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LEACHING OF NITROGEN FORMS FROM SOIL FERTILIZED WITH SEWAGE SLUDGE

WYMYWANIE FORM AZOTU Z GLEBY NAWOŻONEJ OSADAMI ŚCIEKOWYMI

Abstract: The aim of the study has been to evaluate the extent of loss of various nitrogen forms leached from soil fertilized with sewage sludge, farmyard manure and NPK. Sewage sludge and FYM were applied as a single dose of 10 Mg · ha^{-1} or two doses, each of 5 Mg · ha^{-1}. It has been demonstrated that all the objects fertilized with sewage sludge of sewage based composts experienced more severe leaching of total nitrogen and nitrogen forms compared with the control. More total nitrogen was leached from soil to which sewage sludge was introduced as a dose divided into two applications (2 × 5 Mg · ha^{-1}) than from soil which received a single rate of this fertilizer (10 Mg · ha^{-1}). Nitrate(V) nitrogen dominated among the mineral forms of nitrogen in soil filtrate. Higher loss of this nitrogen form occurred in treatments receiving compost made from sewage sludge with straw (10 Mg · ha^{-1}) or dried and granulated sewage sludge than when composted sewage sludge or traditional fertilization were applied. Water was more polluted with $N\text{-}NH_4^+$ when sewage sludge compost was used, but when it was made with straw, $N\text{-}NO_2^-$ was the predominant water pollutant.

Keywords: nitrogen leaching, sewage sludge, compost, soil

Soil fertilization with rates of nutrients higher than demanded by crops may cause changes in the ionic equilibrium of soil solution and contribute to migration of nutrients to surface and groundwater. Thus, it is necessary to determine the level of loss of nutrients in order to guarantee suitable crop nutrition while protecting natural environment from pollution. Being a source of nutrients and organic matter, sludge from wastewater treatment plants can be used to fertilize soil, once it meets the norms established to monitor the content of heavy metals and pathogenic microorganisms.

Amounts of nitrogen washed from soil depend on several factors, including types and rates of fertilizers. Many authors claim that there is positive correlation between the rate

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of fertilizers and the leaching of nutrients from soil [1]. Many authors indicate that there is a relationship between rates of fertilizers and amounts of nutrients leached from soil [2–6]. The concentration of nitrogen in soil leachate is also conditioned by the type of soil. Mineral forms of this element are highly mobile, particularly when their uptake by plants is limited or when high rates of fertilizers are introduced to light soils [7]. Migrating downwards the soil profile, nutrients and rainfall can reach groundwater and, eventually, surface water. One way to monitor quality of this water is via lysimetric tests [8].

The aim of the present study has been to determine the loss of total nitrogen and nitrogen forms from soil fertilized with sewage sludge versus analogous loss when natural and mineral fertilizers are used.

Material and methods

In order to evaluate the effect of sewage sludge on potential leaching of nutrients from soil, a model lysimetric experiment has been performed under controlled laboratory conditions. The experiment was established as strict field trials, during which composted sewage sludge, sewage sludge with straw as well as dried and granulated sludge were examined. The effect produced by sewage sludge was compared with the one obtained when conventional fertilization, consisting of FYM or NPK, was used. Sewage sludge and FYM were applied as a single rate of 10 Mg · ha^{-1} in the first year of the experiment, or an identical dose divided into two treatments, each of 5 Mg · ha^{-1}, introduced to soil in the first and third year of the trials. The soil used in this lysimetric experiment was sampled from three soil horizons: 0–30 cm, 31–60 cm and 61–90 cm. While filling lysimeters with soil material, the original position of soil genetic layers was maintained so as to create conditions as close as possible to the ones in the field. In total, each cylinder was filled with 7.5 kg soil, ie 2.5 kg from each soil horizon.

For washing the soil, redistilled water was used in the amount corresponding to the average annual rainfall in the province of Warmia and Mazury (605 mm).

The following determinations were made in the soil filtrate: total nitrogen by Kjedahl's method, ammonia nitrogen by colorimetry with Nessler's reagent, nitrate(V) nitrogen using an ion-selective electrode, nitrate(III) nitrogen by colorimetry with sulphanilic acid and 1-naphthylamine. Organic nitrogen was calculated as a difference between total and mineral nitrogen.

Results and discussion

In most of the treatments fertilized with sewage sludge or sludge composts, the amounts of total nitrogen and nitrogen forms leached from soil were lower than in the control objects or the treatments involving mineral fertilization (Tables 1–6). The amounts of leached forms of nitrogen in fertilized objects were varied and depended on the type of a fertilizer and its application method. More total nitrogen was leached from the soil to which fertilizers were introduced in doses divided into two applications (2 × 5 Mg · ha^{-1}) compared with the one which received the same rate of fertilizers

given as a single dose (10 Mg · ha^{-1}). The highest quantity of total nitrogen leached from soil, on average 16.64 mg per lysimeter (11.46 kg N · ha^{-1}), was noticed in soil filtrates obtained from treatments fertilized with sewage compost (Table 1). Soil fertilized with sludge compost mixed with straw (both as a double dose 2 × 5 Mg · ha^{-1} or a single dose 10 Mg · ha^{-1}) was determined to lose as much total nitrogen as soil nourished with dried and granulated sludge.

Table 1

Total nitrogen leaching

Dose	Control	NPK	FYM	Dried and granulated sewage sludge	Composted sewage sludge	Composted sewage sludge + straw
[mg per lysimeter]						
10 Mg · ha^{-1}	16.63	18.48	14.78	12.32	16.02	13.55
2 × 5 Mg · ha^{-1}			16.02	14.78	17.25	14.78
Average			15.40	13.55	16.64	14.16
[kg · ha^{-1}]						
10 Mg · ha^{-1}	11.45	12.73	10.18	8.48	11.03	9.33
2 × 5 Mg · ha^{-1}			11.03	10.18	11.88	10.18
Average			10.61	9.33	11.46	9.76

Experiments reported by other researchers prove that fertilization contributes to more profound leaching of nitrogen from soil, and mixed organic and mineral fertilization causes higher nitrogen loss than organic fertilization alone [9]. It has also been shown that higher nitrogen loss can occur when sludge composts [1] or soil liming [3] are applied. Some authors relate nitrogen loss with soil conditions, suggesting that more nitrogen is lost in sandy and loamy soils compared with loess soil [10]. The amount of leached nitrogen can be as high as 140 kg N · ha^{-1}, which is observable particularly in fallow sandy soils [11, 12].

In our experiment, most organic nitrogen was leached from unfertilized soil (Table 2). The leaching of organic nitrogen from fertilized treatments was nearly 32 % lower than from the control object. Among the fertilized objects, similarly to total nitrogen, most organic nitrogen was found in the soil filtrate from soil enriched with mineral fertilizers. More organic nitrogen was lost in the object fertilized with sewage sludge compost, under either of the fertilization methods, than in the objects where dried and granulated sludge or sludge compost with straw were applied.

In a study by Mazur and Sadej [9] on the effect of natural and mineral fertilizers on amounts of leached organic nitrogen, it was found out that more of this nitrogen form was lost following a long-term application of mineral rather than organic fertilizers. These authors found similar quantities of organic nitrogen in all objects treated with natural fertilizers, irrespective of the type and rate of a fertilizer.

Table 2

Organic nitrogen leaching

Dose	Control	NPK	FYM	Dried and granulated sewage sludge	Composted sewage sludge	Composted sewage sludge + straw
[mg per lysimeter]						
10 Mg · ha^{-1}	13.11	12.23	7.83	6.25	10.38	5.98
2 × 5 Mg · ha^{-1}			10.65	8.80	9.42	8.45
Average			9.24	7.53	9.90	7.22
[kg · ha^{-1}]						
10 Mg · ha^{-1}	9.03	8.42	5.39	4.30	7.15	4.12
2 × 5 Mg · ha^{-1}			7.33	6.06	6.49	5.82
Average			6.36	5.18	6.82	4.97

The amount of leached mineral nitrogen ranged from 3.52 to 7.83 mg per lysimeter. Independently from the type or dose of the applied fertilizer, in all the fertilized objects the amount of leached mineral nitrogen was higher than in the control. Higher average loss of mineral nitrogen occurred in the objects fertilized with sludge compost than with dried and granulated sludge (Table 3).

Table 3

Mineral nitrogen leaching

Dose	Control	NPK	FYM	Dried and granulated sewage sludge	Composted sewage sludge	Composted sewage sludge + straw
[mg per lysimeter]						
10 Mg · ha^{-1}	3.52	6.25	6.95	6.07	5.64	7.57
2 × 5 Mg · ha^{-1}			5.37	5.98	7.83	6.33
Average			6.16	6.03	6.74	6.95
[kg · ha^{-1}]						
10 Mg · ha^{-1}	2.42	4.34	4.79	4.18	3.88	5.21
2 × 5 Mg · ha^{-1}			3.70	4.12	5.39	4.36
Average			4.25	4.15	4.64	4.79

The objects which were treated with a split dose of sewage sludge on two dates were found to have more mineral nitrogen leached than the objects where the same amount of sludge was applied in a single dose. A reverse dependence occurred in the case of composted sewage sludge and straw or dried sewage sludge. The amount of mineral nitrogen leached from soil fertilized with NPK was nearly 1.8-fold higher versus the control.

The content of ammonia nitrogen in filtrates was varied. The amount of this form of nitrogen varied over a wide range, from 0.17 to 2.46 mg per lysimeter (Table 4).

Table 4

$N\text{-}NH_4^+$ leaching

Dose	Control	NPK	FYM	Dried and granulated sewage sludge	Composted sewage sludge	Composted sewage sludge + straw
[mg per lysimeter]						
10 Mg · ha^{-1}	0.88	2.20	1.49	1.23	1.23	1.06
2 × 5 Mg · ha^{-1}			1.06	0.17	2.46	1.14
Average			1.28	0.70	1.85	1.10
[kg · ha^{-1}]						
10 Mg · ha^{-1}	0.60	1.52	1.03	0.85	0.85	0.73
2 × 5 Mg · ha^{-1}			0.73	0.12	1.69	0.79
Average			0.88	0.49	1.27	0.76

Among the soil enriching substances, higher $N\text{-}NH_4^+$ leaching was caused by composted sewage sludge than by dried and granulated sludge or composted sludge and straw. The smallest amount of ammonia nitrogen was leached from the soil to which dried and granulated sludge was introduced in the treatment consisting of 2 × 5 Mg · ha^{-1}. Single application of the same sludge caused a seven-fold higher leaching of ammonia nitrogen compared with the object where the same quantity of the fertilizer was introduced in a double application. Fertilization with the conventional organic fertilizer, such as farmyard manure, caused increased leaching of ammonia nitrogen, with higher quantities of this nitrogen form found out in the object fertilized once than in the one which received a dose divided into two parts.

The extent of ammonia nitrogen leaching can also be influenced by the pH of the substratum. When the pH is lower, the amount of this nitrogen form leached from soil can rise considerably [13]. High ammonia nitrogen loss has also been observed when liquid natural fertilizers such as liquid manure or mixed mineral and organic fertilization were applied [9].

Among the mineral forms of nitrogen in filtered water, nitrate(V) nitrogen dominated. The amount of nitrate(V) nitrogen leached from soil was several times higher compared with ammonia nitrogen (Table 5). Among the objects treated with sewage sludge, the highest leaching of nitrate(V) nitrogen appeared in the combination treated with dried and granulated sewage sludge introduced twice, 5 Mg · ha^{-1} each time. Similar amounts of nitrate(V) nitrogen were leached from soil enriched with composted sewage sludge and straw added as a single dose. These results are in accord with the ones obtained by Czyzyk and Kozdras [3]. As for the other objects, independently from the type of fertilizer or fertilization method, the amounts of nitrate(V) nitrogen ions were approximately the same. The extent of this form of nitrogen lost from soil was more profoundly affected by sludge than by mineral fertilization or farmyard manure. Introduction of nitrogen via mineral fertilizers added to soil proved to produce better effects compared with the other fertilizers, as the loss of $N\text{-}NO_3^-$ was the lowest under this fertilization treatment. Similar results were reported by Cwojdzinski and

Majcherczak [14], who determined that more nitrate(V) nitrogen was released from soil when mixed mineral and organic fertilization was applied than after exclusive mineral treatment.

Table 5

$N\text{-}NO_3^-$ leaching

Dose	Control	NPK	FYM	Dried and granulated sewage sludge	Composted sewage sludge	Composted sewage sludge + straw
[mg per lysimeter]						
10 Mg · ha^{-1}	2.55	3.87	4.14	4.05	4.31	5.19
2 × 5 Mg · ha^{-1}			4.05	5.37	4.14	4.31
Average			4.10	4.71	4.23	4.75
[kg · ha^{-1}]						
10 Mg · ha^{-1}	1.76	2.67	2.85	2.08	2.97	3.57
2 × 5 Mg · ha^{-1}			2.79	3.70	2.85	2.97
Average			2.82	2.89	2.91	3.27

Amounts of nitrates leached from soil also depend on the type of crops grown on it. As Smoron et al [15] report, the smallest concentrations of this form of nitrogen have been recorded in leachate from soils under permanent grassland. Additionally, the extent of nitrate(V) nitrogen loss was also affected by the duration of the vegetative growth of plants. More of this nitrogen form was lost from soils under crops characterised by a short growing period. In a study conducted by Pondel [16], the concentration of nitrate(V) nitrogen in lysimetric, drainage and groundwater as well as in watercourses from agricultural basins or downhill effluents varied over a wide range, from 1 to over 40 kg N · ha^{-1} annually.

Table 6

$N\text{-}NO_2^-$ leaching

Dose	Control	NPK	FYM	Dried and granulated sewage sludge	Composted sewage sludge	Composted sewage sludge + straw
[mg per lysimeter]						
10 Mg · ha^{-1}	0.09	0.18	1.32	0.79	0.09	1.32
2 × 5 Mg · ha^{-1}			0.26	0.44	1.23	0.88
Average			0.79	0.62	0.66	1.10
[kg · ha^{-1}]						
10 Mg · ha^{-1}	0.06	0.12	0.91	0.54	0.06	0.91
2 × 5 Mg · ha^{-1}			0.18	0.30	0.85	0.60
Average			0.55	0.42	0.46	0.76

The smallest amount of nitrate(III) nitrogen was found in filtrate obtained from the soil fertilized with composted sewage sludge applied as a single dose of 10 Mg · ha^{-1} (Table 6). The leaching of N-NO_2^- in that case was over 13-fold lower than in the object receiving the same fertilizer applied as a split dose of 5 Mg · ha^{-1} applied on two dates. More extensive leaching of this nitrogen form occurred in the soil fertilized with sewage sludge than in the one treated with FYM or NPK. Mineral fertilization caused a two-fold increase in the content of nitrate(III) nitrogen relative the control.

Conclusions

1. Fertilization of soils with sewage sludge or composted sewage does not lead to elevated leaching of total nitrogen or nitrogen forms compared with conventional fertilization. More total nitrogen is leached from soil which is enriched with dried sewage sludge or with composted sludge and straw applied in a single dose (10 Mg · ha^{-1}) relative to soil where such fertilizers are applied as two doses (2 × 5 Mg · ha^{-1}). When compost is made from sewage sludge alone, it is more beneficial to apply it as a single rather than a split dose.

2. The amount of mineral nitrogen leached from soil fertilized with sewage sludge is small, ranging from 3.88 to 5.39 kg · ha^{-1}. Higher average losses of mineral nitrogen are observed under the influence of composted sludge is applied than when dried and granulated sewage is used.

3. Among the mineral forms of nitrogen, nitrate(V) nitrogen is leached most extensively. The amount of this form of nitrogen washed away from fertilized soils is on average 70 % higher compared with the control. The most severe leaching of this nitrogen form occurred when dried and granulated sludge was introduced to soil as 2 × 5 Mg · ha^{-1} rates or when composted sewage sludge and straw were used.

4. The amount of ammonia nitrogen leached from soils enriched with sewage sludge or sludge composts was nearly 2-fold lower compared with this nitrogen form leached from soil fertilized with dried and granulated sludge, applied as 2 × 5 Mg · ha^{-1}. Single application of 10 Mg · ha^{-1} of dried sludge causes a 7-fold increase in the leaching of ammonia nitrogen.

5. Among the mineral forms of nitrogen, nitrate(III) nitrogen was leached the least extensively. Using processed sludge fertilizers in a single dose of 10 Mg · ha^{-1}, we could observe that the leaching of this nitrogen form was much lower than when the same amount of sludge fertilizer was spilt into two equal doses applied on two different dates.

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WYMYWANIE FORM AZOTU Z GLEBY NAWOŻONEJ OSADAMI ŚCIEKOWYMI

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Abstrakt: Celem badań było określenie ilości strat różnych form azotu na drodze wymycia z gleby nawożonej osadami ściekowymi, obornikiem i NPK. Osady ściekowe i obornik zastosowano jednorazowo w dawce 10 Mg · ha^{-1} oraz dwukrotnie po 5 Mg · ha^{-1} w pierwszym i w trzecim roku doświadczenia. Wykazano, że we wszystkich obiektach, na których stosowano dodatki użyźniające w postaci osadów ściekowych lub kompostów z nich wytworzonych wymycie azotu ogółem i jego form było większe w porównaniu z obiektem kontrolnym. Większe ilości azotu ogółem wymyto z gleby, do której wprowadzano osady ściekowe w dawce podzielonej na dwie części (2 × 5 Mg · ha^{-1}) w porównaniu do gleby, gdzie zastosowano je w dawce jednorazowej (10 Mg · ha^{-1}). Spośród mineralnych form azotu w wodach przesiąkowych dominował azot azotanowy(V). Większe straty tej formy azotu notowano w obiektach nawożonych kompostem z osadu ściekowego z dodatkiem słomy (10 Mg · ha^{-1}) oraz wysuszonym i zgranulowanym osadem ściekowym (2 × 5 Mg · ha^{-1}) w porównaniu z kompostowanym osadem ściekowym oraz nawożeniem tradycyjnym. Do zanieczyszczenia wody $N\text{-}NH_4^+$ w największym stopniu przyczynił się kompost z samych osadów ściekowych, natomiast $N\text{-}NO_2^-$ kompost ten z dodatkiem słomy.

Słowa kluczowe: wymywanie azotu, osady ściekowe, kompost, gleba