DOI: 10.2428/ecea.2012.19(08)085 ECOL CHEM ENG A. 2012;19(8):873-886

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EFFECT OF LIMING AND APPLICATION OF SLUDGE ON THE CONTENT OF NITROGEN AND CARBON IN TEST PLANTS AND IN SOIL IN A FOUR-YEAR POT EXPERIMENT

WPŁYW WAPNOWANIA I OSADU ŚCIEKOWEGO NA ZAWARTOŚĆ AZOTU I WĘGLA W ROŚLINACH TESTOWYCH I W GLEBIE, W CZTEROLETNIM DOŚWIADCZENIU WAZONOWYM

Abstract: The aim of the study was to determine the effect of liming and applying varied doses of sludge (10, 20 and 40 % of fresh mass relative to the weight of soil in a pot) on the content of nitrogen and carbon in plants and in soil, in a four-year pot experiment. Italian ryegrass (*Lolium multiflorum*) was used as the test plant in the first year, maize and silage sunflower in the second and third years and Italian ryegrass again in the fourth year. The total nitrogen and carbon content was determined in soil samples, taken after each harvest, by the elemental analysis method using a CHN autoanalyser. The nitrogen and carbon content in the test plants cultivated on the soil in limed pots was found to be lower than, or comparable with, those cultivated without liming. The highest content of nitrogen was found in Italian ryegrass cultivated in the first year of the experiment, fertilised with sludge, while the highest content of carbon was in maize cultivated in the second and third year. The highest content of carbon was found in unlimed soil in the second year (more so after the sunflower harvest than after maize harvest) and the highest nitrogen content was found in limed soil in the first year of the experiment. The experiment found a positive effect of consequent action of sludge on the content of carbon and nitrogen in the soil of fertilised pots.

Keywords: nitrogen, carbon, test plants, soil, sludge, liming

Nitrogen is one of the fundamental elements, essential for the proper growth and development of plants. It also affects soil fertility and plant yield [1–5]. The taking up and use of the macroelement by plants, introduced to the soil with sludge or in the form of other organic materials, depends mainly on the soil property, agritechnical and humidity conditions and on the plant species. Evaluation of the sludge utility for

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fertilisation is supplemented by determination of its effect on soil [7]. A number of papers have shown the effect of fertilisation on quantitative and qualitative transformations of organic matter in soil [8–11]. The humus-forming value of organic matter depends on the carbon content in it which, in turn, determines the susceptibility of organic compounds to mineralisation and transformation into humic compounds [12]. Czekala [13], Kalembasa et al [14] have shown that sludge introduces large amounts of organic carbon to soil, while the organic compounds contained in it are not readily soluble.

The aim of the study was to determine the effect of liming and applying varied doses of sludge on the content of nitrogen and carbon in test plants and in soil, in a four-year pot experiment.

Material and methods

A pot experiment was conducted during four vegetation seasons in the years 2001–2004 in a greenhouse. This random experiment was conducted in triplicate. Each pot was filled with 10 kg of soil taken from the humus horizon, with the granulometric composition of light loamy sand (acc. to PTG), with $pH_{KCl} = 4.19$, total nitrogen content 0.980 $g \cdot kg^{-1}$, total organic carbon 11.3 $g \cdot kg^{-1}$, available phosphorus and potassium: 1.00 and 1.15 $mg \cdot kg^{-1}$.

Before filling the pots, the soil was sifted through a 1 cm mesh sieve and divided into two parts. One was limed with $CaCO_3$ according to Hh = 1 and left for a month while humidity was maintained at 50–60 % of the maximum water capacity. Thus prepared, the soil was poured into the pots, which resulted in obtaining two series: I – no liming (unlimed soil), II – with liming (limed soil). Subsequently, fresh sludge was introduced to the pots, from communal sewage from the wastewater treatment plant in Siedlce, after methane fermentation, in the amount of 10, 20 and 30 % relative to the soil weight, and mixed thoroughly. The deposit contained 41.5 $g \cdot kg^{-1}$ of nitrogen, 351 $g \cdot kg^{-1}$ of carbon in dry matter; dry matter accounted for 24.5 % of the whole. The chemical composition of the sludge suggested its utility in plant fertilisation [15].

Sludge was applied on a one-off basis 10 days before seeding of Italian ryegrass (in the first year of the experiment). The following were introduced in a sludge dose of 10 % (g per pot): C – 85.9, N – 10.2. The soil humidity in the pots was maintained at 50–60 % of the maximum water capacity.

The following were used as test plants: in the first year – Italian ryegrass (*Lolium multiflorum* Lam.), cultivar Kroto, harvested in four re-growths (cuts), at 30-day intervals; in the second and third years – maize, cultivar Nimba, which was harvested after 75 days of vegetation, and silage sunflower, sown after maize was harvested (into the same pots) and harvested after 70 days of vegetation. In the fourth year, Italian ryegrass was used, harvested as in the first year. One g of grass or 5 seeds of maize or sunflower were sown into each pot; after germination, three plants (maize or sunflower) were left in each pot.

The total nitrogen and carbon content was determined in plant and soil samples taken after each harvest, by the elemental analysis method, using a CHN autoanalyser, manufactured by Perkin Elmer.

The results were worked out statistically; the significance of the differences between average values was evaluated with an analysis of variance (the calculations were made with FR Analvar 3.2 software); when the differences were significant, the $LSD_{0.05}$ values were calculated according to Tukey's test.

Results and discussion

The factors analysed in the four-year pot experiment (liming, fertilisation with sludge) differentiated the content of carbon and nitrogen in test plants (Italian ryegrass in the first and fourth years, maize and sunflower in the second and third year) (Table 1–3).

Carbon content in the plants biomass varied depending on the plant species; throughout the experiment, ranging from 343 $g \cdot kg^{-1}$ (in the first re-growth of Italian ryegrass in the fourth year) to 442 $g \cdot kg^{-1}$ (in maize, in the second year). More carbon was found in Italian ryegrass in the first year (average 413 $g \cdot kg^{-1}$) than in the fourth year (average 390 $g \cdot kg^{-1}$) of the experiment; more in maize biomass (average of two years 430 $g \cdot kg^{-1}$) than in sunflower (average of two years 401 $g \cdot kg^{-1}$).

The average carbon content in biomass of the analysed plants during the four year slightly varied between the pots with unlimed soil (410 $gC \cdot kg^{-1}$; the lowest content – in the pots fertilised with the smallest dose of sludge 399 $g \cdot kg^{-1}$) and where lime was added (408 $gC \cdot kg^{-1}$). Significantly more carbon was found in the pots where 20 % and 30 % of sludge was added (average 416 $g \cdot kg^{-1}$) than in ones where 10 % of sludge was added (399 $g \cdot kg^{-1}$).

Of the plants cultivated in the experiment, the highest content of carbon was found in the biomass of maize (average 435 $g \cdot kg^{-1}$ on unlimed soil and 437 $g \cdot kg^{-1}$ on limed soil in the 2^{nd} year of the experiment; in the 3^{rd} year – 427 and 421 $g \cdot kg^{-1}$, respectively), followed by the biomass of sunflower in the 3^{rd} year (407 and 400 $g \cdot kg^{-1}$, respectively), Italian ryegrass in the 1st year (413 and 414 $g \cdot kg^{-1}$, respectively), sunflower in the 2^{nd} year (397 and 399 $g \cdot kg^{-1}$, respectively), and the lowest content was in Italian ryegrass in the 4^{th} year (401 and 388 $g \cdot kg^{-1}$, respectively). A similar content of nitrogen and carbon in grass fertilised with sludge has been reported by Siuta [16].

Chemical analysis revealed that the nitrogen content was higher in the biomass of Italian ryegrass (especially in the 1st year of the experiment – average of 40.8 $g \cdot kg^{-1}$ in unlimed pots and 39.6 $g \cdot kg^{-1}$ in limed ones; in the 4^{th} year: 19.0 and 17.0 $g \cdot kg^{-1}$, respectively) than in sunflower biomass (average in the 2^{nd} year: 14.6 and 13.7 $g \cdot kg^{-1}$, respectively, and in the 3^{rd} year: 12.1 and 11.9 $g \cdot kg^{-1}$, respectively) and maize (average in the 2^{nd} year: 10.2 and 9.49, and in the 3^{rd} year 6.44 and 6.28 $g \cdot kg^{-1}$, respectively). Mazur et al [2005] report a similar content of nitrogen in meadow sward, ranging from 14.0 to 30.0 $gN \cdot kg^{-1}$ of dry matter. This is mainly a consequence of the genetic properties of the test plants and their yield [17].

Liming significantly affected nitrogen content in test plants in the 1^{st}, 2^{nd} and 3^{rd} year of the experiment (for maize). Fertilisation with sludge significantly affected nitrogen content in the plants, significantly more so in the unlimed pots. The content of the element increased with an increasing dose of sludge as compared with the control in all the years of the experiment. Many authors have confirmed the beneficial effect of sludge on yielding and nitrogen content in crops [18, 19].

Table 1

The content of carbon and nitrogen [$g \cdot kg^{-1}$] in Italian ryegrass in first year in the pot experiment

Fertilization	C	N	C : N	C	N	C : N	C	N	C : N	C	N	C : N	Mean	
	I cut			II cut			III cut			IV cut			C	N
Soil no liming														
Control object	401	19.0	21.1	419	21.7	19.3	410	26.1	15.7	411	38.9	10.6	410	26.4
10 %	409	52.9	7.74	413	45.1	9.17	407	45.9	8.86	413	48.1	8.58	411	48.0
20 %	415	54.1	7.67	417	42.7	9.76	420	46.8	8.98	419	47.7	8.79	418	47.8
30 %	413	51.3	8.05	409	34.9	11.7	416	40.3	10.3	417	45.9	9.09	414	43.1
Mean	410	44.3	11.4	415	36.1	12.5	413	39.8	11.0	415	45.2	9.27	413	40.8
Soil liming														
Control object	408	20.8	19.6	414	21.1	19.6	421	21.8	19.3	419	29.8	14.1	416	23.3
10 %	412	52.0	7.92	414	47.3	8.75	416	40.7	10.2	422	35.4	11.9	416	43.9
20 %	416	53.4	7.79	410	46.8	8.75	416	37.2	11.2	420	44.8	9.37	415	45.6
30 %	401	50.0	8.02	409	43.7	9.35	411	43.4	9.47	414	45.4	9.09	409	45.6
Mean	409	44.1	10.8	412	39.7	11.6	416	35.8	12.5	419	38.9	11.1	414	39.6

	C	N
	First year of experiment	
$LSD_{0.05}$ for: A – for liming, B – for fertilization, C – for cuts B/A; A/B; C/A; A/C; C/B; B/C – interaction	A = 0.197 B = 0.368 C = 0.368 B/A = 0.521 A/B = 0.395 C/A = 0.521 A/C = 0.395 C/B = 0.737 B/C = 0.737	A = 0.192 B = 0.359 C = 0.359 B/A = 0.508 A/B = 0.384 C/A = 0.508 A/C = 0.384 C/B = 0.718 B/C = 0.718

10 %, 20 %, 30 % – of waste activated sludge to the mass of soil.

Table 2

The content of carbon and nitrogen [$g \cdot kg^{-1}$] in maize and sunflower, in second and third year in the pot experiment

Fertilization	C	N	C : N	C	N	C : N	C	N	C : N	C	N	C : N
	second year of experiment						third year of experiment					
	maize			sunflower			maize			sunflower		
Soil no liming												
Control object	426	6.10	69.9	403	11.4	35.4	427	5.67	75.4	399	10.4	38.4
10 %	434	10.1	43.0	396	11.6	34.1	420	5.95	70.6	405	10.8	37.5
20 %	439	9.75	45.0	390	13.1	29.8	435	7.10	59.9	415	11.4	36.4
30 %	440	15.0	29.4	398	22.3	17.8	426	7.05	60.5	409	15.9	25.7
Mean	435	10.2	46.8	397	14.6	29.3	427	6.44	66.5	407	12.1	34.5
Soil liming												
Control object	440	6.30	69.9	396	12.4	32.0	417	5.65	73.8	399	11.1	35.9
10 %	442	7.80	56.7	393	10.2	38.6	422	6.60	64.0	411	10.8	38.1
20 %	428	9.95	43.1	405	12.9	31.4	415	6.10	68.1	391	11.2	34.9
30 %	439	13.9	31.6	403	19.1	21.1	429	6.75	63.6	398	14.3	27.9
Mean	437	9.49	50.3	399	13.7	30.8	421	6.28	67.4	400	11.9	34.2

$LSD_{0.05}$ for:	maize		sunflower	
	C	N	C	N
Second year of experiment				
A – for liming, B – for fertilization, B/A; A/B – interaction	A = n.s. B = 5.06 B/A = 7.16 A/B = 5.16	A = 0.622 B = 1.22 B/A = 1.73 A/B = 1.24	A = n.s. B = n.s. B/A = n.s. A/B = n.s.	A = 0.436 B = 0.857 B/A = 1.21 A/B = 0.872
Third year of experiment				
	A = 2.16 B = 4.24 B/A = 5.99 A/B = 4.31	A = 0.146 B = 0.287 B/A = 0.406 A/B = 0.292	A = 2.67 B = 5.25 B/A = 7.43 A/B = 5.35	A = n.s. B = 0.879 B/A = 1.24 A/B = 0.895

n.s.– non significant difference.

Table 3

The content of carbon and nitrogen [$g \cdot kg^{-1}$] in Italian ryegrass in fourth year in the pot experiment

Fertilization	C	N	C : N	C	N	C : N	C	N	C : N	C	N	C : N	Mean	
	I cut			II cut			III cut			IV cut			C	N
Soil no liming														
Control object	403	13.3	30.3	410	17.6	23.3	374	17.4	21.5	392	17.3	22.7	395	16.4
10 %	416	14.7	28.3	400	18.1	22.1	360	15.7	22.9	391	16.2	24.2	392	16.2
20 %	419	21.6	19.4	403	20.6	19.6	410	20.1	20.4	391	17.2	22.9	406	19.9
30 %	431	27.2	15.9	407	23.1	17.6	399	23.1	17.3	411	20.2	20.3	412	23.4
Mean	417	19.2	23.5	405	19.9	20.7	386	19.1	20.5	396	17.7	22.5	401	19.0
Soil liming														
Control object	408	13.1	31.2	384	15.5	24.8	395	18.2	21.7	398	15.4	25.8	396	15.6
10 %	353	13.1	27.0	398	16.8	23.2	390	19.1	20.4	376	17.5	21.5	377	16.6
20 %	343	16.0	21.4	399	17.8	22.4	385	19.5	19.7	400	18.2	22.0	382	17.9
30 %	395	17.5	22.6	402	15.9	25.3	392	19.8	19.8	394	18.5	21.3	396	17.9
Mean	375	14.9	25.6	394	16.5	23.9	391	19.2	20.4	392	17.4	22.7	388	17.0

$LSD_{0.05}$ for: A – for liming, B – for fertilization, C – for cuts B/A; A/B; C/A; A/C; C/B; B/C – interaction	C	N
	Fourth year of experiment	
	A = n.s. B = 30.9 C = n.s. B/A = n.s. A/B = n.s. C/A = 43.7 A/C = 33.1 C/B = n.s. B/C = n.s.	A = n.s. B = 0.407 C = 0.217 B/A = 0.576 A/B = 0.433 C/A = n.s. A/C = 33.1 C/B = 0.433 B/C = 0.576

n.s.– non significant difference.

The C : N ratio in the test plants was affected by varied content of nitrogen (Table 1–3). The ratio was the broadest in maize in unlimed pots – 29.4–75.4 : 1; on limed pots – 31.6–73.8 : 1; in sunflower it was equal to 17.8–38.4 : 1 and 21.1–38.6, respectively; in Italian ryegrass, the average of regrowths in the 1st year was 8.56–15.5 and 8.97–17.9, respectively, and in the 4th year it was 17.6–24.1 and 21.1–25.4, respectively. The C : N ratio was narrower in pots fertilised with 30 % of sludge and broader in control pots.

When evaluating the fertilising value of sludge, an important feature is the ability to provide plants with nutrients, which is shown in the element content in the test plant biomass. Based on this assumption, Fig. 1 shows the changes in nitrogen and carbon content for the test plant species. The values refer to Italian ryegrass in the 4th year as compared with the 1st year of the experiment and for maize and sunflower in the 3rd year as compared with the 2nd year. The largest decrease in nitrogen content was observed in biomass of Italian ryegrass (over 50 %), followed by maize (about 35 %) and the smallest decrease was in sunflower (about 15 %). Liming also increased the nitrogen content decrease rate. The carbon content in test plants was also decreased by soil liming as compared with soil without liming. The largest decrease in carbon content was observed in Italian ryegrass – about 4 % on average, followed by maize (3 %) and the carbon content in sunflower increased by about 2 % compared with the 2nd of the experiment.

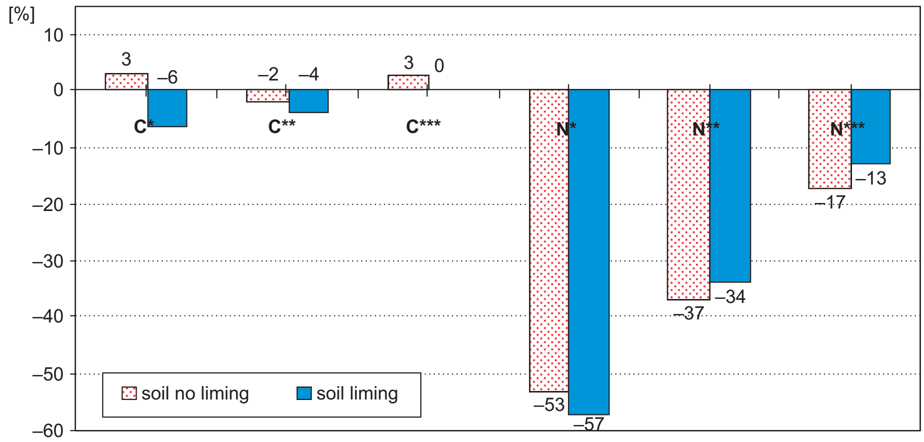

Fig. 1. Changes [%] total nitrogen and carbon in the biomass of the test plants: C* – changes the contents of C in Italian ryegrass, in the fourth year, compared with the year of the study; C** – changes the content of C in maize, in the third year, compared with the second year of the study; C*** – changes to the content of C in the sunflower, in the third year, compared with the second year of the study; N* – changes the content of N in Italian ryegrass, in the fourth year, compared with the year of the study; N** – changes the content of N in maize, in the third year, compared with the second year of the study; N*** – changes the content of N in the sunflower, in the third year, compared with the second year of the study.

The carbon content in the soil after the four-year experiment ranged from 6.40 $g \cdot kg^{-1}$ (after sunflower harvest, in the 2nd year) to 25.8 $g \cdot kg^{-1}$ (after harvesting the first regrowth of Italian ryegrass, in the 4th year) (Table 4–6). Liming significantly differentiated carbon content in the soil after the test plants were harvested, except in

Table 4

The content of carbon and nitrogen [g · kg $^{-1}$] in soil in first year in the pot experiment

Fertilization	C	N	C : N	C	N	C : N	C	N	C : N	C	N	C : N	Mean	
	I cut			II cut			III cut			IV cut			C	N
Soil no limi ng														
Control object	11.2	0.985	11.4	11.1	0.988	11.2	11.2	1.12	9.96	11.9	1.19	9.99	11.4	1.07
10 %	11.9	1.90	6.27	11.9	2.54	4.69	12.8	2.15	5.96	12.6	2.36	5.33	12.3	2.24
20 %	13.6	2.90	4.68	12.5	2.89	4.32	13.8	2.78	4.97	15.3	2.99	5.10	13.8	2.89
30 %	14.9	2.15	6.95	14.9	3.15	4.74	14.1	3.02	4.66	14.1	3.59	3.92	14.5	2.98
Mean	12.9	1.98	7.33	12.6	2.39	6.24	13.0	2.27	6.39	13.5	2.53	6.09	13.0	2.10
Soil liming														
Control object	11.3	1.02	11.1	11.2	1.03	10.9	12.6	2.03	6.20	12.6	1.23	10.2	11.9	1.33
10 %	12.0	2.75	4.37	12.2	2.58	4.71	14.1	3.02	5.06	13.5	2.15	6.27	13.0	2.63
20 %	13.5	2.98	4.67	12.9	2.98	4.45	15.0	3.14	4.77	13.4	3.48	4.52	13.7	3.15
30 %	14.1	2.20	6.39	15.0	3.36	4.44	14.1	3.14	4.48	14.1	3.14	4.48	14.3	2.96
Mean	12.7	2.24	6.63	12.8	2.49	6.13	13.6	2.34	5.13	13.4	2.50	6.37	13.1	2.39

	C	N
	First year of experiment	
$LSD_{0.05}$ for: A – for liming, B – for fertilization, C – for cuts B/A; A/B; C/A; A/C; C/B; B/C – interaction	A = n.s.; B = 0.571; C = 0.571; B/A = n.s; A/B = n.s.; C/A = n.s.; A/C = n.s.; C/B = 1.14; B/C = 1.14	A = 0.030; B = 0.056; C = 0.056; B/A = 0.079; A/B = 0.059; C/A = 0.079; A/C = 0.059; C/B = 0.112; B/C = 0.112

n.s.– non significant difference.

Table 5

The content of carbon and nitrogen [g · kg $^{-1}$] in soil, in second year in the pot experiment

Fertilization	C	N	C : N	C	N	C : N	C	N	C : N	C	N	C : N
	Second year of experiment						Third year of experiment					
	maize			sunflower			maize			sunflower		
Soil no liming												
Control object	15.5	1.80	8.61	6.50	0.701	9.27	8.30	0.900	9.22	7.50	0.710	10.6
10 %	17.8	1.90	9.37	23.0	2.70	8.52	12.8	1.30	9.85	16.4	1.50	10.9
20 %	17.9	2.00	8.95	23.9	2.80	8.54	14.4	1.60	9.00	13.2	1.70	7.76
30 %	15.4	1.80	8.56	19.7	2.00	9.85	18.6	2.10	8.86	18.4	1.90	9.68
Mean	16.7	1.88	8.87	18.3	2.05	9.05	13.5	1.48	9.23	13.9	1.45	9.74
Soil liming												
Control object	9.30	1.10	8.45	6.40	0.80	8.00	9.80	1.00	9.80	7.60	0.700	10.7
10 %	19.4	2.30	8.43	17.8	1.90	9.37	10.4	1.20	8.67	17.2	1.40	12.3
20 %	16.4	3.20	5.13	13.3	1.60	8.31	20.6	2.20	9.36	15.8	1.80	8.77
30 %	11.3	3.10	3.65	19.5	2.10	9.29	19.4	2.10	9.24	18.1	1.81	10.1
Mean	14.1	2.43	6.42	14.3	1.60	8.74	15.1	1.63	9.27	14.7	1.43	10.5

LSD$_{0.05}$ for: A – for liming, B – for fertilization, B/A; A/B– interaction	maize C	maize N	sunflower C	sunflower N
Second year of experiment	A = 0.360; B = 0.707; A/B = 0.720; B/A = 1.00	A = 0.270; B = 0.531; A/B = 0.541; B/A = 0.751	A = 0.697; B = 1.37; A/B = 1.39; B/A = 1.94	A = 0.150; B = 0.300; A/B = 0.305; B/A = 0.424
Third year of experiment	A = 0.294 B = 0.577 A/B = 0.588 B/A = 0.816	A = n.s. B = 0.380 A/B = n.s. B/A = n.s.	A = 0.496 B = 0.976 A/B = 0.992 B/A = 1.38	A = n.s. B = 0.453 A/B = n.s. B/A = n.s.

n.s. – non significant difference.

Table 6

The content of carbon and nitrogen [g · kg^{-1}] in soil, in fourth year in the pot experiment

Fertilization	C	N	C : N	C	N	C : N	C	N	C : N	C	N	C : N	Mean	
	I cut			II cut			III cut			IV cut			C	N
Soil no liming														
Control object	10.5	1.00	10.5	9.70	1.00	9.70	11.0	1.10	10.0	15.0	1.50	10.0	11.6	1.20
10 %	20.6	2.20	9.36	12.1	1.30	9.31	9.70	1.10	8.82	17.1	1.70	10.1	14.9	1.58
20 %	19.9	2.10	9.48	19.1	2.10	9.10	13.7	1.70	8.06	17.2	1.71	10.1	17.5	1.90
30 %	21.4	2.10	10.2	18.7	2.30	8.13	16.8	1.90	8.84	18.2	1.80	10.1	18.8	2.03
Mean	18.1	1.85	9.89	14.9	1.68	9.06	12.8	1.45	8.93	16.9	1.68	10.1	15.7	1.68
Soil liming														
Control object	11.8	1.10	10.7	11.1	1.00	11.1	8.40	1.00	8.40	15.8	1.50	10.5	11.8	1.20
10 %	25.8	2.70	9.56	13.0	1.30	10.0	10.6	1.20	8.83	17.4	1.80	9.67	16.7	1.75
20 %	15.7	1.80	8.72	18.3	1.00	18.3	16.3	1.80	9.06	17.9	1.10	16.3	17.;1	1.43
30 %	20.8	2.30	9.04	22.6	2.40	9.42	15.9	1.80	8.83	18.3	1.30	14.1	19.4	1.95
Mean	11.8	1.15	9.51	16.7	1.75	12.2	17.1	1.43	8.87	19.4	1.95	12.6	16.3	1.57

	C	N
	fourth year of experiment	
$LSD_{0.05}$ for: A – for liming, B – for fertilization, C – for cuts, B/A; A/B; C/A; A/C; C/B; B/C – interaction	A = 0.239 B = 0.450 C = 0.450 B/A = 0.636 A/B = 0.478 C/A = 0.636 A/C = 0.478 C/B = 0.900 B/C = 0.900	A = 0.088 B = 0.166 C = 0.166; B/A = 0.234 A/B = 0.176 C/A = 0.234 A/C = 0.176 C/B = 0.331 B/C = 0.331

the first year of the experiment. The carbon content in unlimed (13.0 g · kg^{-1}) and limed soil (13.1 g · kg^{-1}) in the 1st year of the experiment was comparable, although in the second year there was more in limed than in unlimed soil and more after sunflower harvest than after maize harvest. Significantly more carbon was found in limed soil in the 3rd and 4th year of the experiment compared with unlimed soil, after maize harvest (15.1 and 13.5 g · kg^{-1}), respectively; after sunflower harvest (14.7 and 13.9 g · kg^{-1}) respectively, and after Italian ryegrass harvest (16.3 and 15.7 g · kg^{-1}), respectively.

Fertilisation with sludge significantly differentiated the carbon and nitrogen content in soil after the test plants were harvested. Carbon and nitrogen content in limed and unlimed soil was found to increase with an increasing dose of sludge, especially in the 1st, 3rd and 4th year of the experiment. More carbon and nitrogen was found in unlimed soil, fertilised with 10 and 20 % of sludge after maize and sunflower harvest than in soil fertilised with 30 % of sludge. The largest amount of nitrogen (nearly three times more than in the control) was found in soil after harvesting Italian ryegrass in the 1st year of the experiment, following the largest application of sludge. This is a consequence of the large amount of the element introduced with sludge.

Figure 2 shows the percentage changes of nitrogen and carbon content in limed and unlimed soil in the 1st, 2nd and 3rd year of the experiment. Carbon content in the 2nd year of the experiment increased as compared with the 1st year: in limed soil it increased by about 35 % and in unlimed soil by 8 %. The values in the 3rd year changed: in unlimed soil it decreased by over 20 %, while in limed soil it increased by 5 %. The carbon content in the 4th year of study increased by 15 and 9 %, respectively, as

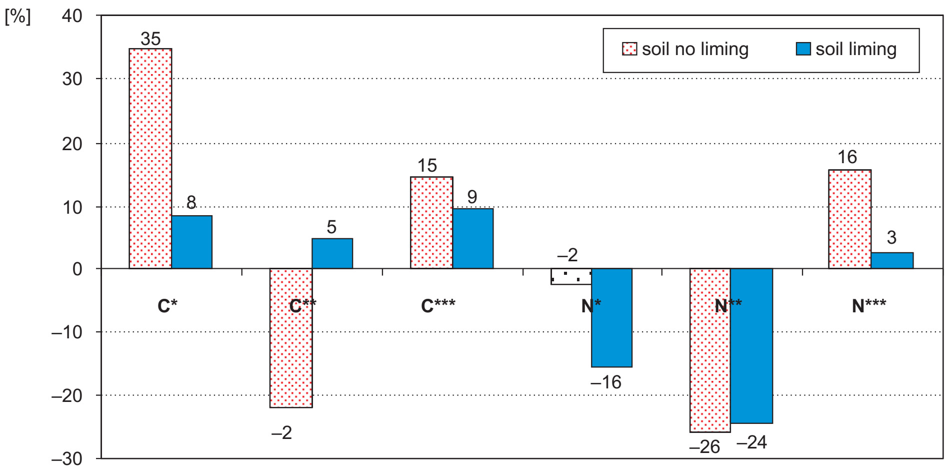

Fig. 2. Changes [%] total nitrogen and carbon in the soil, in the following years experience: C* – changes the contents of C in soil, in the second year compared with the first year of the experiment; C** – changes the contents of C in soil, in the third year compared with the second year of the experiment; C*** – changes the contents of C in soil, in the fourth year compared with the third year of the experiment; N* – changes the contents of N in soil, in the second year compared with the first year of the experiment; N** – changes the contents of N in soil, in the third year compared with the second year of the experiment; N*** – changes the contents of N in soil, in the fourth year compared with the third year of the experiment.

compared with the previous year. The total nitrogen content decreased in the 2nd and 3rd years of the experiment; in the 4th year it increased and there was more in unlimed soil (16 %) than in limed soil (3 %).

Studies conducted by many authors [20–26] have confirmed the significant role played by sludge in restoring carbon resources in agricultural land. Baran et al [22] observed a more beneficial effect of sludge than that of manure on carbon content. Kalembasa et al [14], Kalembasa and Wysokinski [2] reported on the high fertilising value of sludge, which is higher than that of manure in terms of the crop yield.

Conclusions

1. A varied content of carbon and nitrogen was found in test plants in a four-year pot experiment. The highest content of nitrogen was found in Italian ryegrass cultivated in the first year of the experiment, fertilised with sludge, while the highest content of carbon was in maize cultivated in the second and third year.

2. The nitrogen and carbon content in the test plants cultivated on the soil in limed pots was found to be lower than, or comparable with, those cultivated without liming.

3. The broadest C : N ratio was found in maize, followed by silage sunflower and Italian ryegrass.

4. The experiment found a positive effect of the consequent action of sludge on the content of carbon and nitrogen in the soil of fertilised pots. The highest content of carbon was found in unlimed soil in the second year, more so after sunflower harvest than after maize harvest, while the highest nitrogen content was found in limed soil in the first year of the experiment.

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WPŁYW WAPNOWANIA I OSADU ŚCIEKOWEGO NA ZAWARTOŚĆ AZOTU I WĘGLA W ROŚLINACH TESTOWYCH I W GLEBIE, W CZTEROLETNIM DOŚWIADCZENIU WAZONOWYM

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Abstrakt: Celem pracy było zbadanie wpływu wapnowania i zróżnicowanych dawek osadu ściekowego (10, 20 i 30 % św. m. w stosunku do masy gleby w wazonie) na zawartość azotu i węgla w roślinach i glebie, w czteroletnim doświadczeniu wazonowym. Rośliną testową w I roku doświadczenia była życica wielokwiatowa, w II i III roku kukurydza i słonecznik pastewny, w IV roku ponownie życica wielokwiatowa. W próbkach roślinnych i glebowych, pobieranych po każdym zbiorze roślin, badano ogólną zawartość azotu i węgla metodą analizy elementarnej, na autoanalizatorze CHN. W roślinach testowych uprawianych na glebie obiektów wapnowanych stwierdzono mniejszą bądź porównywalną zawartość azotu i węgla niż w roślinach uprawianych bez wapnowania. Najwięcej azotu zanotowano w życicy wielokwiatowej uprawianej w I roku doświadczenia, nawożonej osadem ściekowym, najwięcej węgla w kukurydzy uprawianej w II i III roku. Największą zawartość węgla stwierdzono w glebie bez wapnowania, w II roku, więcej po zbiorze słonecznika niż kukurydzy, największą zawartość azotu w glebie wapnowanej, w I roku eksperymentu. Przeprowadzone badania wykazały korzystny wpływ następczego działania osadu ściekowego na zawartość węgla i azotu w glebie obiektów nawozowych.

Słowa kluczowe: azot, węgiel, rośliny testowe, gleba, osad ściekowy, wapnowanie