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INFLUENCE OF ORGANIC AND MINERAL WASTE ON YIELD, CONTENT OF NITROGEN IN TESTED PLANTS

WPŁYW ORGANICZNYCH I MINERALNYCH ODPADÓW NA PLON I ZAWARTOŚĆ AZOTU W ROŚLINACH TESTOWYCH

Abstract: The research aimed the evaluating of the influence of sewage sludge, hard coal and their ash mixture on yielding, nitrogen content, and its utilization coefficient by cocksfoot and maize. Sewage sludge as mixture of sewage sludge with hard coal ash were applicated as fresh and after three months of composting process in two series: without and with liming. The largest yields of test plants biomass were achieved on objects treated with raw sewage sludge. Nitrogen contents at test plants was significantly higher due to sewage sludge, sludge-ash mixture, as well as mineral nutrition application, while liming considerably decreased the nitrogen contents in the biomass of tested plants. Mineral fertilization significantly enhanced the nitrogen uptake by both test plant species, and applying the waste materials – only at cocksfoot. The coefficient of nitrogen utilization from raw and composted sewage sludge was at similar levels amounting to 26.2 %, on average; addition of hard coal ash into the sludge caused the decrease of this coefficient.

Keywords: waste activated sludge, hard coal ash, yielding of tested plants, the content of nitrogen uptake and coefficient of nitrogen utilization

Hard coal used in an industry as a raw material and as energy source for heating purposes, is ground to achieve fractions from 1 to 20 mm particle diameter, which lets its better utilization as a semi-product and energy source. During the coal combusting, the ash of $\varnothing < 1$ mm is transferred to the storage heaps causing the hazard of dusting and threat for natural environment, thus it should be properly utilized [1]. Sewage sludge – that can be considered as an organic material very usefull as fertilizer which

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consists nitrogen and phosphorus, as well as organic matter – is another waste material that is commonly found in cities and it also should be utilized [2–5].

In Poland and some UE countries the utilization of sewage sludges as organic fertilizer is recommended, because of its content of organic matter and plant nutrients especially nitrogen, phosphorus and sulphur [6–11].

The availability of heavy metals for plants from soil depends upon different parameters *ie* soil pH, soil organic matter content and its concentration in soil. The availability of heavy metals is higher in acid soils because the solubility of heavy metals in acid soils considerably increased [12, 13].

The application of waste activated sludge as fertilizer is the simplest management in agricultural practice which increases the yield of plants in predictable time and other only sludge or as mixture with other mineral addition can be used [6].

The hard coal ash is generated in large cities, where power plants using hard coal for warming the water for central heating systems, simillary as sewage sludge is produced at wastewater treatment plants as a final product during sewage purification. These both waste products, when considered separately, are a serious problem in their rational neutralization. However, their mixing and application for crops as the source of nutrients and improving of soil fertility, is one of the ways for these two wastes utilization [14]. Final mixture with high content of dry mass and organic matter as well as nutrients contents may create advantageous conditions for plants to grow and good yielding. Rules of application and nutrients conversions in the soil applicated in mineral fertilizers are well recognized; however, the availability and utilization of plant nutrients which are contained in wastes (*eg* combustion ashes of sewage sludge) still remains under studies [6, 15, 16].

Present research aimed is evaluating of the influence of waste sewage sludge and hard coal ash as well as their mixture on yield, nitrogen content, and its utilization coefficient by tested plants.

Material and methods

The pot experiment was carried out in a granhouse conditions in completely randomized pattern included the following factors:

I – addition to the soils (10 kg per pot) following organic and mineral materials; raw sewage sludge and sludge composted alone originating from wastewater treatments plants at Siedlce on which municipal and industrial sewages were purified and with mineral materials for three months, hard coal ash from Electricity Power Plant at Siedlce as well as calcium carbonate applicated according to 1 Hh acidity.

The sewage sludge fresh and composted was applied once at the amount of 5 % in relation to the soil mass. Sludge with hard coal ash mixture was prepared in 2:1 ratio as recalculated onto dry matter. The total nitrogen contents in fresh and composted sewage sludge were determined by means of Kjeldahl method [17], which amounted to 52.8 and 44.8 $g \cdot kg^{-1}$ d.m., respectively.

II – NPK applicated in mineral fertilizers

1) with no nutrition;

2) NPK nutrition.

The soil material used for the experiments was strong loamy sand which was samples from 0–20 cm layer of lessive soil. Before experiment, nitrogen and carbon contents were determined in the soil by dry combustion method using CHN Analyser, which amounted to 1.10 and 8.20 g · kg^{-1}, respectively; while available phosphorus and potassium concentrations were 52 and 71 mg · kg^{-1} determinated according to Egner-Riehm method. Pots were illed with the soil at the amounts of 10 kg and humidity was maintained at the level of 60 % of the full water capacity during the vegetation period.

Mineral nutrition for each of tested plants was applied before sowing using urea (3.0 g · pot^{-1}), triple superphosphate (5.2 g · pot^{-1}), and potassium sulfate (7.2 g · pot^{-1}).

Cocksfoot (*Dactylis glomerata*) was the test plant species in the first year of experiment; it was sown at the amount of 1.0 g · pot^{-1} and three cuts were harvested during the vegetation period with 30 days intervals. Maize was grown during the second year of experiment in the amount of 3 plants per every pot and was harvested at the beginning of flowering stage. The dry matter weight of cocksfoot and maize was determined after their harvest and drying. Dried and ground biomass of both test plant species was a subject to total nitrogen analysis applying elemental CHNS/O auto--analyzer equipped with thermal conductivity detector (TCD) and using acetanilide as a standard (No 2400, Perkin Elmer).

Achieved results were statistically processed applying variance analysis (F Fisher––Snedecor test), while $LSD_{0.05}$ values were calculated by means of Tukey's test. Relationship between investigated parameters were assessed according to Pearson's correlation coefficient.

Results and discussion

Nitrogen is a factor that considerably determines the size of achieved crop yields. Nitrogen content in fresh sewage sludge used in this experiment was 52.8, while in composted one 44.8 g · kg^{-1} d.m. Such high nitrogen concentration in sludge from Siedlce sewage purification plant even prevails its content in manure [18].

The cocksfoot yields (Table 1) were significantly differentiated for particular cuts and fertilization objects, ranging for individual cut from 2.63 to 19.4 g · pot^{-1}. The highest yields were harvested from the objects treated with the mixture of fresh sewage sludge with ash or ash with the addition of $CaCO_3$. Therefore, these waste materials can be applied to soil fertilizing purpose, due to significant yield increase. A positive influence of sewage sludge on yield quality was confirmed in other field and pot experiments [19–21]. The application of the mixtures of fresh and composted sludge with hard coal ash caused considerable yield gains in all cuts in relation to yields achieved from the control. Antoniewicz [22, 23] reported similar results. The ash addition to fresh sewage sludge had no impact on cocksfoot yielding, while when added into the composted sludge, the increase of cocksfoot yield at the 1st and 2nd cuts were recorded, but the decrease in the 3rd cut. The higher yields (than for control) were

Table 1

The yield [g · pot^{-1} d.m.] of cocksfoot in the 1st year of experiment

Mineral fertilization	0				NPK				Means	Effect of NPK
Cuts / Organic and mineral materials	I	II	III	Sum	I	II	III	Sum		
Control object	8.00	4.33	3.18	15.5	4.90	13.4	6.10	24.4	19.9	–4.4
Sewage sludge	16.9	17.1	11.4	45.4	9.13	16.5	6.73	32.4	38.9	–6.5
Composted sewage sludge	14.5	17.1	8.4	40.0	7.33	16.2	11.1	34.6	37.4	–2.6
Ash hard coal	8.88	4.35	2.63	15.9	13.5	13.1	3.63	30.2	23.0	+7.1
Sewage sludge + ash	12.5	16.4	10.9	39.8	12.0	16.6	8.60	37.2	38.5	–1.3
Composted sewage sludge + ash	14.5	17.0	8.40	39.9	20.1	11.9	5.87	37.9	38.9	–1.0
Liming	11.3	5.23	3.35	19.9	14.2	6.25	1.83	22.3	21.1	+1.2
Liming + sewage sludge + ash	10.8	8.63	5.90	25.3	18.4	19.4	8.43	46.2	35.7	+10.4
Liming + composted sewage sludge + ash	13.2	12.8	8.20	34.2	17.1	17.0	6.00	40.1	37.2	+3.0
Means	12.3	11.4	6.93	30.6	13.0	14.5	6.48	34.0	32.3	+1.7

Cuts		I	II	III	Means
$LSD_{(0.05)}$ for:	organic and mineral materials	2.6	1.7	1.7	4.95
	fertilization NPK	n.s.	0.49	0.48	n.s.
	organic and mineral materials × fertilization NPK	2.2	1.5	1.4	n.s.

achieved on objects where only liming and only hard coal ash was applied in the first cut; its significant decrease was recorded in other cuts. It indicates that the soil material was acid used in this pot experiment and high the alkalization the decreased cocksfoot yields, which was stated by earlier research [24]. The addition of mineral nutrition contributed to considerable increase of a biomass harvested only in the 2nd cut.

The maize biomass yields in the second year of experiment (Table 2) was significantly differentiated depending on treatment with waste materials and NPK application, ranging from 23.9 on control with no NPK up to 111 g · pot^{-1} on limed and NPK fertilized object. Significantly higher yields – as compared to these from the control – were achieved by applying the raw sewage sludge as well as its mixture with hard coal ash. Also the soil liming, and liming along with composted sewage sludge application and hard coal ash caused significant increase of maize yields. The ash addition into the raw sludge decreased the maize yield, while when added into the composted sludge, the yields were similar. The plant nutrients applicated in the forms of mineral fertilizers significiantly increased (almost twice as high) of maize yields. The highest (in comparison to control) dry matter increase of maize 87.14 g · pot^{-1} caused by NPK fertilization was harvested from the object with liming and the lowest 54.2 g · pot^{-1} from object on which NPK was applicated on the background of fresh sewage sludge with ash from hard coal. Generally the highest increase of NPK in the maize yield 85.4 g · pot^{-1} on the object with the application of liming and the lowest (12.0 g · pot^{-1}) when fresh sewage sludge was mixed with ash.

Table 2

The yield [g · pot^{-1} d.m.] of maize in the 2nd year of experiment

Mineral fertilization / Organic and mineral materials	0	NPK	Means	Effect of NPK
Control object	23.9	88.3	56.1	+64.4
Sewage sludge	58.0	104	81.0	46.0
Fermented sewage sludge	46.8	80.6	63.7	+33.8
Ash hard coal	32.6	81.4	57.0	48.8
Sewage sludge + ash	66.1	78.1	72.1	+12.0
Ferment. sewage sludge + ash	43.7	83.6	63.7	+39.9
Liming	25.6	111	68.3	+85.4
Liming + sewage sludge + ash	37.3	86.7	62.0	49.4
Liming + ferment. sewage sludge + ash	34.3	104	69.1	69.7
Means	40.9	90.9	65.9	

$LSD_{(0.05)}$ for:	organic and mineral materials	8.5
	fertilization NPK	2.4
	organic and mineral materials × fertilization NPK	7.2

The mean nitrogen content in cocksfoot biomass (Table 3) amounted to 36.0 g · kg^{-1} d.m. According to Falkowski [18], such nitrogen level in a sward of green lands should

Table 3

The content of N [g · kg^{-1} d.m.] in cocksfoot in the 1st year of experiment

Mineral fertilization	0				NPK				Effect of NPK
Cuts / Organic and mineral materials	I	II	III	Means	I	II	III	Means	
Control object	25.3	19.2	22.2	22.2	48.6	41.6	44.8	45.0	+22.8
Sewage sludge	46.5	31.0	27.0	34.8	48.7	32.9	32.8	38.1	+3.3
Fermented sewage sludge	44.4	34.0	26.2	34.9	56.7	48.7	43.7	49.7	+14.8
Ash hard coal	24.6	18.0	21.5	21.4	55.3	47.4	30.0	44.2	+22.8
Sewage sludge + ash	51.2	36.9	32.1	40.1	53.4	45.0	42.4	46.9	+6.8
Ferment. sewage sludge + ash	40.8	24.1	26.5	30.5	51.6	41.2	29.0	40.6	+10.1
Liming	23.7	17.5	20.1	20.4	46.6	39.6	18.6	34.9	+14.5
Liming + sewage sludge + ash	45.6	32.3	27.3	35.1	48.9	40.1	29.2	39.4	+4.3
Liming + ferment. sewage sludge + ash	39.6	23.1	22.1	28.3	48.7	38.0	35.6	40.8	+12.5
Means	38.0	26.2	25.0	29.7	50.9	41.6	34.0	42.2	

Cuts		I	II	III	Means
$LSD_{(0.05)}$ for:	organic and mineral materials	3.6	2.3	1.7	n.s.
	fertilization NPK	1.0	0.64	0.48	4.9
	organic and mineral materials × fertilization NPK	3.1	1.9	1.5	n.s.

be considered as high. Applying the sewage sludge, and also sludge-ash mixtures, significantly increased the nitrogen concentration in the 1st cut of grass, while in subsequent cocksfoot cuts, only composted sludge as well as raw sewage sludge with hard coal ash mixture had considerable effects on the increase of the element at test plant species as compared with the control object. Addition of ash into the raw sewage sludge affected the increase, whereas decrease when added into composted sludge, of nitrogen content at biomass of plants harvested from all cuts. According to Wong and Selvam [25], using the composted sewage sludge with hard coal ash mixture can cause the decrease of nitrogen concentration at plant biomass, while treatment with composted sludge increases the level of the macronutrient at cocksfoot biomass. Soil liming led to the decrease of nitrogen content at test grass, but the differences were significant only in the 3rd cut.

The power plant ash contains slight amounts of nitrogen, that during combusting, is released into the atmosphere in a form of oxides and cannot be considered as the nitrogen as source for plants [26]. Nevertheless, ash used in present experiment increased the nitrogen concentration in the 1st and 2nd cuts of cocksfoot, as compared with plants from the control object, which was also confirmed by Ciecko et al [27] results. Such an influence can be accounted for by improved growth and development features of plants resulting from the ash application. Mineral nutrition significantly increased nitrogen content at the test plant biomass harvested in every cut as well as for the mean value of the three cuts, which was also earlier confirmed by other authors [16].

The nitrogen contents at maize biomass (Table 4) was very diverse and dependent on all examined factors. The raw and composted sewage sludge treatment as well as their mixtures with hard coal ash significantly increased the nitrogen concentration in the test

Table 4

The content of N [g · kg^{-1} d.m.] of maize in the 1st year of experiment

Organic and mineral materials \ Mineral fertilization	0	NPK	Means	Effect of NPK
Control object	8.80	13.7	11.3	+4.9
Sewage sludge	8.70	17.5	13.1	+8.2
Fermented sewage sludge	14.1	16.9	15.5	+2.8
Ash hard coal	11.0	14.8	12.9	+3.8
Sewage sludge + ash	9.30	17.9	13.6	+8.6
Ferment. sewage sludge + ash	11.3	15.8	13.6	+4.5
Liming	7.00	12.4	9.7	+5.4
Liming + sewage sludge + ash	7.90	17.4	12.7	+9.5
Liming + ferment. sewage sludge + ash	7.70	16.5	12.1	+8.8
Means	9.53	15.9	12.7	

$LSD_{(0.05)}$ for:	organic and mineral materials	0.98
	fertilization NPK	0.28
	organic and mineral materials × fertilization NPK	0.83

Table 5

Uptake of nitrogen [mg · pot^{-1}] by cocksfoot

NPK fertilization	0				NPK			
Cuts / Organic and mineral materials	I	II	III	Means	I	II	III	Means
Control object	202	83	71	119	238	557	273	273
Sewage sludge	786	530	308	541	445	543	221	403
Fermented sludge	644	581	220	482	416	789	485	563
Ash hard coal	218	78	57	118	747	621	109	492
Sewage sludge + ash	640	605	350	533	641	747	365	584
Ferment. sludge + ash	592	410	222	408	1037	490	170	566
Liming	268	92	67	142	662	248	34	315
Ca + sewage sludge + ash	492	279	161	311	899	778	242	640
Ca + ferm. sludge + ash	523	296	181	333	833	646	214	564
Means	485	328	182	332	658	602	235	498

Cuts		I	II	III	Means
$LSD_{(0.05)}$ for:	organic and mineral materials	76.2	44.2	32.9	n.s.
	fertilization NPK	21.5	12.5	9.30	131
	organic and mineral materials × fertilization NPK	64.6	37.5	27.9	n.s.

plant species biomass. Addition of ash into the composted sludge made the decrease of nitrogen content at maize, as similar as in the case of cocksfoot. Bozkurt et al [28] reported that ash added into the sewage sludge caused considerable decrease in nitrogen content at cereals. Soil liming on objects with no waste material application decreased the nitrogen concentration at test plants, while liming on objects fertilized with sludge-ash mixture led to the increase of the macronutrient in maize biomass, as compared with plants growing on the control object. Mineral nutrition had significant impact on higher nitrogen contents at maize.

The nitrogen uptake by cocksfoot in all cuts (Table 5) was considerably higher due to sewage sludge as well as sludge-ash mixture application. Adding the hard coal ash into the raw sludge caused the increase, while ash addition to composted sludge – decrease of nitrogen uptake by cocksfoot biomass harvested in the 2nd and 3rd cuts. It may indicate the influence of hard coal ash on a rate of organic substance mineralization within sewage sludge. Soil liming on objects with no fertilization using waste materials significantly increased the amount of uptaken nitrogen by cocksfoot biomass in reference to plants grown on objects with no liming, but only in the 1st cut. The cocksfoot harvested in subsequent cuts from limed objects uptook significantly less nitrogen as compared with plants from the control. The NPK nutrition caused considerable increase of nitrogen uptake by test grass in each of harvested cut as well as for mean value of three cuts.

The amount of nitrogen uptaken by maize biomass (Table 6) was diverse for particular objects treated with waste materials; however, the differences were not significant. Only mineral nutrition increased the nitrogen uptake by maize. Nitrogen uptake by test plant species was the highest on objects fertilized with sewage sludge, which was associated with larger yields and nitrogen contents at plants, as compared with other objects.

Table 6

Uptake of nitrogen [mg · pot^{-1}] by maize

NPK fertilization / Organic and mineral materials	0	NPK	Means	Amount of nitrogen up from urea
Control object	210	1210	710	1000
Sewage sludge	505	1820	1162	1315
Fermented sludge	660	1362	1011	702
Ash hard coal	359	1205	782	845
Sewage sludge + ash	615	1398	1007	783
Ferment. sludge + ash	494	1321	908	827
Liming	179	1376	777	1197
Ca + sewage sludge + ash	295	1509	902	1214
Ca + ferm. sludge + ash	264	1716	990	1452
Means	398	1435	917	1037

$LSD_{(0.05)}$ for:	organic and mineral materials	n.i.
	fertilization NPK	300
	organic and mineral materials × fertilization NPK	n.i.

Value of nitrogen utilization coefficient from sewage sludge (Table 7) amounted to 26.2 % (mean for two years of experiment). Similar results were reported by Gondek and Filipek-Mazur [16], who found that the quantity of nitrogen utilized by plants on objects treated with the sewage sludge ranged within 21.8–37.3 %. Nitrogen utilization from raw and composted sewage sludge was at the same levels, which may indicate a fast mineralization of organic nitrogen compounds within that sludge. The hard coal ash addition – both raw and composted – caused the decrease of the coefficient values, which was also confirmed by other research [22]. Therefore, the sewage sludge mixed with the hard coal ash, that has alkalizing properties, may lead to the nitrogen losses in a form of ammonia.

Table 7

The values of the utilization coeficient [%] of nitrogen from sewage sludge

Fertilization	0			NPK		
Years Organic and mineral materials	1	2	Sum	1	2	Sum
Control object	—	—	—	—	—	—
Sewage sludge	27.8	6.48	34.3	3.08	13.4	16.5
Fermented sludge	25.9	10.7	36.6	14.8	3.61	18.4
Ash hard coal	—	—	—	—	—	—
Sewage sludge + ash	27.3	5.63	32.9	15.1	4.24	19.3
Ferment. sludge + ash	24.8	3.85	28.7	6.27	3.30	9.57
Liming	—	—	—	—	—	—
Ca + sewage sludge + ash	—	—	—	—	—	—
Ca + ferm. sludge + ash	—	—	—	—	—	—
Means	26.5	8.21	33.2	9.81	6.14	16.0

In the present study, value of a simple correlation coefficient was considered for yield, nitrogen content, and nitrogen uptake by cocksfoot biomass harvested in particular cuts, as well as for mean value from three cuts and for maize. These dependencies (mean values) for determined parameters at cocksfoot biomass amounted to: 1st cut – yield vs. nitrogen uptake $-r = +0.911^{**}$, nitrogen content vs. nitrogen uptake $-r = +0.89^{**}$, yield vs. nitrogen content $-r = +0.62^{**}$; 2nd cut – yield vs. nitrogen uptake $-r = +0.89^{**}$, nitrogen content vs. nitrogen uptake $-r = +0.83^{**}$, yield vs. nitrogen content $-r = +0.54^{*}$, 3rd cut – yield vs. nitrogen content $-r = +0.49^{**}$. The dependencies for mean value in a biomass from three cuts were: yield vs. nitrogen content $-r = +0.52^{*}$, yield vs. nitrogen uptake $-r = +0.90^{**}$, and nitrogen content vs. nitrogen uptake $-r = +0.77^{**}$. Values of simple correlation coefficients for determined parameters at maize biomass amounted to: yield vs. nitrogen content $-r = +0.76^{**}$, yield vs. nitrogen uptake $-r = +0.95^{**}$, and nitrogen content vs. nitrogen uptake $-r = +0.91^{**}$. Achieved values of correlation coefficients indicate that examined features were highly significant or significantly positively correlated to each other within every cocksfoot biomass cut as well as maize biomass.

Conclusions

1. The largest yields of cocksfoot and maize were achieved on objects treated with raw sewage sludge. Hence, significant yield gains support the helpfulness of these material application for soil fertilizing.

2. Nitrogen contents at test plants was significantly higher due to sewage sludge, sludge-ash mixture, as well as mineral nutrition application; liming considerably reduced the nitrogen concentrations at examined plants.

3. Mineral nutrition significantly enhanced the nitrogen uptake by both test plant species, and applying the waste materials – only at cocksfoot.

4. The nitrogen utilization coefficient values from raw and composted sewage sludge was at similar levels amounting to 26.2 %, on average; addition of hard coal ash into the sludge caused the decrease of the coefficient.

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WPŁYW ORGANICZNYCH I MINERALNYCH ODPADÓW NA PLON I ZAWARTOŚĆ AZOTU W ROŚLINACH TESTOWYCH

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Abstrakt: Celem badań było określenie wpływu zróżnicowanego nawożenia osadami ściekowymi oraz mieszaniną osadowo-popiołową na plonowanie oraz zawartość, pobranie i współczynnik wykorzystania azotu przez kupkówkę pospolitą i kukurydzę. Osady i ich mieszaniny stosowano świeże i po 3-miesięcznej fermentacji w serii bez i z wapnowaniem. Największe plony roślin uzyskano na obiektach nawożonych osadami świeżymi. Zawartość azotu w roślinach testowych była istotnie większa pod wpływem stosowania osadów ściekowych i mieszanin osadowo-popiołowych oraz nawożenia mineralnego, natomiast wapnowanie istotnie obniżyło koncentrację azotu w roślinach. Nawożenie mineralne istotnie zwiększyło pobranie azotu przez obie rośliny testowe, a stosowanie materiałów odpadowych jedynie pod kupkówkę pospolitą. Wykorzystanie azotu z osadów ściekowych i kompostowanych było na tym samym poziomie i wynosiło średnio 26,2 %, a dodatek popiołu do osadów spowodował spadek wartości tego współczynnika.

Słowa kluczowe: osad ściekowy, popiół z węgla kamiennego, plonowanie roślin, zawartość azotu, pobranie, współczynnik wykorzystania