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YIELDING AND MACRONUTRIENTS CONTENTS AT ITALIAN RYEGRASS ON A BACKGROUND OF ORGANIC FERTILIZATION AND LIMING

PLONOWANIE ORAZ ZAWARTOŚĆ MAKROELEMENTÓW W ŻYCICY WIELOKWIATOWEJ NA TLE NAWOŻENIA ORGANICZNEGO I WAPNOWANIA

Abstract: The pot experiment dealt with the evaluating the influence of sewage sludge with coal ash mixture as well as additional mineral fertilization and liming on yield and macronutrients contents at Italian ryegrass. Tested sludge originated from the purification plant in the city of Siedlce (industrial and municipal sewage) that were finally subjected to methane fermentation process. Italian rajgras was tested plant, in which dry matter yield and macronutrients concentrations were determined. Applied mixtures significantly increased the plant yield as well as magnesium and phosphorus contents, while decreased calcium and potassium levels. Liming considerably increased the amount of calcium and phosphorus in Italian ryegrass.

Keywords: Italian ryegrass, yield, macronutrients, sludge, hard coal ash, mixture, liming

A fast development of sewage purification methods and replacing the individual flat heating with municipal central heating has been recently observed, namely in small centers. Hard coal used in industry and for heating purposes is ground (fractions 1–20 mm in diameter), which allows for its better combusting and more efficient energy utilization. Achieved ashes of 1 mm particle diameter is transported to dumps and it has to be often wetted with water, because it is a source of dusting and threats the natural environment [1]. Mixing and further applying for crops fertilization can be one of the ways to utilize both waste products: hard coal ash and sewage sludge. It would make possible to use these wastes and to reduce their amounts stored.

Present study aimed at evaluating the fertilization value of sewage sludge with hard coal ash mixture as well as additional mineral nutrition and liming; the influence of that mixture on macronutrients contents at Italian ryegrass was also examined.

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Material and methods

The three-factor pot experiment in completely randomized design with three replications was set in a greenhouse at Podlasie University in Siedlce. Following factors were examined:

I fertilization (sewage sludge with hard coal ash mixture at the ratio of 2:1 recalculated onto dry matter) taking into account two levels of experimental factor:

– 15 % of mixture amount in relation to the total soil weight;

– 30 % of mixture amount in relation to the total soil weight.

The amount of macronutritions introduced into the soil in materials used for fertilization applied in the 15 % to the soil mass was as follows: N – 0.28 g, P – 0.38 g, K – 0.14 g, Ca 0.84 and Mg – 0.22 g.

Sewage sludge applied in the experiment originated from the purification plant in Siedlce (industrial and municipal sewage) that were subjected to methane fermentation process and partially dehydrated on Bellmer press with flocculants addition at the final processing stage; hard coal ash originated from Energy Plant in Siedlce.

II liming (without or with liming according to 1 H_h of soil in a form of $CaCO_3$);

III mineral nutrition (without or with NPK nutrition). The mineral fertilization was applied once before sowing in forms of urea (285 mg/pot), triple superphosphate (320 mg/pot), and potassium sulfate (470 mg/pot).

The soil used for experiment consisted of light loamy sand collected from 0–20cm lessive soil layer. Before experiment, pH_{KCl} was 4.59 unit, while nitrogen and potassium contents 1.0 and 7.9 $g \cdot kg^{-1}$, respectively. Pots were filled with 2 kg of soil and moisture content during vegetation period was maintained at 60 % level of the field water capacity. Italian ryegrass (*Lolium multiflorum* L.) was tested plant.

Four cuts of tested grass were harvested during the vegetation period, and then dry matter yield as well as total nitrogen (autoanalyzer CHNS/O 2400, Perkin-Elmer), phosphorus, potassium, calcium, and magnesium (ICP-AES technique after sample combustion) were determined in ground plant samples. Raw plant material was combusted at 450 ^{o}C in muffle furnace, then flooded with HCl/H_2O (1:1), and evaporated till dryness. Such prepared samples were dissolved in 10 cm^3 of diluted HCl (10 %) and transferred to measure flasks using 10 % HCl through hard filter paper.

Significant treatments effects and interactions ($P < 0.05$) were identified by analysis of variance (F Fisher-Snedecor's test) by applying FR Anal. Ver 4.1 software.

When significant treatment effects occurred means were separated using Tukey's for test $LSD_{(0.05)}$. Correlation coefficients for the relationship of the estimated factors were calculated.

Results and discussion

The waste activated sludge used in the experiment and consisting the mixture (Table 1) differed with their chemical composition. Sewage sludge originating from purification plant in Siedlce contained 5.57 $g \cdot kg^{-1}$ of nitrogen and phosphorus more than hard coal ash. The content of potassium, sulphur, calcium and magnesium in coal ash was higher than in waste activated sludge. The content of potassium in hard coal ash was 6.5 times waste activated sludge while magnesium 44.1 times higher than in waste activated sludge.

Table 1

The content of select macroelements in sewage sludge and ash coal

Indicate macroelement	Sewage sludge	Ash coal
	g/kg^{-1} [d.m.]	
P	6.37	2.45
K	0.66	4.26
S	1.42	2.56
Ca	9.31	15.1
Mg	0.20	8.82

The high content of calcium and magnesium in hard coal ash might indicate its alkalizing properties.

The dry matter yield of Italian ryegrass (Table 2) oscillated within wide range from 1.47 g/pot d.m. from the 4th cut of not limed control and NPK to 9.70 g/pot d.m. from

Table 2

The yield [g · pot] of *Lolium multiflorum* dry matter

Liming		O			Ca			
Combinations	Cuts	Fertilization		Means	Fertilization		Means	Means
		O	NPK		O	NPK		
Object control	I	4.13	5.36	4.75	5.43	8.45	6.94	5.84
	II	2.64	4.16	3.40	2.16	3.20	2.68	3.04
	III	4.03	4.43	4.23	2.16	2.20	2.18	3.21
	IV	2.13	1.47	1.80	3.47	2.55	3.01	2.41
	Sum	12.95	15.42	14.18	13.22	16.40	14.81	14.50
Sludge + ash 2:1 15 %	I	4.66	5.16	4.91	5.53	5.96	5.75	5.33
	II	5.75	7.26	6.51	4.60	3.96	4.28	5.39
	III	5.80	9.46	7.63	5.70	4.56	5.13	6.38
	IV	3.20	4.33	3.77	2.93	2.83	2.88	3.32
	Sum	19.41	26.21	22.82	18.76	17.31	18.00	20.42
Sludge + ash 2:1 30 %	I	4.76	6.33	5.55	8.36	7.66	8.01	6.78
	II	4.93	6.33	5.63	5.30	6.86	6.08	5.86
	III	8.06	8.02	8.04	9.46	8.06	8.76	8.40
	IV	5.03	7.40	6.22	9.70	4.63	7.17	6.69
	Sum	22.78	28.08	25.44	32.82	27.21	30.20	27.73

$LSD_{(0.05)}$ for:	cuts I	II	III	IV	sum
doses mixture of sewage sludge and ash	ns	1.55	2.87	2.88	1.65
liming	1.63	ns	ns	ns	ns
fertilization NPK	ns	1.04	ns	ns	ns
doses mixture of sewage sludge and ash x liming	ns	ns	ns	ns	2.33

the 4th cut of limed object with additional application of 30 % mixture of waste activated sludge and coal ash. The highest total grass yield as sum of four cuts was achieved from limed objects after application of 30 % mixture (32.82 g/pot d.m.), while the lowest – from not limed control object and without NPK (12.95 g/pot d.m.). The highest Italian ryegrass dry matter yields were achieved from the 1st and 3rd cuts, which can be elucidated by the rate of sewage sludge and hard coal ash mineralization rate [2, 3]. The lowest yields were recorded for the 4th cut of tested plant. Statistical analysis revealed significant influence of all studied experimental factors on plant yields in particular cuts. In the 1st cut, only liming considerably affected the yields. Sludge with hard coal ash mixture had significant effects on the yield of grass biomass in other three cuts and for sum yield of four cuts. Addition NPK fertilization significantly differentiated the biomass yield of grass only in the 2nd cut.

Also significiant influence was found for the interaction between the waste activated sludge and liming in the biomass for the yield of the sum of four cuts.

Nitrogen content in the biomass of Italian ryegrass (Table 3) was medium ranging from 16.8 g · kg^{-1} in the plant biomass harvested as biomass the 4th cut from not limed

Table 3

The content of nitrogen in *Lolium multiflorum* [g · kg^{-1}]

Liming		O			Ca			Means
Combinations	Cuts	Fertilization		Means	Fertilization		Means	
		O	NPK		O	NPK		
Object control	I	28.1	24.2	26.15	26.9	30.8	28.85	27.50
	II	31.0	36.9	33.95	27.8	30.1	28.90	31.43
	III	30.0	32.6	31.30	29.3	30.8	30.05	30.68
	IV	31.8	21.3	26.55	31.2	18.7	24.95	25.75
	Means	30.23	28.75	29.49	28.8	27.60	28.20	28.84
Sludge + ash 2:1 15 %	I	34.3	31.5	32.90	28.7	32.8	30.75	31.83
	II	32.2	32.5	32.35	29.4	29.9	29.65	30.00
	III	26.1	27.2	36.65	27.3	29.5	28.40	27.53
	IV	23.9	16.8	20.35	35.0	19.4	27.20	23.78
	Means	29.12	27.00	28.06	30.10	30.10	30.10	28.53
Sludge + ash 2:1 30 %	I	39.7	31.0	35.35	32.9	31.8	32.35	33.85
	II	30.7	39.2	34.95	39.1	28.7	33.90	34.43
	III	27.9	25.5	26.70	29.3	22.8	26.05	26.38
	IV	21.7	20.2	20.95	23.7	24.2	23.95	22.45
	Means	30.00	28.97	29.49	31.25	31.25	31.25	26.88

	cuts			
	I	II	III	IV
$LSD_{(0.05)}$ for:				
doses mixture of sewage sludge and ash	1.86	ns	2.09	ns
liming	ns	ns	ns	ns
fertilization NPK	1.25	ns	ns	3.40
doses mixture of sewage sludge and ash x liming	2.16	2.14	ns	ns
doses mixture of sewage sludge and ash x fertilization NPK	2.16	2.14	2.43	3.95
liming x fertilization NPK	1.76	ns	ns	ns

object with additional 15 % mixture and NPK, to 39.7 g · kg^{-1} in the 1st cut from not limed object with additional 30 % mixture application. The nitrogen content decreased in the biomass of grass harvested from objects fertilized with sludge with hard coal ash mixture in subsequent cuts (Table 3), which can indicate a fast rate of organic matter mineralization in applied sewage sludge with narrow C:N ratio. Statistical analysis revealed significant influence of sludge with coal ash mixture and NPK nutrition applied, while liming had not considerable impact on nitrogen concentration in the biomass of tested plants, which was consistent with observations made by Pronczuk [4], who found that the soil acidity had no influence on nitrogen accumulation in a fodder. Interaction between all investigated factors revealed significiant influence but in differentiated cuts for example between doses of mixture x liming for biomass harvested as 1st and 2nd cuts, for doses of mixture NPK in biomass of four cuts and for liming x NPK only in biomass harvested as 1st cut.

Hay containing 3 g of phosphorus · kg^{-1} d.m. is considered as balanced in reference to phosphorus content [5, 6]. Italian ryegrass grown in present experiment contained varied quantities of phosphorus, which is presented in Table 4. Many authors report that

Table 4

The content of phosphorus in *Lolium multiflorum* [g · kg^{-1}]

Liming		O			Ca			Means
Combinations	Cuts	Fertilization		Means	Fertilization		Means	
		O	NPK		O	NPK		
Object control	I	4.67	4.49	4.58	4.56	5.10	4.83	4.71
	II	4.41	4.81	4.61	5.14	4.10	4.62	4.62
	III	5.55	5.14	5.35	6.56	4.90	5.73	5.54
	IV	3.55	3.08	3.32	4.23	3.60	6.92	3.62
	Means	4.55	4.38	4.47	5.12	4.43	4.78	4.62
Sludge + ash 2:1 15 %	I	8.25	8.23	8.24	7.31	6.28	6.80	7.52
	II	6.24	5.74	5.99	5.49	4.62	5.06	5.52
	III	5.59	5.20	5.40	6.24	4.71	5.48	5.44
	IV	4.19	4.18	4.19	4.66	4.11	4.39	4.29
	Means	6.07	5.84	5.96	5.93	4.93	5.43	5.69
Sludge + ash 2:1 30 %	I	8.28	8.74	8.51	10.02	9.54	9.78	9.15
	II	8.03	6.01	7.02	7.35	6.68	7.02	7.02
	III	5.63	5.21	5.42	5.64	5.39	5.52	5.47
	IV	4.16	4.07	4.12	4.14	4.05	4.10	4.11
	Means	6.50	6.01	6.26	6.79	6.42	6.61	6.43

$LSD_{(0.05)}$ for:	cuts I	II	III	IV
doses mixture of sewage sludge and ash	1.30	0.515	0.288	0.328
liming	ns	ns	ns	0.221
fertilization NPK	ns	0.347	ns	0.221
doses mixture of sewage sludge and ash x liming	1.84	0.728	ns	ns
mixture of sewage sludge and ash x fertilization NPK	ns	ns	ns	ns
liming x fertilization NP.	ns	0.407	ns	ns

phosphorus level at Italian ryegrass oscillates from 2.1 to 5.0 g · kg^{-1}. Phosphorus content in plants from the control object was within that range, while in objects where sludge with hard coal ash mixture plus NPK nutrition was applied, it often exceeded the optimum values, which was confirmed by other studies [7].

Like for nitrogen, phosphorus concentration in cultivated plants on objects treated with sewage sludge with hard coal ash decreased in subsequent cuts, which was associated with sludge organic matter mineralization. Statistical analysis revealed significant influence of all experimental factors on phosphorus level at tested grass. In the 1st, 2nd, and 4th cuts, both 15 % and 30 % mixture considerably increased the phosphorus content as compared with the control. Mineral fertilization of the 2nd, 3rd, and 4th cuts significantly decreased phosphorus concentration in reference to objects that were not NPK fertilized. Liming had significant effect on discussed trait only in the 4th cut. Italian ryegrass from that cut was characterized by significantly higher phosphorus content on limed objects.

Concentration of potassium at tested plant oscillated within wide range (Table 5) and in all cases it exceeded the optimum amounts for that element in a fodder [8]. NPK

Table 5

The content of potassium in *Lolium multiflorum* [g · kg^{-1}]

Liming		O			Ca			Means
Combinations	Cuts	Fertilization		Means	Fertilization		Means	
		O	NPK		O	NPK		
Object control	I	42.3	42.9	42.60	41.7	45.6	43.65	43.13
	II	36.5	44.3	40.40	42.3	27.5	34.90	37.65
	III	38.7	37.8	38.25	31.8	27.5	29.65	33.95
	IV	26.8	26.5	26.65	35.2	24.0	29.60	28.13
	Means	36.08	37.88	36.98	37.75	31.15	34.45	35.72
Sludge + ash 2:1 15 %	I	40.1	43.4	41.75	38.7	43.0	40.85	41.30
	II	41.3	43.5	42.40	35.1	42.1	38.60	40.50
	III	30.4	45.3	37.85	31.9	35.7	33.80	35.83
	IV	26.8	24.9	25.85	26.5	26.7	26.60	26.23
	Means	34.65	39.28	36.96	33.05	36.88	34.96	35.97
Sludge + ash 2:1 30 %	I	33.7	47.3	40.50	38.8	46.3	42.55	41.53
	II	28.1	41.6	34.85	39.3	33.7	36.50	35.68
	III	25.6	31.9	28.75	33.4	36.3	34.85	31.80
	IV	21.8	30.9	26.35	39.3	23.5	31.50	28.89
	Means	27.30	37.93	32.61	37.7	34.95	36.33	34.47

$LSD_{(0.05)}$ for:	cuts I	II	III	IV
doses mixture of sewage sludge and ash	ns	4.02	3.40	ns
liming	ns	ns	ns	2.52
fertilization NPK	3.41	ns	2.29	2.52
doses mixture of sewage sludge and ash x liming	ns	ns	3.97	ns
doses mixture of sewage sludge and ash x fertilization	ns	4.71	3.97	ns
liming x fertilization NPK	ns	3.85	3.24	3.56

fertilization at the 1st, 3rd, and 4th cuts significantly affected the increase of potassium level in plants, which is fully plausible. Applying the mixture of sludge with ash at 30 % rate for the 2nd and 3rd cut grass considerably decreased the potassium level. Probably higher nitrogen dose introduced along with the sludge was the reason, which was also confirmed by other studies [9]. The liming effect was apparent in the 4th cut manifesting with the increase of potassium content at Italian ryegrass. Statistical analysis also revealed significant interactions of all studied factors with potassium amounts in the grass.

Calcium content at tested plants (Table 6) oscillated around values commonly considered as optimum (6.1 to 12.0 g · kg^{-1}): its highest levels were recorded in the 3rd cut grass. Sewage sludge with hard coal ash mixture significantly decreased the element concentration in all cuts as compared with the control, while liming had the opposite influence. Mineral nutrition in the 1st and 2nd cuts considerably decreased the calcium concentration at Italian ryegrass.

Table 6

The content of calcium in *Lolium multiflorum* [g · kg^{-1}]

Liming		O			Ca			Means
Combinations	Cuts	Fertilization		Means	Fertilization		Means	
		O	NPK		O	NPK		
Object control	I	8.11	7.67	7.89	8.28	8.69	8.69	8.19
	II	9.27	7.91	8.59	9.60	11.93	10.77	9.68
	III	12.46	10.41	11.44	12.94	12.30	12.62	12.03
	IV	7.86	6.88	7.37	9.86	9.41	9.62	8.50
	Means	9.43	8.22	8.82	10.17	10.58	10.38	9.60
Sludge + ash 2:1 15 %	I	7.29	7.29	7.29	8.64	7.12	7.88	7.59
	II	8.62	8.48	8.55	9.72	8.22	8.97	8.76
	III	10.16	9.77	9.97	11.92	9.60	10.76	10.37
	IV	6.80	6.76	6.78	7.31	7.92	7.62	7.20
	Means	8.22	8.08	8.15	9.40	8.22	8.81	8.48
Sludge + ash 2:1 30 %	I	7.06	5.92	6.49	8.02	6.40	7.21	6.85
	II	8.27	8.09	8.18	8.86	8.31	8.59	8.39
	III	9.99	10.64	10.32	10.17	10.38	10.28	10.30
	IV	6.60	6.50	6.55	5.72	6.65	6.19	6.37
	Means	7.98	7.79	7.89	8.19	7.94	8.07	7.98

	cuts			
	I	II	III	IV
$LSD_{(0.05)}$ for:				
doses mixture of sewage sludge and ash	0.799	0.587	0.840	0.661
liming	0.539	0.396	0.567	0.446
fertilization NPK	0.539	ns	0.567	ns
mixture of sewage sludge and ash x liming	ns	0.686	ns	0.773
doses mixture of sewage sludge and ash x fertilization NPK	ns	0.686	0.982	ns

The optimum magnesium content at tested grass is – according to Falkowski [8] – 2.5 g · kg^{-1}. Here examined Italian ryegrass contained from 1.96 g · kg^{-1} on control to 4.45 g · kg^{-1} of magnesium on object fertilized with the mixture of sewage sludge with hard coal ash at 30 % rate (Table 7). As similarly as for calcium, the highest magnesium content was recorded at plants from the 3rd cut. All examined factors significantly influenced on the element concentration, although sludge with ash mixtures, that significantly increased the magnesium content in all cuts of plants, had the strongest impact. That fact can be accounted for by high magnesium concentration in hard coal ash (8.82 g · kg^{-1}). Liming only in the 1st cut of Italian ryegrass increased magnesium level, while NPK nutrition applied for the 3rd cut significantly decreased the macronutrient content at tested plants.

Table 7

The content of magnesium in *Lolium multiflorum* [g · kg^{-1}]

Liming		O			Ca			Means
Combinations	Cuts	Fertilization		Means	Fertilization		Means	
		O	NPK		O	NPK		
Cbject control	I	2.32	2.40	2.36	2.35	2.74	2.55	2.46
	II	3.60	3.51	3.56	3.35	3.52	3.44	3.50
	III	3.71	3.50	3.61	3.90	3.39	3.65	3.63
	IV	2.21	1.96	2.09	2.35	2.35	2.35	2.22
	Means	2.96	2.84	2.91	2.99	3.00	3.00	2.95
Sludge + ash 2:1 15 %	I	2.50	2.83	2.67	3.43	2.93	3.18	2.93
	II	4.09	4.04	4.07	3.96	3.42	3.69	2.88
	III	4.27	3.84	4.06	4.35	3.85	4.10	4.08
	IV	3.16	2.86	3.01	3.01	2.97	2.99	3.00
	Means	3.51	3.39	3.45	3.69	3.29	3.49	3.47
Sludge + ash 2:1 30 %	I	3.51	2.78	3.15	3.80	3.12	3.46	3.31
	II	4.07	3.82	3.95	4.45	4.17	4.31	4.13
	III	4.23	4.15	4.19	4.31	4.15	4.23	4.21
	IV	2.99	2.77	2.88	2.52	2.88	2.70	2.79
	Means	3.70	3.38	3.54	3.77	3.58	3.68	3.61

	cuts			
	I	II	III	IV
$LSD_{(0.05)}$ for:				
doses mixture of sewage sludge and ash	0.473	0.282	0.322	0.224
liming	0.319	ns	ns	ns
fertilization NPK	ns	ns	0.217	ns
doses mixture of sewage sludge and ash x liming	ns	0.329	ns	ns
liming x fertilization NPK	ns	ns	ns	0.214

The values of the correlation coefficient between the uptake of nitrogen, phosphorus, potassium and calcium by the biomass of Italian ryegrass and the of those macroelements introduced into the soil with materials used for fertilization (waste activated sludges and the ash of hard coal) were significient and reach the following values respectivally: r = + 0.589*, r = + 0.659*, r = + 0.445* and r = + 0.449*.

Conclusions

1. Significant influence of the application of sewage sludge with hard coal ash mixture on the yield biomass of ryegrass harvested in the 2nd, 3rd, 4th cuts and the sum of all was found.

2. Liming significiantly increased the biomass yield of ryegrass expressed as the sum of four cuts harvested as during experiment.

3. The application of sewage sludge with hard coal ash mixture considerably increased phosphorus and magnesium contents at tested plants, while the mixture at 30 % rate significantly decreased calcium and potassium levels.

4. The biomass of Italian ryegrass contained significantly higher content calcium and phosphorus harvested from limed object than without application of lime.

References

[1] Antonkiewicz J.: Ecol. Chem. Eng. 2006, **13**(9), 865–874.
[2] Meller E.: Fol. Univ. Agric. Stetin. Agricultura 1999, **78**, 203–214.
[3] Strączyńska S.: Fol. Univ. Agric. Stetin. Agricultura 1998, **72**, 289–293.
[4] Prończuk J.: Zesz. Probl. Post. Nauk Roln. 1983, **276**, 29–35.
[5] Moraczewski R.: Łąki i pastwiska w gospodarstwie rolnym. SGGW, Warszawa 1996, 220 pp.
[6] Niczyporuk A. and Jankowska-Huflejt H.: Zesz. Probl. Post. Nauk Roln. 2001, **479**, 217–221.
[7] Kozłowski S., Goliński P., Zielewicz W. and Biniak J.: Zesz. Probl. Post. Nauk Roln. 2001, **479**, 163–171.
[8] Falkowski M., Kozłowski S. and Kukułka I.: Właściwości chemiczne roślin łąkowych. Wyd. AR Poznań, Poznań 1990, 110 pp.
[9] Kochanowska R. and Nowak W.: Roczn. Glebozn. 1992, **XLIII**(1/2), 99–111.

PLONOWANIE ORAZ ZAWARTOŚĆ MAKROELEMENTÓW W ŻYCICY WIELOKWIATOWEJ NA TLE NAWOŻENIA ORGANICZNEGO I WAPNOWANIA

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Abstrakt: W doświadczeniu wazonowym badano wpływ mieszaniny osadów ściekowych z popiołem węgla kamiennego w warunkach dodatkowego nawożenia mineralnego i wapnowania na plon i zawartość makroelementów w życicy wielokwiatowej. Badane osady pochodziły z oczyszczalni ścieków w Siedlcach (ścieki przemysłowe i komunalne), które w końcowym procesie obróbki poddano fermentacji metanowej. Rośliną testową był rajgras włoski, w którym oznaczono plon suchej masy oraz zawartość makroelementów w biomasie życicy wielokwiatowej. Stosowanie mieszaniny znacznie zwiększyło plon rośliny testowej oraz zawartość w jej biomasie magnezu i fosforu, a obniżyło zawartość wapnia i potasu. Natomiast wapnowanie znacznie zwiększyło zawartość wapnia i fosforu w biomasie życicy wielokwiatowej.

Słowa kluczowe: rajgras włoski, plon, makroelementy, osady, popiół z węgla kamiennego, mieszanina, wapnowanie