 10.1023/A:1021561628045

Bęza R. 1967. *Amino acids in animal nutrition*. Wyd. PWRiL, Warszawa. (in Polish)

Bonde T.A., Schnurer J., Rosswall T. 1988. *Microbial biomass as a fraction of potentially minerrolizable nitrogen in soils from long-term field experiments*. Soil Biol. Biochem., 20 (4): 447-452. Doi: 10.1016/0038-0717(88)90056-9

Brand T.S., Cruyweggen C.W., Brandt D.A., Viljoen M., Burger W.W. 2003. *Variation in the chemical composition, physical characteristics and energy values of cereal grains produced in the Western Cape area of South Africa.* South Afr. J. Anim. Sci., 33: 117-126.

Carbonell G., de Imperial R.M., Torrijos M., Delgado M., Rodriguez J.A. 2011. *Effect of mu-*

nicipal solid waste compost and mineral fertilizer amendments on soil properties and heavy metals distribution in maize plants (Zea mays L*.)*. Chemosphere, 85(10): 1614-1623. Doi: 10.1016/j.chemosphere.2011.08025

CUI Z.L., CHEN X.P., XU J.F., SHI L.W., ZANG F.S. 2006. *Effect of fertilization on grain field of winter wheat and apparent N losses*. Pedosphere, 16(6): 806-812. Doi: 10.1016/S1002-0160(06)60117-3

DUBETZ S., GARDINER E.E. 1980. *Protein content and amino acid composition of seven wheat cultivars subjected to water stress: Effects of nitrogen fertilizer treatments.* J. Plant Nutrit., 2 (5): 517-523. Doi: 10.1080/01904168009362794

FAO/WHO. 1991. *Protein quality evaluation*. Report of Joint FAO-WHO Expert Consultation. Food Nutr., 51: 4-8.

FLAETE N.E.S., HOLLUNG K., RUUD L., SOGN T., FAERGESTAD E.M., SKARPEID H.J., MAGNUS E.M., UHLEN A.K. 2005. *Combined nitrogen and sulfur fertilisation and its effect on wheat quality and protein composition measured by SE-FPLC and proteomics*. J. Cereal Sci., 4: 357-369. Doi: 10.1016/j.jcs.2005.01.003

FUENTES A., LLORENS M., SÁEZ J., AGUILAR M.I., ORTONO J.F. MESEGUER V.F. 2004. *Phytotoxicity and heavy metals speciation of stabilized sewage sludge*. J. Hazard. Mat., 108: 161-169. Doi: 10.1016/j.jhazmat.2004.02.014

GONDEK K., KOPEĆ M. 2004. *Heavy metal binding by humus in soil of long-term static fertilizer experiment at Czarny Potok*. Ecol. Chem. Engineer., 11 (7): 561-572.

IBRAHIM M., HASSAN A., IQBAL M., VALEEM E.E. 2008. *Response of wheat growth and yield to various levels of compost and organic manure.* Pak. J. Bot., 40 (5): 2135-2141.

IUSS Working Group WRB. 2006. *World reference base for soil resources 2006*. World Soil Resources Reports No. 103. FAO, Rome.

JAMIL M., QASIM M., UMAR M. 2006. *Utilization of sewage sludge as organic fertilizer in sustainable agriculture*. J. Appl. Sci., 6: 531-535

JAMIL M., QASIM M., UMAR M., REHMAN K. 2004. *Impact of organic wastes (sewage sludge) on the yield of wheat (Triticum aestivum* L*.) in a calcareous soil*. Int. J. Agric. Biol., 6: 465-467.

JASIEWICZ CZ., BARAN A. 2011. *Comparison of the effect of mineral and organic fertilization on the composition of amino acids in green biomass maize*. Ecol. Chem. Engineer. A, 18(4): 545-551.

KOPEĆ M., PRZETACZEK-KACZMARCZYK M. 2006. *Changes of soil abundance in microelements in long-term fertilizer experiment (Czarny Potok).* Pol. J. Soil Sci., 39 (1): 91-96.

KRZYWY E. 1999. *Environmental management of sewage and sludge*. Wyd. AR w Szczecinie. (in Polish)

MALLARINO A.P., BORDOLI J.M., BORGES R. 1999. *Phosphorus and potassium placement effects on early growth and nutrient uptake of no-till corn and relationships grain yield*. J. Agronom., 91 (1): 37-45.

MIKKELSEN R., HARTZ T.K. 2008. *Nitrogen sources for organic crop production.* Better Crops, 92 (4): 16-19.

MŘLLER J., THŘGERSEN R., KJELDSEN A.M., WEISBJERG M.R., SŘEGAARD K., HVELPLUND T., BŘRSTING CH.F. 2000. *Composition and feeding value of feedstuffs for cattle*. Ed. The National Department of Cattle Husbandry and Danish Institute of Agricultural Sciences.

OSTROWSKA A., GAWLIŃSKI A., SZCZUBIAŁKA Z. 1991. *Methods of analysis and assessment of soil and plant properties.* Wyd. IOŚ, Warszawa. (in Polish)

PRASAD M.N.W. 1995. *Inhibition of maize leaf chlorophylls, carotenoids and gas exchange functions by cadmium.* Photosynthetica, 31: 635-640.

SHEWRY P.R. 2007. *Improving the protein content and composition of cereal grain.* J. Cereal Sci., 46: 239-250. Doi: 10.1016/j.jcs.2007.06.006

SIELING K., STAHL C., WINKELMANN C., CHRISTEN O. 2005. *Growth and yield of winter wheat in the first 3 years of a monoculture under varying N fertilization in NW Germany*. Europ. J. Agron., 22: 71-84. Doi: 10.1016/j.eja.2003.12.004

STANISZ A. 1998. *Straightforward course of statistics basing on programme Statistica PL examples from medicine.* Wyd. Statsoft Poland. (in Polish)

STEWART J.I., HASH CH.T. 1982. *Impact of weather analysis on agricultural production and planning decisions for the semiarid areas of Kenya*. J. App. Meteorol., 21(4): 477-494. Doi: 10.1175/1520-0450(1982)021<0477

TAMRABET L., BOUZERZOUR H., KRIBAA M., MAKHLOUF M. 2009. *The effect of sewage sludge application on durum wheat (Triticum durum).* Int. J. Agric. Biol., 11: 741-745.

YRUELA J. 2005. *Copper in plants*. Braz. J. Plant Physiol., 17(1): 145-156.