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EFFECT OF LONG-TERM SEWAGE SLUDGE APPLICATION ON SOIL CHEMICAL INDICES

DZIAŁANIE WIELOLETNIEGO NAWOŻENIA OSADEM ŚCIEKOWYM NA CHEMICZNE WSKAŹNIKI GLEBY

Abstract: Field trial was carried out during the consecutive years 2001–2006 on a lessive soil (Albic Luvisols). The objective was to evaluate the influence of sewage sludge applied at different yearly rates, simultaneously with mineral fertilization, on soil properties, mainly organic carbon and total nitrogen content as well as changes in pH and the level of available phosphorus at the humus layer and the subsoil. Investigations were carried out on two three-years rotation: potatoes – spring barley – winter rye. Sewage sludge was applied at the rates (on dry matter basis) 2.0 Mg · ha^{-1} yearly, 4.0 Mg · ha^{-1}, each two years, 8.0 Mg · ha^{-1} each three years. This corresponded to the legally regulated amounts, ie, 10 Mg · ha^{-1} for a five-year period. Moreover sludge was applied at the rates 4 and 8 Mg · ha^{-1} dry matter, yearly. The control treatment consisted of mineral fertilization, only. It was found, that the application of sewage sludge, irrespective of the rate and the frequency did not exert (in most cases) a significant influence on investigated soil indices. This concerned at whole soil pH, organic carbon and total nitrogen content as well as partly the available phosphorus level. In the case of phosphorus, its amounts decreased during the first three years of investigations, whereas in the second cycle of the rotation, P levels raised extremely at the highest sludge rate. Taking into consideration the biogenic effect of phosphorus as in the case of its accumulation in soils under conditions of long-term sludge application, therefore phosphorus balance at the field level may be a targeted task, particularly for soil rich or very rich in phosphorus.

Keywords: sewage sludge, fertilization, soil properties

The rational use of sewage sludge is a concern, which requires to be solved since few years, mainly organizationally and ecologically. According to GUS [1], more than 501 thousands Mg of sewage sludge dry biomass were produced in municipal sewage treatment plants in Poland, of which 64.2 thousands Mg in the Wielkopolska province. Taking into consideration the way sewage sludge is managed, it appears that at the country scale, 40.6 % of the formed sewage biomass was agriculturally used whereas in the Wielkopolska province, 24 %. In this aspect, sewage sludge has to be considered as

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a source of organic matter and nutrient, in one hand [2, 3] and as a carrier of organic and mineral contaminants on the other hand [4–7]. This is why the agricultural and ameliorative application of sewage sludge is legally regulated in Poland, in order to prevent from unfavorable changes in the soil environment. For this reason, except the fertilizer aspect, chemical changes of soil properties are frequently considered, such as soil reaction (pH), organic carbon content and trace elements, but also phosphorus content. This is due to the necessity of considering its role in the ecosystems and the need for a sustainable fertilization as a system under requirements of environmental protection. Therefore phosphorus topic has to be also considered in given cases as an environmental toxicant.

On the basis of these views, long-term investigations over the influence of sewage sludge applied at different rates on changes of pH, phosphorus, potassium and magnesium at the humus layer and subsoil.

Material and methods

Field trial was carried out during the consecutive years 2001–2006 on a lessive soil (Albic Luvisols) at Zlotniki (52°29′N, 16°50′E) an Experimental-Teaching Station of the University of Life Sciences in Poznan. Selected properties in the soil humus layer are reported in Table 1 and experimental design in Table 2.

Table 1

Selected properties in the soil humus layer (average content)

pH_{KCl}	Organic C	Total N	C : N	Diameter of fraction [%]		Available [$mg \cdot kg^{-1}$]		
	[$g \cdot kg^{-1}$]			< 0.02 mm	< 0.002 mm	P	K	Mg
5.60	6.68	0.60	11.1	14.0	3.0	98.4	118.6	60.3

Table 2

Experimental design

No	Treatment	Fertilization	
1	NPK	According to nutrient requirements of plant	
2	Sewage sludge	2 $Mg \cdot ha^{-1}$ d.m. yearly	+ NPK
3		4 $Mg \cdot ha^{-1}$ d.m. each two years	
4		6 $Mg \cdot ha^{-1}$ d.m. each three years	
5		4 $Mg \cdot ha^{-1}$ d.m. yearly	
6		8 $Mg \cdot ha^{-1}$ d.m. yearly	

Mineral fertilization was elaborated according to nutrient requirements of plant grown on two three-years rotation: potatoes – spring barley – winter rye. Fertilizer rates were accordingly 120–22–83, 50–29–100 and 60–35–90 $kg \cdot ha^{-1}$, respectively for N, P, K.

Each plot (42 m^2) was replicated four times. The area where potatoes were harvested was 42 m^2 and for cereals, 24 m^2.

For each experimental year, sewage sludge was collected from the same sewage treatment plant whose purification technology is based on the mechanical-technological-biological system. Selected properties of the sewage sludge are reported in Table 3.

Table 3

Selected properties of the sewage sludge

Parameter	Unit	Content
pH_{KCl}	—	6.52–7.18
Dry matter	[$g \cdot kg^{-1}$]	198.2 ± 12.76* (168.0–203.6)**
Organic matter		736.5 ± 51.85 (668.0–797.0)
Organic carbon ($C_{org.}$)	[$g \cdot kg^{-1}$ d.m.]	320.4 ± 15.88 (295.1–341.7)
Total nitrogen (N_{tot})		57.33 ± 5.48 (48.72–62.70)
C : N	—	5.69 ± 0.77 (4.74–6.62)
P		25.82 ± 2.16 (22.83–28.56)
K	[$g \cdot kg^{-1}$ d.m.]	7.06 ± 1.72 (3.95–8.28)
Mg		8.44 ± 3.18 (5.67–14.68)
Ca		16.25 ± 5.40 (11.60–24.83)

* Average; ** range.

Soil chemical analyses were performed as follows:
– pH, potentiometrically in 1 M KCl,
– organic carbon, according to the method of Tiurin,
– total nitrogen by the method of Kjeldahl,
– available phosphorus and potassium by the Egner-Riehm method,
– available magnesium according to the method of Schachtschabel, and further determined by flame atomic absorption spectrometry (FAAS).

The dry biomass of sewage sludge was determined by the dry method at the temperature of 105 ^{o}C, and the organic matter by the ashing method at 550 ^{o}C, total nitrogen by the Kjeldahl method. Calcium and potassium were determined by the atomic emission spectroscopy method (AES) and magnesium by the FAAS method, after ashing the samples at 550 ^{o}C, and hot dissolving the ash in a solution of 3 M HCl.

Results and discussion

Sewage sludge may be used for agricultural purposes with respect to their composition [4, 6]. But the condition for such application is regulated by the standards dealing with the hygienic aspect of sewage sludge and heavy metal contents. From the agricultural point of view, sewage sludges was assessed to date mainly with respect to their effect on pH, organic matter content and fertilizer nitrogen value as well as the problem of heavy metals. It appears from data reported in Table 4, that under experimental conditions the application of sewage sludge influenced slightly pH changes, but a decreasing trend was clearly observed at the last year of field trial.

Table 4

Changes of humus layer of soils pH throughout years of experiments

Treatment	Years of trials					
	2001	2002	2003	2004	2005	2006
1	5.60	5.86	5.44	5.42	5.33	4.85
2	5.82	5.87	5.16	5.35	5.44	5.09
3	5.44	5.87	5.25	5.34	5.46	4.97
4	5.60	5.86	5.08	5.35	5.28	4.96
5	5.87	5.88	5.21	5.40	5.28	5.12
6	5.68	5.84	5.47	5.37	5.34	4.93

The reported decrease concerned not only treatments with sewage sludges, but also those with mineral fertilization exclusively. Since sewage sludge contained relatively notable amounts of calcium (on average 16.25 $g \cdot kg^{-1}$ d.m.) (Table 3), it was expected its effect on pH to be more pronounced. This means that the application of sewage sludge did not exert an influence on the decreasing rate of soil pH. Since the experimental design did not involve a treatment with applied sewage sludge exclusively, therefore it was impossible to assess the main source favorising such pH changes. It should not be excluded that the observed pH decrease was induced mainly by the mineral fertilization which activated the mineralization process of the organic matter [8]. Sewage sludge applied at different frequency in officially permissible rates (treatments 2 to 4) has evoked pH changes as reported above. In general, sewage sludge applied to soil does not lead to pH changes [9] even at high rates [10]. In turn, according to Kuziemska and Kalembasa [11], irrespective of its origin and rates, sewage sludge applied to the soil induced pH decrease. This was earlier reported by Baran [12] who observed a systematic decrease of soil pH along with time after sludge application. The occurrence of organic acids could be one the factors controlling the observed reactions [13, 14].

With respect to the content of organic matter, sewage sludge is considered as its source to the soil, however not significant relationship is always observed in terms of an increase in soil organic carbon after the application of sludge. According to Zukowska and Flis-Bujak [15], changes in soil organic carbon content depended on its content and the rate of applied sludge.

However, a systematic decrease of organic carbon content along with progressing time was observed. Moreover it has been shown that the application of sludge decrease the susceptibility of humic compounds to chemical oxidation with a simultaneous increase of non-hydrolizable fraction of humic substances. An increase in the content of organic carbon in the soil with a simultaneous slight decrease of total nitrogen was reported by Kuziemska and Kalembasa [11]. Results reported in Table 5 indicate that the amounts of organic carbon changes varied with years of experimentation but differences between fertilization treatments were not significant in general, except for years 2004 and 2006.

Table 5

Organic carbon, total nitrogen [g · kg^{-1} d.m.] and C : N at the humus layer of soil

Treatment	Organic carbon ($C_{org.}$)			Nitrogen (N)			C : N		
	Crop rotation		Average	Crop rotation		Average	Crop rotation		Average
	2001– –2003	2004– –2006	2001– –2006	2001– –2003	2004– –2006	2001– –2006	2001– –2003	2004– –2006	2001– –2006
1	6.13	5.75	5.94	0.56	0.56	0.56	10.95	10.20	10.50
2	6.18	6.04	6.11	0.60	0.61	0.61	10.30	10.11	10.18
3	6.10	6.12	6.11	0.58	0.60	0.59	10.52	11.21	10.34
4	6.11	5.66	5.89	0.60	0.56	0.58	10.18	9.88	10.09
5	6.22	5.91	6.06	0.57	0.59	0.58	10.91	10.08	10.41
6	6.32	6.59	6.46	0.61	0.66	0.63	10.36	10.00	10.05
$LSD_{0.05}$	n.s.	0.37	0.33	0.02	0.05	0.03	—	—	—

n.s. – not significant.

By analyzing the dynamics of changes, it should be concluded that the highest organic carbon decrease (23.2 %) in 2006 was observed in the treatment with only mineral fertilization, as compared with organic carbon level at the start of the trial. Furthermore, the application of sludge at the highest rate, ie 8.0 Mg · ha^{-1} d.m. has stabilized the level of organic carbon similar to that of the year 2001 (Start of the trial). Also the systematic yearly application of sludge at the rate 2.0 Mg · ha^{-1} has significantly limited losses of organic carbon by 7.0 % as compared with 19.3 % recorded for the year application of 4.0 Mg · ha^{-1}.

To sum up, it should be mentioned, that next to mineral fertilization, sludge application at agriculturally permissible rates, does not guarantee keeping constant the level of organic carbon. This may be attributed to a possible enhanced mineralization of soil carbon under the control of microorganisms assimilating easily soluble low molecular carbon bonds as well as nitrogen from the sludge. The amounts of these bonds of fulvic acid nature is variable and depends of the way of waste waters purification [12], however they are prevailing most frequently. According to Mazur [16], sewage sludges are characterized by a low value of soil humus formation, and this observation is supported by data reported in Table 3 as referred to the total content of organic carbon. The quality of humic compounds is another topic.

Sewage sludge did not significantly influence the content of nitrogen in the soils (Table 5), irrespective of the applied rates, in spite of its high content in the sludges (Table 3). It is wondering about the transformation of this element, whose amounts varied from 97.4 to 125.4 kg · ha^{-1} at the rate 2.0 Mg · ha^{-1} and from 389.6 to 501.6 kg · ha^{-1} at the rate 8.0 Mg · ha^{-1}. It is basically important that no significant differences were observed for plant yields (unpublished data). One of the reason for such effect of the sewage could be attributed to the relatively low availability of nitrogen in the sludge, where it occurs preponderantly in organic bonds, resistant to breakdown.

According to Kutera [17], the recovery of nitrogen at the first year of sludge application is ca 20 % which appears to be high enough as compared with data from authors in the order 2.5 to 5.0 % [18]. Further investigations are needed in order to elucidate the fate of such high amounts of nitrogen in the soil after the application of both mineral fertilizers and sewage sludge in one way and the lack of its accumulation in the soils, on the other hand.

From the ecological point of view phosphorus is becoming more and more important. Its productive effect is without reservations, but restrictions are needed in terms of sludge application under conditions of soils rich in phosphorus. Therefore sludge application for fertilization purposes should be managed not as a supplement of mineral fertilization but instead of the latter one. This is becoming necessary with respect to exhausting the reserves of mineral resources involved in phosphorus production and also with environmental threat created by this element [19].

When considering the permissible rate of sludge in Poland, ie, 10 Mg d.m. $\cdot$ ha^{-1} for the five-year period, therefore from 228.5 to 285.5 kg P $\cdot$ ha^{-1} were introduced into soils with the sludges tested in the current research. Furthermore with the highest rate it has been applied yearly during the experimental period from 182.6 to 228.5 kg P $\cdot$ ha^{-1}. These amounts are high and exceed those commonly applied in Polish agriculture. In spite of this, just at the first year of experimentation no significant differences were obtained for available phosphorus between the treatments (Table 6).

Table 6

Influence of mineral fertilization and sludge application on changes of available phosphorus, potassium and magnesium average content at the humus soil layer [mg $\cdot$ kg^{-1} d.m.]

Treatment	Phosphorus (P)			Potassium (K)			Magnesium (Mg)		
	Crop rotation		Average	Crop rotation		Average	Crop rotation		Average
	2001–2003	2004–2006	2001–2006	2001–2003	2004–2006	2001–2006	2001–2003	2004–2006	2001–2006
1	86.0	104.6	95.3	96.2	124.0	110.1	59.2	68.8	64.0
2	88.6	105.1	96.8	121.2	146.0	133.6	56.6	68.2	64.2
3	91.0	114.8	102.9	104.0	113.9	116.8	58.0	71.5	64.7
4	90.2	104.5	95.3	93.3	107.5	103.1	57.1	64.5	61.0
5	92.1	109.7	100.9	91.3	102.4	107.0	60.2	63.2	61.1
6	105.3	123.6	107.7	112.7	146.5	129.6	60.7	72.8	66.8
$LSD_{0.05}$	n.s.	n.s.	9.47	15.51	17.93	11.09	n.s.	6.31	n.s.

Simultaneously, its amounts decreased for the next consecutive two years, ie, to the end of the first rotation. It should not be excluded that some amounts of phosphorus underwent chemical changes towards strongly stable forms, for instance for calcium which is an intrinsic component of sludges and occurs in high amounts (Table 2). Data reported by other workers [20] show that the solubility of the available fraction of phosphorus decreased when calcium oxide or ash from brown coal were added to sludge. In turn, during the second rotation an increasing trend in the content of available phosphorus was observed on all treatments, but more in those where sludge was applied. At both rotation periods, lowest levels of available phosphorus occurred in the treatments receiving only mineral fertilization, whereas the more phosphorus-fertile treatment reflected the highest sludge rate. The difference between both extreme treatments for the consecutive rotation was ca 48.3 and 35.3 %, respectively. The most important is the fact, that along with the years elapsing after the year-to-year application of sludge, differences between treatments were getting wider and exhibiting significant differences at the level $p < 0.05$. The influence for such phosphorus behaviour in the soil may be attributed to different factors, among others weather conditions as well as plants growth. Data obtained in the current work indicate also, as reported above, that when applying sludge as fertilizer, phosphorus content should be considered. The latter one will be intended to replace totally or partly phosphorus from mineral fertilizers. This results in the necessity of balancing this element, which next to nitrogen, belongs to the group of biogenic elements in the ecosystem.

Sewage sludge contain usually low levels of potassium (Table 3) which are not considered as an important source for plants. Nevertheless, under conditions of systematic application of sewage sludge, some amounts of available K may accumulate at the humic layer as indicated by results reported in Table 6. Throughout the whole period of experimentation, a distinct increase in the pool of available K forms was observed during the second rotation (2004–2006) as compared with the first rotation (2001–2003), but no explicit trends were recorded, when referring to those which took place in the case of phosphorus. Nevertheless, significant differences in potassium content (Table 6) occurred mainly for the year-to-year application of sludge at the rates 2 $Mg \cdot ha^{-1}$ and 8 $Mg \cdot ha^{-1}$ (on dry weight basis), as compared with the control treatment (without sludge). Therefore, based on such differences, it can be pointed out the fertilizer effect of potassium contained in the sludge. The trends were important and affected mean values of potassium content in the soils for the whole period of investigation.

Decidedly, sludge exerted a slight influence on available magnesium content in the humic layer (Table 6). Moreover, it should be stressed on similar and not significant differences in magnesium content on all treatments, but at a different level between the periods of study.

Conclusions

Sewage sludge is a source of organic matter, nitrogen and additional nutrients, phosphorus among others. On this basis, sewage sludge may be a material of fertilizer nature. However, the results of six years of experiments indicated that sewage applied at recommended and beyond rates did not exert a significant role on the accumulation of organic carbon and total nitrogen in the soil. Furthermore it was observed a decrease in soil pH along with years of experimentation, implying a need for periodic soil liming, even under conditions of applying sludge rich in calcium. Taking into consideration the biogenic effect of phosphorus as in the case of its accumulation in soils under constant sludge application, therefore phosphorus balance at the field level may be a targeted task.

The content of available potassium in the humic layer increased along with the period of experimentation. The highest quantitative and significant differences of potassium forms, as compared with other treatments, were observed on treatments receiving year-to-year sewage sludge at rates 2 and 8 Mg · ha^{-1}.

No significant influence of sewage sludge on available magnesium content was proved in spite of an increase of its content in the humic layer.

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Abstrakt: Doświadczenie polowe przeprowadzono w latach 2001–2006 na glebie płowej. Jego celem było określenie wpływu osadu ściekowego stosowanego w zróżnicowanych corocznych dawkach wspólnie z nawożeniem mineralnym na właściwości gleby, w tym gromadzenie węgla organicznego i azotu ogólnego, oraz na zmiany odczynu i zawartości fosforu przyswajalnego w poziomie próchnicznym i podglebiu. Badania prowadzono w dwóch trzyletnich cyklach zmianowania: ziemniaki – jęczmień jary – żyto ozime. Osad stosowano (w przeliczeniu na suchą masę) w dawkach 2 Mg · ha^{-1} corocznie; 4 Mg · ha^{-1} co dwa lata i 8 Mg · ha^{-1} co trzy lata. Odpowiadało to ilościom normowanym prawem, tzn. 10 Mg · ha^{-1} w okresie pięcioletnim. Poza tym stosowano osad w ilości 4 i 8 Mg · ha^{-1} suchej masy corocznie. Obiektem kontrolnym była kombinacja z wyłącznym nawożeniem mineralnym.

Wykazano, że osad ściekowy bez względu na dawkę i częstotliwość stosowania w większości nie miał znaczącego wpływu na badane wskaźniki gleby. Dotyczyło to w całości odczynu, zawartości węgla organicznego i azotu ogólnego oraz częściowo przyswajalnego fosforu.

W pierwszych trzech latach badań stwierdzono spadek zawartości fosforu, a w drugim cyklu zmianowania systematyczny wzrost, największy przy ekstremalnej dawce osadu. Mając na uwadze gromadzenie się przyswajalnego fosforu w warunkach wieloletniego nawożenia osadem, jak i jego biogenne działanie w środowisku należy ilości wprowadzonego składnika do gleby uwzględnić w bilansie nawozowym pola, szczególnie przy wysokiej i bardzo wysokiej zasobności w ten składnik.

Słowa kluczowe: osad ściekowy, nawożenie, właściwości gleby