Original Research

The Effect of Increased Doses of Compost on Leaching of Mineral Nitrogen from Arable Land

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Abstract

This work presents the analysis of the effect of compost addition on leaching of mineral nitrogen from arable land, plant biomass production and soil properties. Compost used for experiment consists of the basic raw materials for the production of reclamation substrates in company CKB. These substrates are often used for restoring the damaged agricultural lands. Therefore, this compost was applied in increased doses (300% of recommended dose) to determine the potential impact on the parameters above. To demonstrate this effect, five variants with same doses of compost and different doses of mineral and organic fertilizers, were prepared. The highest decrease of mineral nitrogen leaching was observed by the simultaneous applications of soluble humic substances and compost to soil samples, about 400% in comparison with the control variant.

Keywords: compost, reclamation, mineral nitrogen, arable land

Introduction

In recent years, considerable funds were used to restore landscape damaged by human activities. One of the most important human activities affecting the landscape is agriculture.

Current modern agriculture causes water and wind erosion, loss of soil nutrients, contamination of drinking water sources, and decrease of soil fertility [1]. These problems can be solved only by sustainable farming. Sustainable agriculture is not possible without sustainable soil. But soil cannot be sustained without satisfactory soil organic matter (SOM), which in turn largely depends on organic matter additions and its handling [2]. Organic matter can be applied to the soil in various forms. For example, we can use plowing of crop residues or the application of new organic fertilizers (lignohumat). The main problem is the price and the limited feasibility of these procedures. For many countries, use of organic residues is the only way for effective and inexpensive application of organic matter in agricultural soils [3]. For example, many resource-poor African farmers cannot afford to use purchased fertilizers. Many authors [2, 4-6] have confirmed the importance of using organic residues. These authors also point to the importance of using these organic residues as basic substrates for the composting process. The main product is called compost, which may be defined as the stabilized and sanitized product of composting, which is compatible and beneficial to plant growth.

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Application of compost has a positive effect on basic soil properties (physical, chemical, and biological fertility). Composition of the input substrate has a significant effect on compost quality [5].

Compost and products made from it (reclamation substrates) are commonly used to increase soil fertility in the conditions of the Czech Republic. Compost can be used not only to increase soil fertility but also to stop the leaching of mineral nitrogen. Leaching of mineral nitrogen (N_{min}) from arable soil is a major threat to the drinking water quality of underground reservoirs in the Czech Republic [7, 8]. The chemical compounds of compost are interesting. Among the most important substances in compost: carbon, two forms of nitrogen (organic and inorganic) and phosphorus are available. More than 85-90% of the total nitrogen content in compost is organic, while the remaining 10-15% is inorganic and immediately available to the plants [5]. The positive effect of the compost addition on leaching of N_{min} is based on its chemical composition. Available carbon is a source of energy for microorganisms, thus this energy can be subsequently used for the processing of nitrogen. Increasing microbial activity results in increased capacity for mineral nitrogen retention (additionally supplied from compost and another mineral fertilizer). N_{min} is captured in SOM [5, 9].

In the present paper, the effect of increased doses of compost to prepare reclamation substrate on leaching of mineral nitrogen from arable land and on biomass production was performed in a laboratory experiment. For this experiment, soil samples from the area of our interest (Březová nad Svitavou) were used. This area is the largest source of underground drinking water in the Czech Republic. Unfortunately, water from this source has been slowly and regularly contaminated by nitrates since the seventies. This process continues even though inputs of mineral fertilizers have been radically reduced since the 1990s [10]. This is due to disruption of the microbial complex in the soil, which was caused by excessive doses of mineral fertilizers in recent years. Currently, this microbial complex is disrupted by atmospheric deposition containing nitrogen.

This paper reports the result of a laboratory experiment, carried out by the Department of Microbiology, to detect the consequences of the application of a high amount of compost (300% of recommended dose) on leaching of mineral nitrogen, and nitrogen availability in soil microbial biomass, soil pH and EC.

Material and Methods

Experimental Design

Our experiment was carried out in plastic experimental containers filled with arable land from the area Březová nad Svitavou (Fig. 1). As mentioned above, this land is significantly affected by human activities. Experimental containers were filled with 550 g of soils with or without the addition of compost and mineral fertilizers. Soil sampling was done on the 10 November 2012. Compost (CP) used for the experiment was collected on 30 November. Compost samples were taken from the CKB company. Soil sampling complied the requirements of ČSN ISO 10 381-6 and CP sampling was in accordance with ČSN EN 46 5735.

The compost was applied into the individual variants of the experiment with or without organic and inorganic fertilizers. All used fertilizers and compost are registered (the Fertilizers Act) for agriculture use in the Czech Republic. For the following experiment, these fertilizers were used: organic fertilizer *Lignohumat – type B* (LG B) and inorganic (mineral) fertilizer GSH. The exact composition of LG and GSH by [11]: Lignohumat is a product of chemical transformation of lignosulfonate. This material is completely transformed into the final product: solution containing 90% of humic salts (humic and fulvic acids in the ratio 1:1). GSH is a common mineral fertilizer containing N, P, K, and S in the ratio 10:10:10:13. To determine the effect of increased doses of CP on plant production, *Lactuca sativa* L. was used as a model crop. Ten seeds of *Lactuca sativa* L. (salad) were planted in each container. After one week, one germinated seed was left in each container. The first 10 days, salad was daily irrigated with 25 ml of distilled water and in the remaining period of the experiment the salad was irrigated with 35 ml of distilled water four days a week. The experiment was conducted from 1 December 2012 to 4 January 2013. All pot experiments carried out in our department are located in the growing box. During the whole experiment, plants were grown in the following conditions: at 22ºC with a day length of 16 h and a light intensity of 300 $\mu m \cdot m^{-1} \cdot s^{-1}$ and cultivated for 35 days. After this time, containers were dismantled and plants were dried at 105ºC to constant weight.

To demonstrate the effect of increased doses of CP, four variants with same doses of CP and different doses of mineral and organic fertilizers (V4-V7), two variants only with addition of CP (V2) or GSH (V3) and one variant only with soil (V1), were prepared. Each variant was done in three repetitions. Individual variants in detail: V1 – control vari-

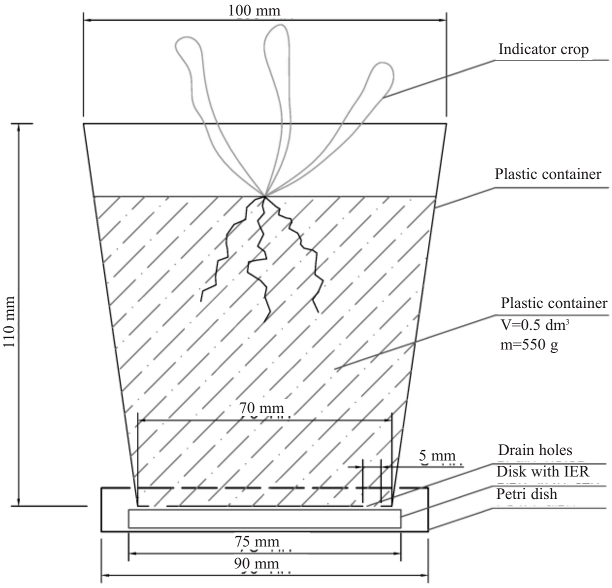

Fig. 1. Experimental container.

ant (only soil) without the addition of CP or another fertilizer. Into variants V2, V4-V7, doses 90 g of CP were applied. This dose of CP is three times greater in comparison with the recommended dose in accordance with ČSN EN 46 5735 (50 $Mg \cdot ha^{-1}$). This dose represents 150 $Mg \cdot ha^{-1}$. These variants (V4-V7) were further complemented by: V4 – application of 90 $g \cdot m^{-2}$ GSH (100% of the recommended dose); V5 – application of 50 $ml \cdot m^{-2}$ of LG B; V6 – application of 50 $ml \cdot m^{-2}$ of LG B + 45 $g \cdot m^{-2}$ GSH (50% of the recommended dose); V7 – 150 $ml \cdot m^{-2}$ LG B (300% of the recommended dose) + 45 $g \cdot m^{-2}$ GSH. Furthermore, variant 3 (V3) was fertilized with mineral fertilizer only (90 $g \cdot m^{-2}$ of GSH).

Soil and CP samples used for the experiment were sieved through a grid size of 2 mm. Before storage, the samples of soil and compost were preincubated at 18.5ºC for 30 days. Prepared samples were then stored at 2.5ºC.

Measuring Mineral Nitrogen Leaching

Mineral nitrogen (N_{min}, consisting of NH_4^+-N and NO_3^--N), which leached out of the experimental containers, was captured by resin grain. These grains were placed into special plastic (PVC) discs that were located under all containers. Each disc was composed of a plastic ring that was 75 mm wide and 5 mm thick. From both side of each disc, nylon mesh was glued (grid size of 0.1 mm). Resin grains for capture of N_{min} are called ion exchange resin (IER). Mixed IER was used for this experiment. This IER consists of cation exchange resin (CER for capturing NH_4^+-N) and anion exchange resin (AER – for capturing NO_3^--N) in ratio 1:1. IER used for the experiment were made by the Purolite Company. These types were applied: (1) AER Macroporous Strong Base Anion Exchange Resin – A520E (total capacity 0.9 eq/l) and (2) CER Gel Strong Acid Cation Resin – C100E (total capacity 1.9 eq/l).

Quantification of trapped ions (NH_4^+-N and NO_3^--N) was carried out according to [12]: After application, discs were removed from Petri dishes (under containers) and dried at 18ºC (laboratory temperature) for 7 days. Dry IER were removed from discs and divided by variants. Trapped N_{min} was extracted from resin by 100 ml of 1.7 M NaCl. Extracted N_{min} was determined by distillation and titration method by Peoples et al. [14]. The results obtained from the discs with IER were expressed in mg of N_{min} per dm^{-3}, of soil (mg/dm^{-3}).

Index of Nitrogen Availability

Index of nitrogen availability is the method for measuring the content of available nitrogen in soil. Available soil nitrogen is estimated from NH_4^+-N production during the 7-day waterlogged incubation. This method is described by [13]. The whole method is divided into two procedures: the first determines the content of mineral nitrogen before incubation, and the second determines the content of ammoniacal nitrogen released from the microbial biomass.

The contents of N_{min} were performed by extraction with 2 M KCl. Extraction was realized in sealed glass containers. From each replication (V1 a, b, c; V2 a, b, c; V3 a, b, c etc.), 20 g of soil was collected. This sample was inserted into glass containers and shaken for 60 minutes with 2 M KCl. After shaking, the determinations of N_{min} were made by distillation and titration method according to [14]. The amount of NH_4^+-N was measured after 7 days of incubation at 40ºC. Samples were prepared for incubation: 50 ml of distilled water and 20 g of soil sample (from each replication) were placed into 125 ml incubation bottles. After the 7-day incubation, 50 ml of 4 M KCl was added and this solution was shaken for 60 min. Subsequently, the suspension was filtered and NH_4^+-N was determined in the filtrate as above. The results were expressed in mg of $N_{min} \cdot kg^{-1}$ and in mg of NH_4^+-$N \cdot kg^{-1}$ of soil.

Determination of pH and EC

Active pH and electrical conductivity at the start (in soil, compost and in mixture of compost and soil) of the experiment were measured and after its termination (in each repetition of individual variants). Both parameters were measured by HACH LANGE sesIONTM+. Active pH was measured in soil and in soil with the addition of compost according to ČSN ISO 10 390. In compost active pH was measured according to ČSN EN 46 5735. EC was measured for each sample according to ČSN ISO 11 265.

Statistical Analysis

The measured values of leached N_{min}, cumulative CO_2 production, nitrogen availability in microbial biomass, pH, and EC were analyzed by one-way analysis of variance (ANOVA) in combination with Tukey's test. All data were analyzed using Statistica 10 software. Graphic processing of measured data was performed in Microsoft Excel 2010.

Results and Discussion

Leaching of Mineral Nitrogen

Mineral nitrogen is an important indicator of soil state. High leakage of nitrogen from the soil indicates the disruption of microbial activity and saturation of the soil nutrients [1]. The amount of N_{min} captured on IER is shown in Fig. 2.

Leaching of N_{min} was measured by using IER. Fixed form of N_{min} (NH_4^+-N and NO_3^--N form) was extracted from the IER and converted to mg of NH_4^+-N and NO_3^--N per dm3 of soil. The value of N_{min} was calculated as the sum of the detected ammonium and nitrate form. Fig. 4 shows a significant difference of leached N_{min} between the variants with the addition of CP and without compost. The graph shows how values of leaching of N_{min} increase in variant without CP addition. The highest detection of N_{min} was found in variant V3 (9.44 $mg \cdot dm^{-3}$). Conversely, the lowest detection of

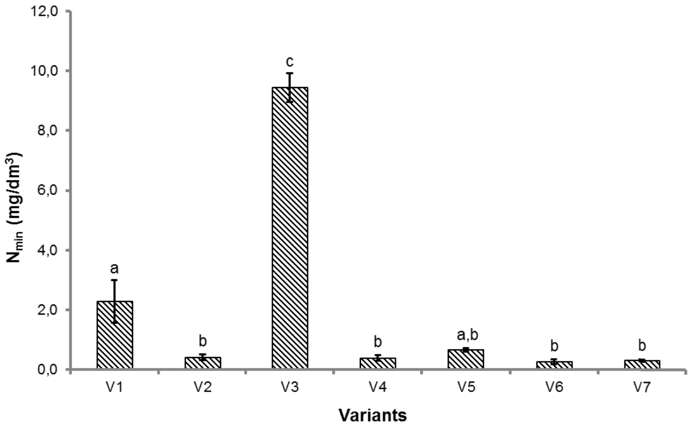

Fig. 2. Detection of mineral nitrogen (mean values ± standard error are shown, n = 3, different letters indicate significant differences at the level 0.05 – ANOVA, P<0.05)
The values of detection N_{min} represent the amount of nitrogen (mg) per cubic decimeter (dm^3).

N_{min} was measured in variant V6 (0.27 $mg \cdot dm^{-3}$). This status confirms the positive impact of CP addition on leaching of N_{min}.

Some authors suggest that in the production of compost microbial activities are developing. The reason is diverse composition of the compost. It contains a lot of nutrients (especially C_{org} – organic carbon). The authors also argue that the activity of microorganisms continues even after the application of compost [15]. Development of microorganism activity is an essential prerequisite for the retention and use of excessive nitrogen in the soil [1]. Therefore, variations with the addition of compost showed a minimal detection of mineral nitrogen. The addition of another C_{org} (Lignohumat in V5, V6, and V7) did not have a demonstrable (p<0.05) effect on reducing leakage.

Ammonium Production during Waterlogged Incubation

Ammonium production during waterlogged incubation, i.e. index of nitrogen availability, was used to determine the amount of nitrogen that was stored in the microbial biomass. The effect of compost addition on nitrogen availability in microbial biomass is illustrated in Fig. 3. The measured values indicated a positive effect of compost addition on nitrogen deposits in microbial biomass. For comparison, consider Figs. 2 and 3. The least amount of ammonium nitrogen was found in the variants with the highest leakage of mineral nitrogen. Positive effects of compost application on availability of nitrogen (organic and inorganic forms) in soil are confirmed by [16].

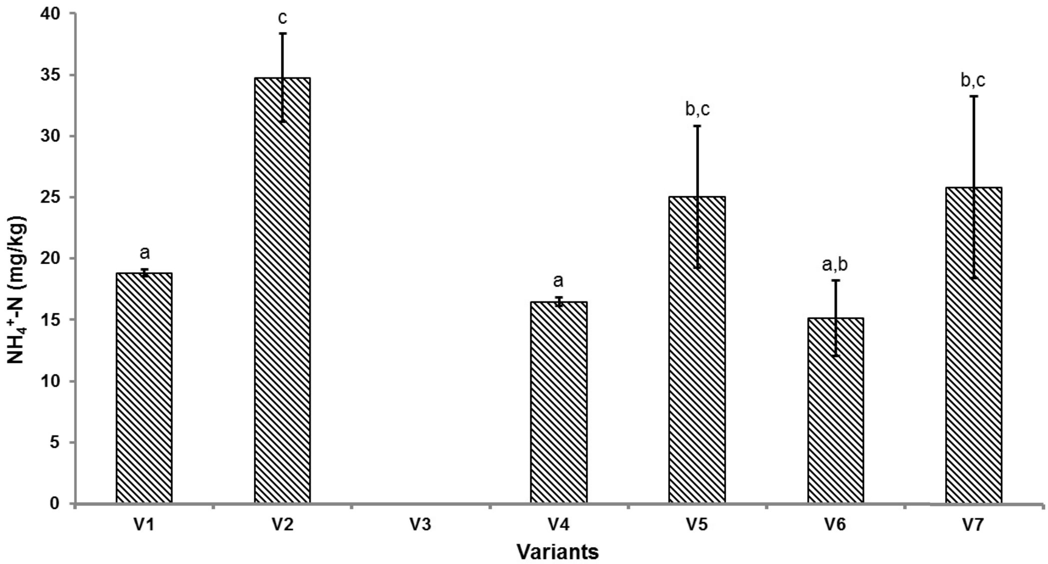

Fig. 3. Index of nitrogen availability (mean values ± standard error are shown, n = 3, different letters indicate significant differences at the level 0.05 – ANOVA, P<0.05).
The content of NH_4^+-N in microbial biomass is expressed in mg of ammonium nitrogen per kilogram (kg) of soil. The amount of NH_4^+-N was minimal (near zero) and the chosen method is not stable in V3.

Production of Plant Biomass

Indicator plant (*Lactuca sativa* L.) was grown 35 days in a grow box and its production is the main indicator of phytotoxicity of each variant. Production of biomass is illustrated in Fig. 4. This graph consists of two axes and two parts. The horizontal axis shows variant of experiment and the vertical axis indicates the solids of plant biomass. The first part presents data relating to production of aboveground biomass and the second part underground biomass. Consider Fig. 4, which shows significant (P<0.05) changes in production of plant biomass. Toxicity of high doses of compost to the indicator crop has not been demonstrated. Conversely, most biomass was produced in variants with increased addition of compost in combination with mineral and organic fertilizer. The positive effect of the addition of fertilizers on salad was confirmed by [17].

Increased biomass production indicates a positive influence of the lignohumat addition on growth of indicator crop. Lignohumat contains humic acids, which have a positive influence on the development of the root system and accessibility of nutrients for plants. Lignohumat is a solution that contains 90% humic salts (humic and fulvic acids in the ratio 1:1).

The Values of pH and EC in the Soil Solution

The values of pH and EC are an important indicators of the soil state and they affect the chemical and physical processes in the soil. For example, the values of pH and EC have a direct impact on microbial activity and thus they indirectly affect nitrification and denitrification. These processes are important for the availability of N in the rhizosphere. This was confirmed by [18, 19]. For the complete results of pH and EC see Table 2.

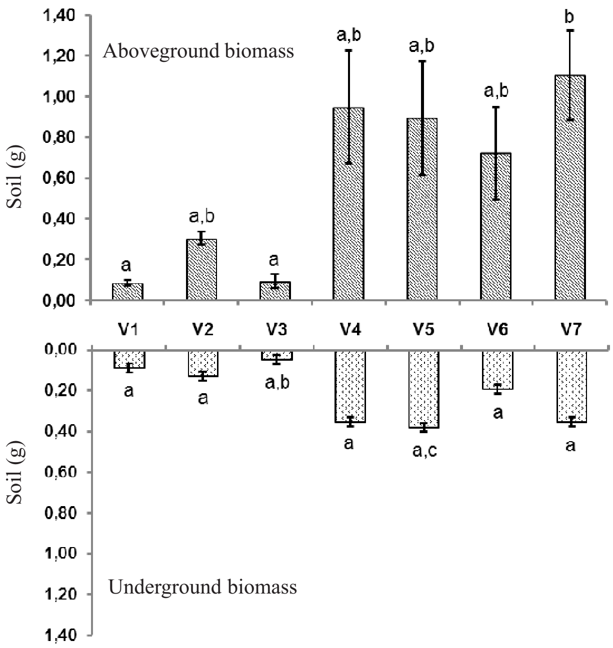

Fig. 4. Production of plant biomass (mean values ± standard error are shown, n=3).

Table 1. Soil salinity of soil solution.

Variants	pH	±SE	Mean differences
V1	6.4	0.10105	a
V2	7.4	0.03756	b,d,e,f
V3	5.5	0.03283	c
V4	7.2	0.00577	d
V5	7.6	0.04163	e
V6	7.5	0.08452	e
V7	7.4	0.01453	f,e

Different letters indicate significant differences at the level 0.05 – ANOVA, P<0.05).

Table 2. EC of soil solution.

Variants	EC ($dS\cdot m^{-1}$)	±SE	Mean differences
V1	0.12	0.00393	a
V2	0.31	0.00536	b,e,f
V3	0.47	0.02200	c,f,g
V4	0.71	0.05351	d
V5	0.29	0.01676	e,f
V6	0.37	0.01550	f
V7	0.55	0.04395	g

Different letters indicate significant differences at the level 0.05 – ANOVA, P<0.05).

The highest pH values were measured in variants with the addition of compost (V2, V4, V5, V6, V7). The lowest value of pH was found in variants with the addition of GSH (V3). This value is quite low and indicates acidic soil reaction. According to Act No. 156/1998 (Fertilizers Act), which establishes the quality requirements for arable land in the Czech Republic, the optimum range of pH is from 6.6 to 7.2. Optimal value of pH was measured only at variant with the addition of compost and GSH (V4). The value of pH was 8.06 in the pure sample of compost and 5.45 in the pure sample of soil. Organic waste compost was used for this experiment. This CP is produced from pruning remains, leaf litter, and sludge. Therefore, it is known as organic-waste. The optimal pH for organic-waste CP is the range of 7 to 8 [20]. Acidic soil reaction in combination with an acidic inorganic fertilizer was neutralized by the addition of alkaline CP.

The ability to modify soil reaction by adding CP is very important for Czech agriculture, because in recent years there were no funds to state the limits. The absence of limits has a direct negative impact on soil reaction (pH). This negative effect is manifested by reduced soil reaction below 5.

The values stated in Table 2 indicate the influence of CP on EC in soil solution. The measured values of EC indicate increase of salinity in the soil solution. The relation between EC and salinity is confirmed by [21]. The highest

Table 3. USDA soil salinity classes [21].

Salinity class	Salt content (%)	EC (dS m-1)
Non-saline	0	0-2
Very slightly saline	0.00-0.15	2-4
Slightly saline	0.15-0.35	4-8
Moderately saline	0.35-0.65	8-16
Strongly saline	>0.65	>16

values of EC were measured in variants with the addition of CP (V4 and V7). These values are conclusive ($p<0.05$) in comparison with control variant and variant with application of only GSH.

Table 3 shows the evaluation of soil salinity. Variants with a combination of compost and GSH (V4-V7) are ranked, according Table 3, from medium to high salinity. The control variant is very slightly saline, variant with only the addition of compost (V2) is slightly saline, and the variant with the addition of only GSH (V3) is moderately saline. The differences between these variants are significant. Measured values of EC show the influence of increased addition of CP on soil salinity (its value increases). This phenomenon is caused by increased content of minerals and organic substances. Risk of high doses of CP is described by [5]. The author draws particular attention to the possibility of increasing the content of salts and heavy metals in the soil. Disposable high doses of CP in combination with fertilizer can lead to salinization of arable land. Provided farmers will respect the recommended dose of CP (for example in CZE 50 $Mg \cdot ha^{-1}$). Salinity cannot increase. This fact is confirmed by [5, 22-24]. Conversely, compost can be used for amelioration of soils with a high content of salts [24].

Conclusions

Our experiment with increased doses of compost showed the potential risks. Increased doses of compost can have a negative effect on soil pH and EC. Based on the results of mineral nitrogen leaching, production of plant biomass and index of nitrogen availability, we can conclude that the increased dose of compost has a positive effect on microbial activity and declines leaching of mineral nitrogen from the arable soil. The results demonstrate that a single high dose of compost does not pose phytotoxic effects and, moreover, it promotes microbial activity. Compost and reclamation substrates made from it can be used for intensive remediation. The condition is that these substances must not be re-applied to the soil in the following years.

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