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Original Research

The Yield and Utilization Coefficient of Nitrogen by Plants after Applying of Fresh and Composted Sewage Sludge with Mineral and Organic Additions

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Abstract

We investigated the influences of fertilization using fresh and composted sewage sludge with the addition of calcium oxide, brown coal ash, straw, and sawdust on the yield and nitrogen content in maize biomass, as well as the values of utilization coefficient. The biomass yields of maize fertilized with only sewage sludge, as well as sludge with brown coal ash and sawdust, were similar. Lower yields were achieved when sewage sludge with calcium oxide and straw were used. Amounts of harvested maize biomass from objects fertilized with fresh and composted sewage sludge were similar. The highest efficiency of 1g nitrogen was recorded when the mixture of sewage sludge with brown coal ash was applied. The largest nitrogen concentrations were observed in maize amended with sewage sludge with calcium oxide, while slightly less – after adding the sewage sludge only and sludge with brown coal ash. The lowest nitrogen content was determined in biomass harvested from objects fertilized with mixtures of sewage sludge with sawdust and straw. The coefficient values of nitrogen utilization by maize were similar for all three series of experiments on objects fertilized with the sewage sludge only as well as sludge with calcium oxide and brown coal ash addition; slightly lower values were recorded when sewage sludge plus sawdust and straw were added. No significant influence of composting the sewage sludge from Siedlce on nitrogen content and its utilization coefficient for nitrogen was observed. On the other hand, composted sewage sludge from Łuków enhanced the content and nitrogen utilization by the test plant.

Keywords: composting process, maize, nitrogen, sewage sludge, yield

Introduction

The quantity of sewage sludge used in agriculture in Poland is increasing [1]. Utilizing these waste organic materials in an agriculture as fertilizers enables their cheap neutralization and returns nutrients into the soil [2]. Applying sewage sludge in agriculture makes it possible to lower the production costs and to improve profitability [3]. In the European Union, utilization of sewage sludge as organic fertilizer is recommended due to the content of organic matter and nutrients for plants, namely nitrogen [4]. Therefore, the necessity of storing the sewage sludge can be avoided and organic substance introduced into the soil is a

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material for building the complex humus compounds. Organic matter and nutrient contents in sewage sludge depend on the type of purified wastewaters and methods applied for separating and concentrating the sludge [5-7].

Sewage sludge can be used for fertilizing purposes if it does not contain excessive amounts of heavy metals, nor disease-forming bacteria and living eggs of parasites [8, 9]. Sewage sludge generated in most wastewater treatment plants in general contains low levels of hazardous substances, such as heavy metals [10, 11]. Heavy metal availability from sewage sludge for plants and their accumulation in soil have been the subject of numerous studies [12-15]. In order to eliminate or reduce the negative effects of sewage sludge on the soil environment and plants, it is a subject of diverse transformations by means of physical, chemical, or biological processing [8]. Physical methods lead to a final product with dry matter content over 50%, as a result of adding the organic materials with low humidity such as brown coal, peat, straw, bark, sawdust, or leaves. Water excess can be removed by evaporation, although it is an energy-consuming and expensive method. Biological methods for sewage sludge conversion consist in using natural processes occurring in nature, such as composting or vermicomposting. Chemical processing, leading among other issues to sewage sludge sanitation, consists in their mixing with chemicals, which changes the sludge properties. Most often, adding calcium oxide is the example of these methods. Alkalization of sewage sludge may be also be done by adding hydroxides and calcium carbonate, and even mineral wastes with high calcium contents, such as power plant ash [16, 17]. The processing leads both to quantitative and qualitative changes in chemical composition of sewage sludge, thus affecting the availability of nutrients for plants after their introduction to the soil [18-21].

The aim of our present research was to evaluate the influence of fertilization using fresh and composted sewage sludge with the addition of calcium oxide, brown coal ash, straw, and sawdust on maize biomass yields, as well as nitrogen content and its utilization coefficient.

Table 1. Scheme of pot experiment.

Fertilizer objects	
Applied organic fertilizer	Type of component added to sewage sludge (or only to soil**)
Without organic fertilization (control object)	without addition*
	with added CaO**
	with added ash**
	with added straw**
	with added sawdust**
Fresh sewage sludge from Siedlce (after methane fermentation)	without additions
	CaO
	ash
	straw
	sawdust
Fresh sewage sludge from Łuków (stabilized in oxygenic conditions)	without addition
	CaO
	ash
	straw
	sawdust
Composted sewage sludge from Siedlce	without addition
	CaO
	ash
	straw
	sawdust
Composted sewage sludge from Łuków	without addition
	CaO
	ash
	straw
	sawdust

*only soil
**soil with added CaO, ash, straw, or sawdust.

Experimental Procedures

The experiments dealt with the sewage sludge from mechanical-biological municipal-industrial sewage treatment plants in the Polish towns of Siedlce and Łuków. At the final stage of separation and concentration, sludge from Siedlce was subjected to methane fermentation and partially de-hydrated on a band press, while that from Łuków was stabilized under aerobic conditions and water excess was removed by centrifuging. Dry matter DM contents in sewage sludge from Siedlce and Łuków were 15.0 and 14.5%, respectively. Fresh sludge was mixed separately with calcium oxide, brown coal ash, rye straw, and mixed sawdust at a 2:1 ratio (for dry matter basis). Amounts of applied additions to 1 kg of both sludge types were 75.0 and 72.5 g, respectively. Mixtures and native sludge were composted in 200 dm^3 capacity plastic containers for 3 months at room temperature. Composted materials were twice stirred, after 30 and 60 days to ensure optimum conditions for the composting process. After 3 months, fresh sewage sludge mixtures from Siedlce and Łuków were prepared again (18% DM and 15% DM), adding 90 and 75 g CaO, brown coal ash, straw, or sawdust into the 1 kg of these materials to achieve a 2:1 dry matter:components weight ratio. Then fresh and composted sewage sludge as well as their mixtures in the amount of 1 kg were placed into pots containing 9 kg of soil. The capacity of pots was 12 dm^3. The control objects included the soil itself, soil with CaO, brown coal ash, straw, and sawdust added in the amounts corresponding to their mean weight introduced with fresh

Table 2. Some properties of soil used in the experiment.

Parameters	Value
Granulometric composition	Light dusty loamy sand
pH in 0.01 mol $CaCl_2 \cdot dm^{-3}$	4.0
Content of:	
$C_{organic}$	9.08 $g \cdot kg^{-1}$
N_{total}	0.820 $g \cdot kg^{-1}$
P_{total}	0.371 $g \cdot kg^{-1}$
K_{total}	0.321 $g \cdot kg^{-1}$
Ca_{total}	0.630 $g \cdot kg^{-1}$
Mg_{total}	0.280 $g \cdot kg^{-1}$
S_{total}	0.089 $g \cdot kg^{-1}$
P available for plants	2.57 $mg \cdot 100\ g^{-1}$
K available for plants	5.78 $mg \cdot 100\ g^{-1}$

mixtures of sludge from Siedlce and Łuków (82.5 g $DM \cdot pot^{-1}$). A detailed scheme of the pot experiment carried out in 2005-07 is presented in Table 1. The scheme of experiment contained two investigated parameters: first – the kind of sewage sludge, second – the addition of mineral and organic compounds. The pot experiment layout was completely randomized. The experiment was carried out in three replications.

The soil used in the experiment was taken from the ploughing layer (Ap layer) and sieved through 1 cm mesh. Some chemical properties of soil used in the pot experiment are presented in Table 2. Fresh and composted sewage sludge, as well as their mixtures, were applied once in the first year (10 days before seed sowing), while the after-effects were studied in the second and third years – series (vegetative season). The quantities of nitrogen introduced in the soil on experimental objects were presented in Table 3. Due to low potassium content in the sludge and its mixtures, as well as the possibility of phosphorus retro-gradation in objects with CaO application, the complementary phosphorus and potassium nutrition were added for all pots once in the first experimental series (year): 0.45 g P (granulated triple superphosphate – 20% P) and 1.25g $K \cdot pot^{-1}$ (potassium sulfate – 49.8% K).

Maize (Nimba cv.) was the test plant in each series. Five seeds were sown into every pot, and only three seedlings per pot remained after their emergence. The pot experiment was carried in a greenhouse in which the temperature was kept in the range 20-25ºC and 60% humidity. The above-ground parts of maize were harvested after 120 vegetation days.

The yield of dry mass of maize biomass was marked by drying at 105ºC. Nitrogen content in harvested plant material was determined by elemental analysis method using the CHN instrument by Perkin-Elmer. Calculated value of nitrogen coefficient is expressed in a percentage and shows what percentage of nitrogen applied in fertilizer is taken up by plants. The value is calculated by subtracting the amount of nitrogen taken up by plants, and the amount of nitrogen taken up by plants harvested from control object and divided by the amount of this element applied in fertilizer and expressed as a percentage.

The difference between mean values of examined features was verified on the basis of variance analysis in a completely randomized system (F-Fischer-Snedecor test), while $LSD_{0.05}$ values for mean value comparisons were calculated using Tukey test.

Results

Sewage sludge originating from wastewater treatment plants in Siedlce and Łuków contained similar nitrogen levels (Table 3). The addition of CaO to the sewage sludge caused decreasing nitrogen content in mixture, although slightly higher brown coal ash, straw, and sawdust were added. The fresh mixtures of sewage sludge with calcium oxide contained 42.8% less nitrogen in dry matter than those with no additives. When brown coal ash, straw, and sawdust were added into the sewage sludge, the decrease on nitrogen concentration amounted to 35.8%, 31.9%, and 33.3%, respectively.

The decrease of nitrogen content was stated during the composting process (Table 3) and was more prominent in the case of sewage sludge stabilized under aerobic conditions (12.7%) than that after methane fermentation (7.5%). The largest nitrogen losses during composting process were recorded in sewage sludge with no additives (13.6%), slightly less in that with brown coal ash addition (11.5%), while the least were in mixtures of sludge with straw (9.4%), CaO (8.3%), and sawdust (7.8%).

The yield of maize biomass, the efficiency of 1g nitrogen introduced in the soil, as well as nitrogen content and its utilization coefficient significantly depended on the type of sewage sludge and the additive used, as well as a series of cultivation (Tables 4-8). The total yield of maize biomass for 3 series of pot experiments harvested from objects fertilized with only sewage sludge, as well as its mixtures with brown coal ash, was not significantly different. As compared to these fertilization objects, lowest yields of the tested plant species were achieved when sewage sludge was applied along with CaO and straw. The amount of maize biomass harvested from the objects fertilized with the sewage sludge plus sawdust was similar to that amended with those waste organic material with no additives as well as with CaO and straw addition. The yields of maize fertilized with sewage sludge with sawdust were lower than after its applying in mixture with brown coal ash. Yield of maize harvested from objects treated with fresh sewage sludge stabilized under aerobic conditions was higher than fresh sewage sludge subjected to methane fermentation. Statistical analysis of achieved results revealed the lack of significant influences of composting process of the sewage sludge and its mixtures on test plant yields.

Table 3. The content of nitrogen in fresh and composted sewage sludge and their mixtures with CaO, brown coal ash, straw, and sawdust, g N·kg^{-1}.

Specification			Nitrogen content (N_{tot}) in fresh matter	Nitrogen content (N_{tot}) in dry matter	Decrease N_{tot} contents (%) in fresh matter	Decrease N_{tot} contents (%) in dry matter
Fresh sewage sludge designed to composting	from Siedlce	without addition	9.68	64.53	-	-
		with CaO	8.31	35.97	14.2**	44.3**
		with ash	8.64	40.75	10.7**	36.8**
		with straw	9.12	43.85	5.8**	32.1**
		with sawdust	8.50	42.08	12.2**	34.8**
	from Łuków	without addition	10.24	70.62	-	-
		with CaO	9.16	41.26	10.5**	41.6**
		with ash	9.33	46.19	8.9**	34.6**
		with straw	9.61	48.29	6.2**	31.6**
		with sawdust	9.05	47.63	11.6**	32.6**
Composted sewage sludge	from Siedlce	without addition	9.53*	57.90	1.5***	10.3***
		with CaO	8.19*	33.21	1.4***	7.7***
		with ash	8.06*	36.90	6.7***	9.4***
		with straw	8.87*	41.10	2.7***	6.3***
		with sawdust	8.45*	40.53	0.6***	3.7***
	from Łuków	without addition	9.78*	58.70	4.5***	16.9***
		with CaO	8.94*	37.58	2.4***	8.9***
		with ash	8.97*	39.97	3.9***	13.5***
		with straw	9.43*	42.25	1.9***	12.5***
		with sawdust	8.98*	41.96	0.8***	11.9***
Fresh sewage sludge applied to soil	from Siedlce	without addition	10.12*	56.22	-	-
		with CaO	8.87*	31.88	12.4**	43.3**
		with ash	8.98*	36.17	11.3**	35.7**
		with straw	9.43*	38.27	6.8**	31.9**
		with sawdust	8.70*	37.42	14.0**	33.4**
	from Łuków	without addition	11.03*	73.53	-	-
		with CaO	9.79*	42.75	11.2**	41.9**
		with ash	9.92*	46.95	10.1**	36.2**
		with straw	10.53*	50.17	4.5**	31.8**
		with sawdust	9.98*	49.75	9.5**	32.3**

*the amount of nitrogen introduced into soil [g·pot^{-1}]
** relative to sewage sludge without additives
***relative to fresh sewage sludge and their mixtures with CaO, ash, straw, and sawdust

Table 4. The yield of maize [g D.M.·pot^{-1}].

Fertilizer objects		Series of experiment 1st	2nd	3rd	Sum for objects
Control object		83.6	44.4	34.1	162.1
CaO		112.7	60.1	27.0	199.8
Ash		67.0	50.0	31.6	148.6
Straw		12.4	62.6	32.6	107.6
Sawdust		32.6	44.3	28.8	105.6
	averages	61.7	52.3	30.8	144.7
Fresh sludge from Siedlce	without additions	236.1	149.9	82.7	468.7
	with CaO	190.5	130.4	59.6	380.5
	with ash	238.0	157.2	81.0	476.2
	with straw	202.5	141.2	62.3	406.0
	with sawdust	255.1	107.0	67.0	429.1
	averages	224.4	137.2	70.5	432.1
Fresh sludge from Łuków	without additions	249.7	148.6	67.3	465.6
	with CaO	186.8	173.0	57.8	417.6
	with ash	260.3	253.8	58.8	573.0
	with straw	202.7	200.0	67.3	470.1
	with sawdust	235.2	156.6	65.1	456.9
	averages	227.0	186.4	63.3	476.6
Composted sludge from Siedlce	without additions	235.2	202.8	86.4	524.3
	with CaO	195.9	129.3	79.0	404.3
	with ash	245.9	166.0	79.3	491.2
	with straw	231.1	123.4	59.9	414.5
	with sawdust	279.0	131.3	54.2	464.5
	averages	237.4	150.5	71.8	459.7
Composted sludge from Łuków	without additions	230.2	185.9	61.8	478.0
	with CaO	189.7	183.5	46.3	419.5
	with ash	247.8	223.2	73.8	544.8
	with straw	228.3	127.4	47.6	403.3
	with sawdust	244.9	160.5	56.3	461.6
	averages	228.2	176.1	57.2	461.4
Averages in series		195.7	140.5	58.7	394.9
$LSD_{0.05}$ for:	series	11.0			–
	type of sludge / type of addition	33.4	37.3	12.8	43.8

The total yields as the sum of three series of maize dry matter on particular fertilization objects (Table 4) do not significantly depend on a nitrogen dose introduced in the soil (Table 3), and correlation coefficient value for both calculated parameters was $r=+0.22$ ($p\leq0.05$).

Maize dry matter yields significantly decreased in subsequent series of the experiment (Table 4). The yield harvested in the second and third series of cultivation were by 28.2 and 70.0% lower in reference to the first series. The differences in yield among the series of pot experiment probably was caused by immobilization – the mineralization process of organic carbon and nitrogen from organic material applied in the soil as well as decreasing plant nutrients in the following years.

Efficiency of 1g nitrogen introduced into the soil within fertilizers expressed in grams of maize dry matter, was not significantly different on objects treated with sewage sludge only as well as its mixtures with CaO, straw, and sawdust (Tables 5 and 8). The highest effect of 1 g nitrogen was observed on objects amended with sewage sludge along with the brown coal ash addition. Efficiency of 1 g N was significantly higher on objects fertilized with composted sewage sludge originating from Siedlce rather than after raw sewage sludge application. In the case of fresh and composted sludge from Łuków, a similar effect of 1 g nitrogen was recorded.

Efficiency of 1 g N significantly decreased in subsequent series of the experiment (Table 5). The effect of 1 g N observed during the second and third series after the element introduction were by 19.9% and 85% lower than in the first series. If the total efficiency of 1 g N for three experimental series is assumed to be 100%, it would amount to 51.4%, 41.1%, and 7.5%, respectively, in all three series.

The nitrogen contents in dry matter of maize mean values for three series grown on particular objects were within the range 5.34 to 8.86 g $N\cdot kg^{-1}$ (Table 6). Nitrogen concentrations in maize biomass fertilized with sewage sludge only and its mixtures with brown coal ash were similar (Table 8). Compared to those fertilization objects, maize fertilizing the mixtures of sewage sludge with CaO addition contained more, while that amended with sewage sludge plus the sawdust mixture – less nitrogen. Significantly, the lowest content of nitrogen was determinated in the maize biomass fertilized with sewage sludge with straw addition.

The nitrogen content in biomass of maize amended with fresh and composted sewage sludge from Siedlce was similar (Table 8). When fresh sludge from Łuków was applied, lower nitrogen concentration in the biomass of tested plants was recorded than after composted sludge introduced in the soil.

The highest nitrogen content in the biomass of maize was achieved during the first series of cultivation (Table 6). The nitrogen quantity determinated in maize harvested in the second and third series of study was by 24.1% and 23.1% lower than in the first series.

Values of nitrogen utilization coefficients (Tables 7 and 8) were similar on objects fertilized with the sewage sludge only (31.7%) and its mixtures with CaO (31.6%) and sawdust (29.6%). Significantly, the largest value of nitrogen utilization coefficient by maize (36.4%, as average) was calculated for objects fertilized with sewage sludge with brown coal ash addition, while the smallest value was found in objects fertilized with sewage sludge with straw (21.6%).

Table 5. Effect of 1 g nitrogen [g D.M. of maize 1 g N^{-1}] introduced into soil.

Fertilizer objects		Series of experiment 1st	2nd	3rd	Sum for objects
Fresh sludge from Siedlce	without additions	15.06	9.33	2.69	27.09
	with CaO	12.05	9.70	1.71	23.46
	with ash	17.19	12.57	4.08	33.84
	with straw	12.61	10.27	1.90	24.78
	with sawdust	19.71	7.20	2.60	29.51
	averages	15.32	9.82	2.76	27.74
Fresh sludge from Łuków	without additions	15.06	9.45	2.08	26.58
	with CaO	10.54	13.14	1.37	25.05
	with ash	17.81	21.12	1.46	40.38
	with straw	11.31	14.78	2.18	28.27
	with sawdust	15.19	11.24	2.07	28.51
	averages	13.98	13.95	1.83	29.76
Composted sludge from Siedlce	without additions	15.90	16.62	4.41	36.93
	with CaO	13.71	10.37	4.23	28.32
	with ash	20.13	15.09	4.33	39.55
	with straw	16.63	8.91	1.75	27.29
	with sawdust	23.12	10.28	1.17	34.57
	averages	17.90	12.26	3.18	33.33
Composted sludge from Łuków	without additions	14.99	14.48	1.79	31.25
	with CaO	11.86	15.56	0.22	27.64
	with ash	18.30	19.94	3.28	41.52
	with straw	15.34	8.81	0.34	24.49
	with sawdust	17.95	12.93	1.33	32.21
	averages	15.69	14.34	1.39	31.42
Averages in series		15.72	12.59	2.29	30.60
$LSD_{0.05}$ for:	series	1.50			–
	type of sludge	n.i.	4.01	n.i.	5.08
	type of addition	4.55	4.78	n.i.	6.06

n.i. – not important

Table 6. Nitrogen content in maize, g N·kg^{-1} D.M.

Fertilizer objects		Series of experiment 1st	2nd	3rd	Average for objects
Control object		4.53	5.30	6.20	5.34
CaO		6.90	5.50	6.00	6.13
Ash		5.70	5.35	5.70	5.58
Straw		6.60	5.50	6.15	6.08
Sawdust		5.47	6.25	6.20	5.97
	averages	5.84	5.58	6.05	5.82
Fresh sludge from Siedlce	without additions	8.67	6.70	7.45	7.61
	with CaO	11.20	7.40	7.10	8.57
	with ash	7.90	7.20	5.75	6.95
	with straw	6.87	5.55	5.60	6.01
	with sawdust	8.10	6.10	6.75	6.98
	averages	8.55	6.59	6.53	7.22
Fresh sludge from Łuków	without additions	10.10	6.85	6.10	7.68
	with CaO	12.00	6.35	6.85	8.40
	with ash	8.80	6.90	5.60	7.10
	with straw	7.97	5.70	5.80	6.49
	with sawdust	8.07	5.50	6.45	6.67
	averages	9.39	6.26	6.16	7.27
Composted sludge from Siedlce	without additions	9.37	6.95	6.10	7.47
	withCaO	10.47	7.05	5.75	7.76
	with ash	8.07	6.55	7.80	7.47
	with straw	6.80	6.25	5.90	6.32
	with sawdust	8.17	6.20	6.45	6.94
	averages	8.57	6.60	6.40	7.19
Composted sludge from Łuków	without additions	11.10	7.45	5.65	8.07
	with CaO	11.13	7.90	7.55	8.86
	with ash	10.60	7.50	7.35	8.48
	with straw	9.07	6.15	7.30	7.51
	with sawdust	11.10	6.05	7.95	8.37
	averages	10.60	7.01	7.16	8.26
	Averages in series	8.44	6.41	6.47	7.10
$LSD_{0.05}$ for:	series	0.08			–
	type of sludge	0.22	0.24	0.19	0.12
	type of addition				

Table 7. The value of nitrogen utilization coefficient by maize, %.

Fertilizer objects		Series of experiment 1st	2nd	3rd	Sum for objects
Fresh sludge from Siedlce	without additions	16.47	7.60	4.00	28.07
	with CaO	19.78	8.23	2.39	30.40
	with ash	16.72	9.99	2.83	29.54
	with straw	10.72	5.82	1.46	18.00
	with sawdust	19.40	4.80	2.77	26.97
	averages	16.62	7.29	2.99	26.60
Fresh sludge from Łuków	without additions	19.43	7.09	1.81	28.33
	with CaO	19.02	8.82	1.89	29.73
	with ash	19.27	15.29	1.19	35.75
	with straw	11.74	8.59	1.70	22.03
	with sawdust	15.21	6.27	2.09	23.58
	averages	16.94	9.21	1.74	27.88
Composted sludge from Siedlce	without additions	19.14	12.32	3.31	34.77
	withCaO	20.41	8.26	2.97	31.64
	with ash	19.91	10.57	5.05	35.53
	with straw	13.44	6.04	1.61	21.09
	with sawdust	22.47	6.85	1.64	30.96
	averages	19.07	8.81	2.92	30.80
Composted sludge from Łuków	without additions	22.25	11.76	1.41	35.42
	with CaO	19.38	13.59	1.55	34.51
	with ash	25.05	16.04	3.69	44.79
	with straw	17.93	5.82	1.44	25.19
	with sawdust	26.05	8.19	2.63	36.87
	averages	22.13	11.08	2.15	35.36
	Averages in series	18.69	9.10	2.45	30.16
$LSD_{0.05}$ for:	series	1.27			–
	type of sludge	3.91	2.86	1.17	4.24
	type of addition	4.65	3.40	1.39	5.05

Like nitrogen contents in the test plant species biomass, values of utilization coefficients on objects fertilized with fresh and composted sewage sludge from Siedlce also were not significantly different. Maize fertilized with fresh sewage sludge originating from Łuków utilized considerably smaller quantities of nitrogen as compared to sludge subjected to the composting process.

The value of nitrogen utilization coefficient by maize increased in subsequent series of the experiment and can be listed in the following sequence: 1st series > 2nd series > 3rd series (Table 7).

Table 8. Average of nitrogen content [g N·kg^{-1}], total yield [g·pot^{-1}], total effect of 1g N [g D.M. 1 g N^{-1}], and total value of utilization coefficient [%] by maize with three series for investigated factors.

Studied factor		Yield	Effect of 1g N	Nitrogen content	Utilization coefficient of N
Type of addition to the sewage sludge	without additions	419.7 bc	30.46 a	7.23 c	31.65 bc
	CaO	364.3 a	26.12 a	7.94 d	31.57 bc
	ash	446.7 c	38.82 b	7.12 c	36.40 c
	straw	360.3 a	26.21 a	6.48 a	21.58 a
	sawdust	383.5 ab	31.20 a	6.99 b	29.59 b
$LSD_{0.05}$ for type of additives		43.8	6.06	0.12	5.05

a, b, c, d – average appointed with different letters

Discussion of Results

Sewage sludge introduced into the soil enhances the natural resources of nutrients. At the same time, it affects the physical and biological soil properties and, in consequence, influences plant growth and development. Determining the physical and chemical features of a sewage sludge as well as quantitative and qualitative traits of achieved biomass enables us to draw conclusions about the usefulness of these organic wastes for plant production. In order to additionally increase the dry matter content in sewage sludge that is subject to dehydration on press or centrifuge, mineral or organic substances with low water concentration are added. Calcium oxide added to sewage sludge makes dry matter increase in achieved mixtures proportionally to its amounts introduced, thus ensuring the product with advantageous physical properties from transport, storage, and field surface spreading points of view. Moreover, sludge is alkalized, ammonia is emitted, and nitrogen content is decreased, which leads to lower fertilization value of such a prepared mixture [18, 19]. In the presented experiment, lower changes in nitrogen quantities were observed after adding the brown coal ash, straw, and sawdust, rather than CaO, into the sewage sludge. Lower nitrogen contents after adding straw or sawdust to the sludge should mainly be attributed to the "dilution" effect due to introducing material with very low levels of the element. Slightly higher losses of nitrogen quantities after brown coal ash, and the largest – due to the CaO addition, probably resulted from sewage sludge alkalization. Furthermore, CaO was added into the sludge-bound water during the hydration process. In theory, 1 kg CaO could react with 0.32 kg water, producing 1.32 kg $Ca(OH)_2$. During composting the sewage sludge only, as well as its mixtures and nitrogen content, decreased a bit, which could be an effect of organic substance mineralization [22]. Slightly larger nitrogen losses occurred while composting the sewage sludge stabilized under aerobic conditions rather than after methane fermentation. This indicates better susceptibility toward mineralization of organic matter contained in the sludge stabilized under aerobic conditions than methane fermentation, in which the part of organic compounds susceptible to decomposition had just been stabilized [21]. Moreover, lower nitrogen content (when recalculated onto dry matter) during sewage sludge mixture composting, namely containing CaO and sawdust, were less considerable than in sewage sludge only. Weaker microbiological activity due to sewage sludge alkalization (with CaO) and biological sorption processes (organic matter in a form of sawdust or straw) could be reasons for such a situation.

Results achieved in the present study confirm yield-forming properties of sewage sludge, which are described in literature [14, 23-25]. Studies performed upon the fertilizing value of sewage sludge with brown coal addition applied for acidic soils, indicated the possibility of reaching higher crop yields and higher efficiencies of 1 g nitrogen, when sewage sludge only was used [18, 19]. The addition of CaO into the sewage sludge affected the lack of significant influence of such sanitation on fertilized crops yields [26], or achieving lower yields and worse 1 g nitrogen effects as compared to sewage sludge only [18, 19]. Performed research confirmed a positive impact of brown coal ash addition into the sewage sludge, as well as the negative influence of CaO, straw, and sawdust on test plant yields.

When studying the fertilizing value of sewage sludge from Siedlce and Łuków, Kalembasa and Symanowicz [27, 28] recorded higher yields of Italian ryegrass-treated sludge from Łuków rather than from Siedlce. Also, our own study revealed higher fertilizing value of raw sewage sludge from Łuków – measured by the quantity of produced biomass of the test plant – than from Siedlce. Other studies upon fertilizing value of sewage sludge from Siedlce and Łuków did not confirm significant differences in the amount of produced biomass of test plants fertilized using that sludge [19].

Our experiment along with literature data indicate the lack of significant influence of composting the sewage sludge on their yield-forming value [29].

Presented results, like those from literature references, on nitrogen content and utilization by maize give the basis for concluding that sewage sludge is a good nitrogen source for plants and thus is even a better fertilizer than manure [14, 29].

Moreover, research made by Kalembasa et al. [30] showed that the coefficient of nitrogen utilization from the sewage sludge may be greater than that for manure. The above authors achieved nitrogen utilization from sewage sludge from Siedlce and Łuków after two experimental years as 74.4% and 60.9%, respectively, whereas the utilization coefficient for manure is 50.9%. Nitrogen utilization from sludge at such a high level can be achieved by introducing a small portion of the element into the soil [31]. Our own study revealed that introducing from 8.06 to 11.03 g N·pot^{-1} into the soil with sewage sludge and its mixtures, nitrogen utilization during the first series reached 18.7% (for sludge with no additives and after adding CaO, brown coal ash, straw, and sawdust). Compared with the literature data that indicate about 20% nitrogen utilization from sewage sludge a year after its introduction, here the achieved value can be counted as similar [32, 33]. Furthermore, 25% nitrogen from the sludge was utilized in the following series [32]. Average nitrogen utilization (for 3 experimental series) in the current study, amounted to 30.2% (when sewage sludge with no additives and in mixtures with CaO, brown coal ash, straw, and sawdust was applied). A considerable decrease of nitrogen utilization was observed after straw added into the sewage sludge, while brown coal ash slightly increased the coefficient value. Literature reports the increasing influence of brown coal ash addition as well as decreasing effects of CaO and sawdust added into the sewage sludge in the amount of uptaken nitrogen and the coefficient of its utilization by plants [19, 34].

Conclusions

1. The addition of calcium oxide and straw into the sewage sludge decreased, while brown coal ash increased the maize biomass yields. Composting the sludge and its mixtures had no significant effects on test plant yield.
2. The efficiency of 1 g N (expressed as grams of maize biomass dry matter) was similar on objects treated with sewage sludge only as well as its mixtures with CaO, straw, and sawdust. As compared to these fertilization objects, significantly better effects of 1 g N were achieved after adding the brown coal ash into the sewage sludge.
3. Maize treated with sewage sludge with no additives and with brown coal ash added contained less nitrogen than when the sludge with calcium oxide was applied. The addition of straw and sawdust into the sludge decreased the nitrogen content in test plants.
4. Applying calcium oxide, brown coal ash, and sawdust into the sewage sludge had no significant effects on the coefficient of nitrogen utilization, while the straw addition decreased macronutrient utilization from the sludge.
5. Composting the sewage sludge from Siedlce did not significantly affect the content and coefficient of nitrogen utilization by maize. More nitrogen in maize and higher nitrogen utilization coefficient were recorded for composted sludge from Łuków, rather than it being applied in raw form.
6. The fertilizing value (measured as the amount of achieved maize biomass as well as efficiency of 1g nitrogen introduced into the soil along with raw and composted sewage sludge and its mixtures with calcium oxide, brown coal ash, straw, and sawdust) decreased in subsequent series of test plant growth.

References

1. Central Statistical Office – CSO, Statistical Yearbook of the Republic of Poland. Environmental Protection, pp. 106-133, **2009**.
2. TURKMEN O., SENSOY S., DURSUN A., TURAN M. Sewage sludge as a substitute for mineral fertilization of spinach (*Spinacia oleraceae* L.) at two growing periods. Acta Agric Scand, Sect B, Plant and Soil Sci **54**, 102, **2004**.
3. GÓRECKI H. Mineral organic fertilizers from industrial and agricultural wastes. Prace Naukowe Akademii Ekonomicznej we Wrocławiu, **792**, 134, **1998** [In Polish].
4. Council Directive 86/278/EEC on the protection of the environment, and in particular of the soil, when sewage sludge in used in agriculture. Official J. of the Eur. Communities, L181, p.6 (4.7.**1986**).
5. PEVERLY J.H., GATES P.B., CLAPP C.E., LARSON W.E., DOWDY R.H. Utilization of municipal solid waste and sludge composts in crop production systems. Am. Soc. of Agron. **1994**, 193, **1993**.
6. SMERNIK R.J., OLIVER J.W., REMINGTON G. Characterization of Sewage Sludge Organic Matter Using Solid-State Carbon-13 Nuclear Magnetic Resonance Spectroscopy. J. Environ. Qual. **32**, 1516, **2000**.
7. CZEKAŁA J. Selected properties of sewage sludge from sewage treatment plants in Wielkopolska. Part I. Reaction, dry matter, organic matter, organic carbon and macronutrients. Acta Agrophysica **70**, 75, **2002** [In Polish].
8. Decree on wastes from 27 April 2001. J. L. No. 62, Item 628, **2001** [In Polish].
9. Decree of Ministry of Environment on municipal sewage sludge from 1 August 2002. J. L. No. 134, Item 1140, **2002** [In Polish].
10. LI Y.X., WANG M.I., WANG Z.S. Heavy metals in contemporary Chinese sewage sludges. Toxicol. & Environ. Chem. **69**, (1), 229, **1999**.
11. CZEKAŁA J., JAKUBUS M., MOCEK A. Selected properties of sewage sludge from sewage treatment plants in Wielkopolska. Part III. Heavy metals and polycyclic aromatic hydrocarbons. Acta Agrophysica **70**, 91, **2002** [In Polish].
12. SIMARD R., BEAUCHEMIN S., LAVERDIERE M.R. Limed sewage sludge effects on nutrient status and metal fractions in aciolic soils. Canadian J. of Soil Sci. **79**, (1), 173, **1999**.
13. BOZKURT M.A., YARILGAC T. The Effects of Sewage Sludge Applications on the Yield, Growth, Nutrition and Heavy Metal Accumulation in Apple Trees Growing in Dry Conditions. Turk. J. Agric. For. **27**, 285, **2003**.
14. BOZKURT M.A., AKDENIZ H., KESHIN B., YILMAZ I.H. Possibilities of using sewage sludge as nitrogen fertilizer for maize. Acta Agric Scand, Sect B, Plant and Soil Sci **56**, (2), 143, **2006**.

15. JAKUBUS M., CZEKAŁA J. Heavy Metal Speciation in Sewage Sludge. Pol. J. Environ. Stud. **10**, (4), 245, **2001**.
16. KALEMBASA S., KALEMBASA D. Some chemical and biological methods for the processing of waste activated sludge. Biotechnology, **1**, (36), 45, **1997**.
17. JACKSON B.P., MILLER W.P. Soil Solution Chemistry of Fly Ash-, Poultry Litter-, and Sewage Sludge-Amended Soil. J. Environ. Qual. **29**, 430, **2000**.
18. KALEMBASA S., WYSOKIŃSKI A. The influence of fertilization with sewage sludges mixed with the brown coal ash or with CaO on the yield and chemical composition of the plants. Part I. The yield of plants. Adv. of Agric. Sci. Probl. Issues **482**, 251, **2002** [In Polish].
19. KALEMBASA S., WYSOKIŃSKI A. The influence of alkalization type waste activated sludges on the yield, content and value of utilization coefficient of nitrogen by tested plants. Pol. J. of Soil Sci. **39**, (2), 197, **2006**.
20. KORBOULEWSKY N., DUPOYET S., BONIN G. Environmental risks of applying sewage sludge compost to vineyard: carbon, heavy metal, nitrogen and phosphorus accumulation. J. Environ. Qual. **31**, 1522, **2002**.
21. WYSOKIŃSKI A., KALEMBASA S. Some physicochemical parameters of fresh and composted sewage sludges and their mixtures with CaO or brown coal ash. Acta Sci. Pol., Form. Circumiectus, **5**, (1), 51, **2006** [In Polish].
22. IGLESIAS-JIMENEZ E., PEREZ-GARCIA V. Composting of domestic refuse and sewage sludge. II. Evolution of carbon and some "humification" indexes. Resour. Conserv. Recycl. **6**, 243, **1992**.
23. TAMOUTSIDIS E., PAPADOPULOS I., TOKATLIDIS I., ZOTIS S., MOVROPOULOS T. Wet sewage sludge application effect on soil properties and element content of leaf and root vegetables. J. of Plant Nutr. **25**, (9), 1941, **2002**.
24. TEJADA M., GONZALES J.L. Application of Different Organic Wastes on Soil Properties and Wheat Yield. Agron. J. **99**, 1597, **2007**.
25. WIECZOREK J., GAMBUŚ F. The effect of fertilization with farmyard manure and sewage sludge on yields and chemical composition of Italian ryegrass. Ecol. Chem. and Eng. **15**, (10), 1163, **2008**.
26. STĘPIEŃ W., SZULC W., MERCIK S. Evaluation of fertilizing value of sewage sludge bas been used alone or mixed with brown coal or CaO. Fol. Univ. Agric. Stetin. 211, Agric. **84**, 465, **2000** [In Polish].
27. KALEMBASA S., SYMANOWICZ B. The influence of mineral fertilization the mixtures of waste activated sludges with bares and sawdusts on the Fielding and chemical composition of ryegrass (*Lolium Multiflorum* LAM). Folia Univ. Agric. Stetin. 200 Agric. **77**, 129, **1999** [In Polish].
28. KALEMBASA S., SYMANOWICZ B. The usefulness of brown coals and waste activated sludges and their mixtures in manuring of *Lolium Multiflorum* LAM. Part I. The influence of brown coals and waste activated sludges and their mixtures in yielding of *Lolium Multiflorum* LAM. Folia Univ. Agric. Stetin. 200 Agric. **77**, 135, **1999** [In Polish].
29. PATORCZYK–PYTLIK B., SPIAK Z., RABIKOWSKA B. Estimation of fertilizing value of farmyard manure and sewage sludge – vermicomposts in the second year after their application. Adv. of Agric. Sci. Probl. Issues **409**, 143, **1993** [In Polish].
30. KALEMBASA S., KALEMBASA D., KANIA R. Fertilization value of activated sludges from selected sewage treatment plants of Siedlce region. Adv. of Agric. Sci. Probl. Issues **475**, 279, **2001** [In Polish].
31. CZEKAŁA J. The activated sludge the source of organic matter and the nutrients components. Folia Univ. Agric. Stetin. 200 Agric. **77**, 33, **1999** [In Polish].
32. MAZUR T. Ecological results of organic fertilization. Folia Univ. Agric. Stetin. 172 Agric. **62**, 331, **1996** [In Polish].
33. KALEMBASA S., KUZIEMSKA B. The influence of doses and term sof waste activated sludge application on the field of hay and values of utilization coefficient of nitrogen and phosphorus from waste. Folia Univ. Agric. Stetin. 200 Agric. **77**, 121, **1999** [In Polish].
34. COUTINHO J., ARROBAS M., RODRIGES O. Effect of composted sewage sludge amendment on soil nitrogen and phosphorus availability. Commun. in Soil Sci and Plant Anal. **28**, (19), 1845, **1997**.