Effect of Organic-waste Compost Addition on Leaching of Mineral Nitrogen from Arable Land and Plant Production

Jakub Elbl, Lukas Plošek, Antonín Kintl, Jaroslav Záhora, Jitka Přichystalová, Jaroslav Hynšt

***Abstract*—**Application of compost in agriculture is very desirable worldwide. In the Czech Republic, compost is the most often used to improve soil structure and increase the content of soil organic matter, but the effects of compost addition on the fate of mineral nitrogen are only scarcely described. This paper deals with possibility of using combined application of compost, mineral and organic fertilizers to reduce the leaching of mineral nitrogen from arable land. To demonstrate the effect of compost addition on leaching of mineral nitrogen, we performed the pot experiment. As a model crop, *Lactuca sativa* L. was used and cultivated for 35 days in climate chamber in thoroughly homogenized arable soil. Ten variants of the experiment were prepared; two control variants (pure arable soil and arable soil with added compost), four variants with different doses of mineral and organic fertilizers and four variants of the same doses of mineral and organic fertilizers with the addition of compos. The highest decrease of mineral nitrogen leaching was observed by the simultaneous applications of soluble humic substances and compost to soil samples, about 417% in comparison with the control variant. Application of these organic compounds also supported microbial activity and nitrogen immobilization documented by the highest soil respiration and by the highest value of the index of nitrogen availability. The production of plant biomass after this application was not the highest due to microbial competition for the nutrients in soil, but was 24% higher in comparison with the control variant. To support these promising results the experiment should be repeated in field conditions.

***Keywords*—**Nitrogen, Compost, Salad, Arable land.

I. Introduction

THE largest part of global nitrogen pollution stems from agricultural activities [8]. Reduction of fertilizing is not satisfactory to prevent losses of mineral nitrogen from agricultural systems [20]. It will be necessary to change the method of farming. One option is to support the microbial activity in humus horizon (rhizosphere). Microbial activity can be supported by the addition of carbon [17]. Microbial processes supported by added carbon increase the capacity of the soil for capturing of mineral nitrogen. Nitrogen is subsequently stored in soil organic matter. The deposited organic nitrogen can be used later by plants or soil microorganisms and cannot be easily lost from arable land [1], [5], [7], [16], [19].

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From previously reported features of N transformations in soils, importance of soil organic matter is obvious. Microbial processes cannot exist without the presence of organic matter in the soil. Supply of soil organic matter can be reached by adding of compost [20]. Compost, the main product of the composting, may be defined as the stabilized and sanitized product of organic matter decomposition [5].

Leaching of mineral nitrogen (consisting of NH_4^+-N and NO_3^--N) from arable land is a major threat to the quality of drinking water from underground reservoirs in the Czech Republic [6], [9]. In the present paper, effect of compost addition on leaching of mineral nitrogen from arable land and production of plant biomass was investigated in laboratory experiment. Soil covering sources of drinking water near the town Brezova nad Svitavou was used for the experiment. In this area, application of mineral fertilizers has been radically reduced. Unfortunately, this step was not sufficient and increasing amount of NO_3^- is still detected in the water. Therefore, possibility of compost application as a source of organic matter for N stabilization in soil was investigated. Hypothesis which claims that addition of compost stimulates growth of plants at lower level of N leaching were tested. Realized laboratory experiment was built on research of mineral forms of N release from arable land, which has already been carried out for a long time in the Department of Microbiology.

II. Materials and Methods

A. Experimental Design

Experiment was performed in experimental containers with a square floor plan (Fig. 1). Eight seeds of *Lactuca sativa* L. (salad) were planted in each container. Containers were filled with 530g of soil with added fertilizer according to respective treatment. After one week, we left one germinated seed in each container. First 10 days, salad was irrigated with 20ml of distilled water every day. In the remaining time of experiment, salad was irrigated with 30ml of distilled water five days a week. During whole experiment, plants were kept in a climate chamber at 22^{o}C with a day length of 16h and a light intensity of 300μmol m^{-1} s^{-1}. After 35 days of cultivation, containers were destructively sampled, plants were dried at 105^{o}C and dry weight of aboveground and belowground plant biomass was determined [4]. Soil samples were stored at 4^{o}C until further analyses.

Two groups of the treatments "V and K" were prepared (V- only arable soil; K – arable soil with addition of compost). The both groups were formed by five variants (V1-V5; K1-K2), every variants with three repetitions. V1-V5 contained only arable soil (530g) and K1-K5 contained arable soil (500g) with addition of compost (30g). Applied dose of compost (30g) is in accordance with Czech Technical Standard (CSN EN 46 5735). In conversion, this dose represents 50Mg ha^{-1}.

We used organic fertilizer *Lignohumat - type B* (LG B) and inorganic fertilizer *GSH* for variants with addition of fertilizers. Lignohumat is 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. The doses of fertilizers were dissolved in 600ml of distilled water (for each variant). Fertilizers irrigation was applied twice a week.

Control variants (V1 and K1) were without addition of fertilizers. These variants were prepared: V2 and K2 – application of 90g m^{-2} of GSH; V3 and K3 – application of 50ml m^{-2} of LG B; V4 and K4 – application of 50ml m^{-2} of LG B + 45g m^{-2} of GSH (50% of the recommended dose); V5 and K5 – application of 25ml m^{-2} of LG B (50% of the recommended dose) + 45g m^{-2} of GSH.

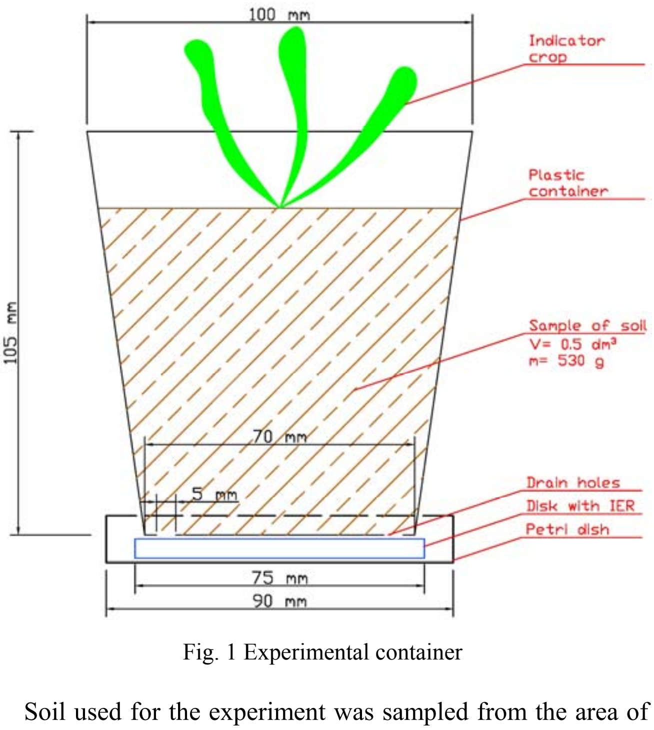

Fig. 1 Experimental container

Soil used for the experiment was sampled from the area of interest Brezova nad Svitavou. Soil sampling was done on the 28th of September. Compost samples were taken from the Central Composting Plant in Brno on the 30th of November. All used fertilizers and compost are registered (under the Fertilizers Law) for agriculture use in the Czech Republic. Applied compost was in accordance with CSN EN 46 573. Soil sampling was in accordance with CSN ISO 10 381-6 and compost sampling was in accordance with CSN EN 46 5735. Before using soil and compost samples were sieved through a sieve (grid size of 2mm). Prepared samples were then stored in a thermostat at a temperature of 4°C. Before application to the experimental containers, the samples were preincubated at laboratory temperature for 30 days.

B. Measurement of the Leaching of Mineral Nitrogen

Mineral nitrogen (NH_4^+-N and NO_3^--N) leached from the soil was captured by special discs with mixed IER (Ion Exchange Resin, see Fig. 2), which were located under each experimental container. The discs were made from plastic (PVC) tubes. Each disc was 75mm in diameter and 5mm thick. From both sides of each disc, nylon mesh was glued (grid size of 0.1mm). Mixed IER (CER– Cation Exchange Resin and AER– Anion Exchange Resin in ratio 1:1) were then placed into the inner space of annular flat cover [14].

Fig. 2 Plastic disk with IER

For the quantification of N_{min} trapped by the resin (CER and AER), the IER were allowed to dry at room temperature. Captured N_{min} was extracted from resin using 100 ml of 1.7 M NaCl. Released N_{min} was determined by distillation and titration method [15]. The results obtained from the Ion Exchange Discs were expressed in mg of N_{min} dm^{-3} of soil.

C. Ammonium Production during Waterlogged Incubation

In this method, soil N availability is estimated from NH_4^+-N produced during a 7 days waterlogged incubation. Method is based on the determination of difference between the original and final content of mineral nitrogen (ammonia and nitrate nitrogen at the beginning and ammonia only after the incubation) in the soil solution. This difference is appropriate to the amount of nitrogen that was presumably stored in the original microbial biomass before the incubation. The only anaerobic as well as facultative anaerobic thermophiles (these bacteria constitute a minority in the original soil environment) can survive this extreme conditions waterlogged incubation at 40°C. Organic N from original microorganisms is mineralized during the incubation and accumulated as NH_4^+-N [3].

We placed 50ml of distilled water and 20g soil sample into of 125ml incubation bottle. All variants (V1-V5; K1-K5) were prepared in three individual replications. The bottles were placed in an incubator at 40°C. After 7 day incubation we added 50ml of 4M KCl and we performed filtration. The ammonium was determined by distillation and titration method according [15].

The contents mineral nitrogen was estimated before the incubation. From each replication we took 20g of soil sample and shook for 60 minutes with 2M KCl. After shaking the determinations of ammonia and nitrate nitrogen (main compounds of mineral nitrogen) were made. This determination was performed according the same methods as for the determination of ammonia nitrogen after incubation.

The results obtained from the determination of mineral nitrogen (before incubation) and ammonia nitrogen (after incubation) were expressed in mg of N_{min} kg^{-1} and in mg of NH_4^+-N kg^{-1} of soil.

D. Determination of Cumulative CO_2 Production

Cumulative production of CO_2 was determined by measuring the CO_2 production from soils incubated in airtight bottles for 18h. Soil samples (20g) from specific variant (V1, V2 etc.) were placed into the 1000ml airtight bottles (three repetitions for each variant were prepared). CO_2 production was determined by the method using soda lime according to [10].

Soda limes granules consist of NaOH and $Ca(OH)_2$ and about 13-18% absorbed water. Water is required for chemical absorption of CO_2 to form Na_2CO_3 and $CaCO_3$. Carbonate formation is reflected in weight gain of granules. Weight gain of soda lime must be measured on oven-dried granules so that differences in water content of the initial batch of soda lime, and water absorption during exposure do not interfere with measured weight gain of CO_2 [10].

We used for our experiment soda lime granules, which a mesh size of 2-5mm. Soda lime was had placed petri dishes, which were located into airtight bottles on metal tripod. In each box 4.52g soda lime (0.06g cm^{-2} of soil surface in airtight bottle) was put. Soda lime was dried at 105°C for 14h before application. After 24h incubation soda lime was dried again (105°C; 14h) and weighed with an accuracy of four decimal places. In addition to all variants, we have prepared the three blank samples. These samples were made up of soda lime, which was placed into airtight bottles without soil samples. We used the same airtight bottle as for incubation. Soda lime was dried and weighed the same way as in the previous cases.

Cumulative production of CO_2 was calculated by the modified formula [10] (originally), as in (1). The results obtained from the determination of cumulative CO_2 production were expressed in g of C m^{-2} day^{-1}.

$$\text{Soil } CO_2 \text{ efflux (g C m}^{-2}\text{day}^{-1}) = \left\{\frac{\text{sample weight gain (g) - mean blank w. gain (g)} \times 1.69}{\text{chamber area (m}^2)}\right\} \times \left[\frac{24\text{ h}}{\text{duration of exposure (h)}}\right] \times \left[\frac{12}{44}\right] \quad (1)$$

E. Determination of pH and EC

Before filling the experimental containers, we performed measurements of active pH and electrical conductivity (EC) of soil, compost and soil with addition of compost. EC and active pH were measured by HACH LANGE sesION^{TM}+. After the end of the experiment, pH and EC was determined in each soil sample (from each repetition of individual variants: V1a, V1b, V1c, K5a, K5b, K5c etc.). EC in individual samples was determined in accordance with CSN ISO 11 265 and active pH was determined in accordance with CSN ISO 10 390 and CSN EN 46 5735.

Active pH was measured in suspension, which was created by extraction of soil with boiled distilled water. Extraction was performed by shaking the solution of soil and water (in ratio 1:5) for 60 minutes. This procedure was used for arable soil and arable soil with addition of compost (in accordance with CSN ISO 10 390). For compost we used a similar procedure (in accordance with CSN EN 46 5735). We used the same ratio of soil and extraction solution (boiled distilled water), but extraction by shaking was performed only 10 minutes.

EC was measured in filtrate, which was produced by filtering a suspension of soil sample (or compost) and boiled distilled water (in ratio 1:5). This suspension was performed by shaking the soil sample and extract-ant for 30 minutes (in accordance with CSN ISO 11 265).

F. Statistical Analysis

Differences in the amount of leached mineral nitrogen, respiration, pH and EC were analyzed by one-way analysis of variance (ANOVA) in combination with the Tukey´s test. All analyses were performed using Statistica 10 software.

III. Results and Discussion

The subject of our interest was to determine the positive influence of compost and other fertilizers addition on leaching of mineral nitrogen from arable land and plant biomass production. To confirm or refutation of this hypothesis, pot experiments were conducted. The main results of the experiment are the values of detection of mineral nitrogen. These values are supplemented by further determination which expresses the microbial activity (respiration) and the effect of the compost addition on soil properties (pH, EC).

Obtained results are divided into four sections: leaching of mineral nitrogen, ammonium production during waterlogged period, plant biomass production and finally cumulative CO_2 production.

A. Leaching of Mineral Nitrogen

Leaching of mineral nitrogen was expressed as the detection of ammonium and nitrate forms on the Ion Exchange Resin (mg N_{min} $dm^{-3}$of soil). Expression of results was explained in the preceding section.

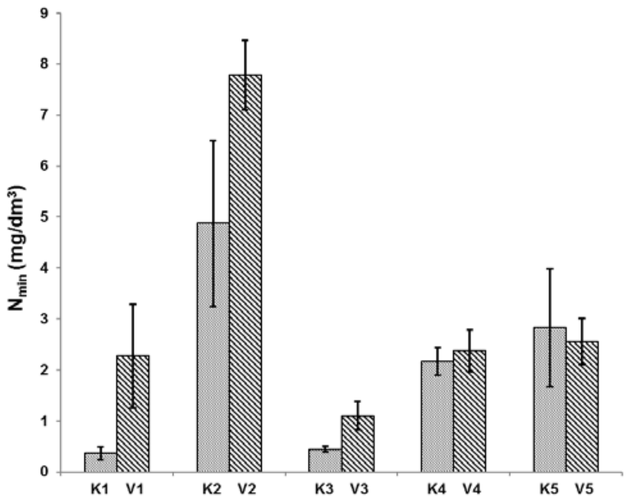

Fig. 3 Detection of mineral nitrogen

The above Fig. 3 ($\overline{x}$ from each variant, ± σ) indicates a significant difference between the variants K1 (K2) and V1 (V2) in detection of mineral nitrogen (N_{min}). Higher detection of N_{min} (V2 = 7.78 mg dm^{-3}) was recorded at the variant without the addition of compost or another organic substance (Lignohumat). These results indicate positive influence of C_{org} (organic carbon) addition on leaching of N_{min} from arable soils. All variants with addition of C_{org} showed lower detection of nitrogen than variants without. C_{org} was present in all variants with addition of compost (K1-K5) and in variants with addition of Lignohumat (V3-V5).

B. Ammonium Production during Waterlogged Period-Index of Nitrogen Availability

Ammonium N, which was determined in filtered extracts, indicates the amount of NH_4^+-N in the microbial biomass.

Results are presented in Fig. 4 ($\overline{x}$ from each variant, ± σ) show influence of compost (K1-K5) and another organic carbon (V3-V5) addition on availability of NH_4^+-N in microbial biomass. This situation can perhaps be explained by the fact that addition of compost (or Lignohumat) leads to an increase in the contents of utilizable nutrients in the soil. Development of the microbial activity has a positive effect on leaching of N_{min} from arable soils. Positive effect of compost addition on nitrogen availability is described for example by [13].

The largest stockpile of NH_4^+-N was detected in variants with addition of compost. Specifically, it was noticed in the variant K3 (34.77mg kg^{-1}). Consider Fig. 3, which shows detection of mineral nitrogen. In variant K3, second lowest nitrogen leak (0.44 mg dm^{-3}) was measured, whereas from variant V2 with minimal contents of NH_4^+-N (see Fig. 4), the greatest amount of mineral nitrogen was released.

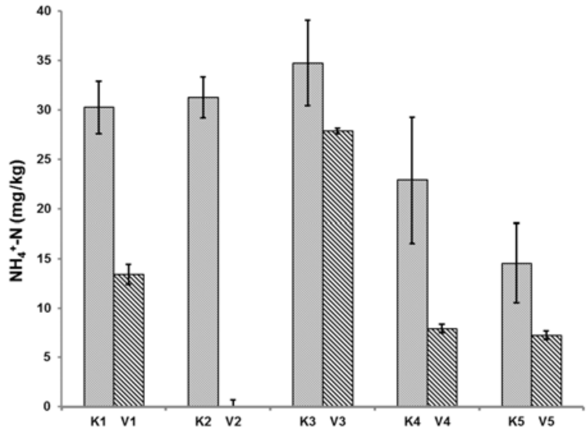

Fig. 4 Ammonium production during waterlogged period

C. Plant Biomass Production

Production of plant biomass was chosen as the main indicator of the impact of compost addition on plant vitality. The largest biomass production was achieved in variants with the addition of compost.

Consider Fig. 5 ($\overline{x}$ from each variant, ± σ) which shows a significant difference between the variants with addition of compost and without. The horizontal axis indicates variant of experiment and the vertical axis shows the solids (in g) of plant biomass. The graph is composed of two parts, which presents data relating to production of aboveground and underground biomass. Indicator crop was grown 35 days.

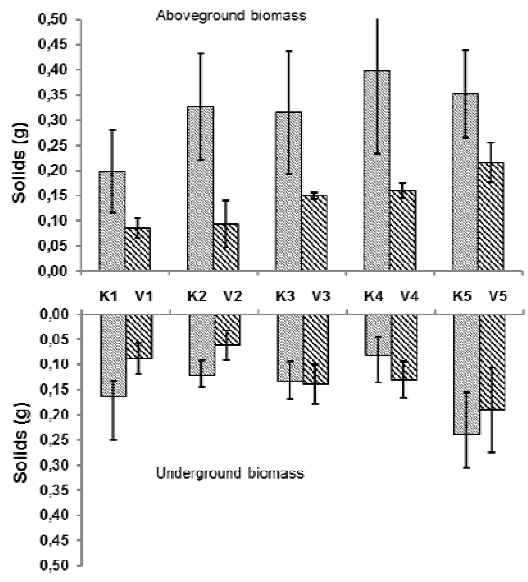

Fig. 5 Production of plant biomass

The above values show that the addition of compost in combination with mineral and organic fertilizer has a positive effect on plant biomass production. Reason for this is a combination of energy source (C_{org} in compost) with essentials nutrients (NPK in mineral fertilizer). Reference [2] confirms positive effect of compost addition on plant production.

D. Cumulative CO_2 Production

Cumulative CO_2 production was determined during 18h incubation and under laboratory conditions. Methodic of this measurement can be found in the section above.

From Fig. 6 ($\overline{x}$ from each variant, $\pm \sigma$), we can see that CO_2 production reaches a peak at the variant K3 (2.086 g C m^{-2} day^{-1}). There is a contrast between variants with addition of compost and variants without compost or another source of C_{org} (V1 and V2). In variants V1 and V2, the lowest values (V1 = 0.026 and V2 = 0,132 g C m^{-2} day^{-1}) were detected, whereas in variants V3 – V5, rise of CO_2 production was observed. This increase can perhaps be explained by the fact that these variants (V3-V5) were complemented by C_{org}.

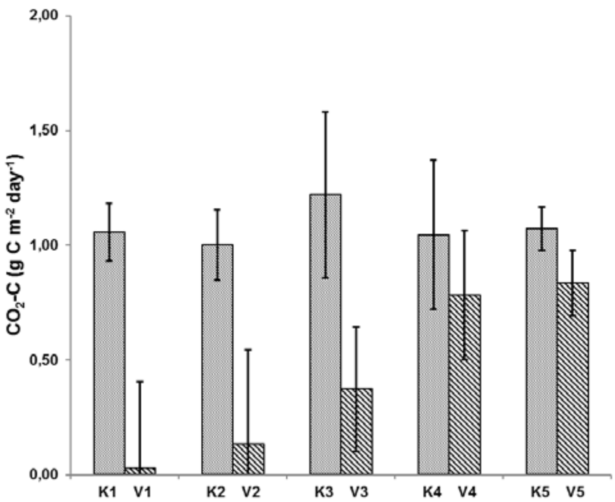

Fig. 6 Cumulative CO_2 production

Organic carbon represents the energy for microorganisms, which use it for their development. The growth in microbial activity is reflected in rise of their respiration. An arable soil with high microbial activity has a greater ability to retain Nm_{in} in the rhizosphere. Consider Fig. 3, which shows the lowest detection of N_{min} in variant K1 a K3. Similarly in this variant, the highest respiration was measured. This situation confirms that the addition of compost has a positive effect on microbial activity and reduces leaching of N_{min}. Influence of C_{org} addition and humidity on microbial activities was confirmed by [9], [12], [18].

E. pH and EC of Soil Solution

EC and pH values are very important indicators which directly affect the soil microbial properties. This was confirmed by [17], who studied the influence of pH on denitrification in soil. High or low pH can inhibit the process of denitrification. EC was determined because there is a direct connection with the content of salts in the soil solution. This is confirmed by for example [11].

For the complete results of pH and EC, see Figs. 7 and 8. Both graphs consist of two groups of points. Black dot represents the variant with addition of compost and small black cross represents the variant without. The y axis indicates values of pH or EC and the x axis shows designation of experiment variations: 1 – control, 2 – addition of NPK, 3 – addition of LG etc. This distribution of fertilization variants were listed in preceding section (materials and methods).

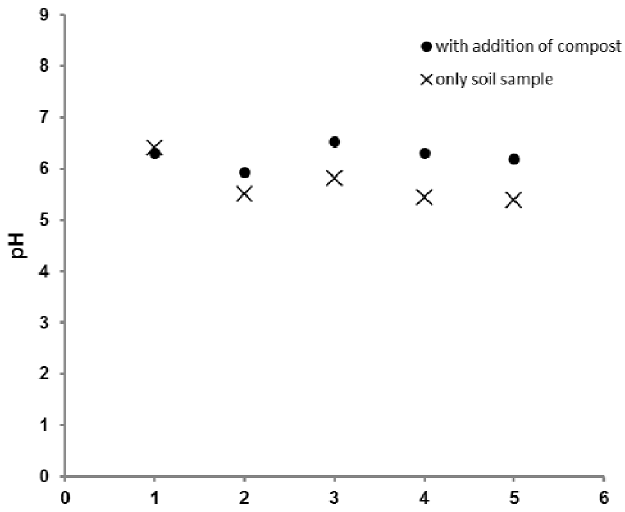

Fig. 7 pH of soil solution

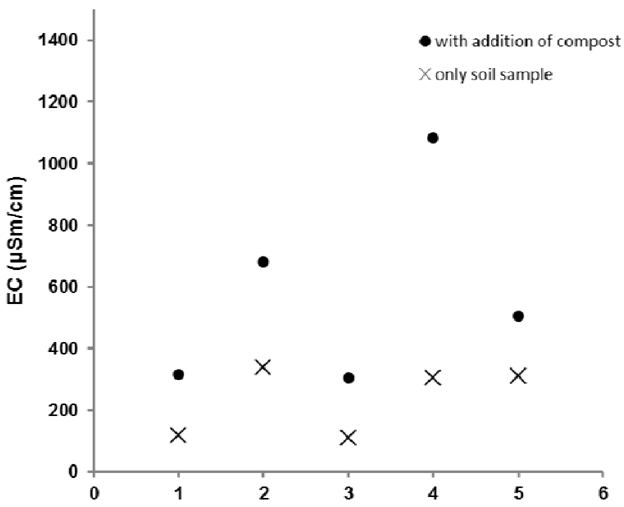

Fig. 8 EC of soil solution

Measured values of pH in variant with compost addition are accordance with Czech standard for arable soil (under the Fertilizers Law). Values of EC do not suggest on increase salinity in the soil solution.

IV. Conclusions

Based on these results, we can conclude that the addition of compost have a positive effect on microbial activity and decrease in leaching of mineral nitrogen from the soil. For these comparisons, we may draw the following conclusions. There are large differences between arable soils with addition of compost and arable soils without, as it was expected. Compost has a positive impact on the soil environment. This positive effect is manifested in all variants of fertilization. The authors are aware that the experiment was conducted under laboratory conditions and it should be repeated as a field-experiment.

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