

Mineral Nitrogen Retention, Nitrogen Availability and Plant Growth in the Soil Influenced by Addition of Organic and Mineral Fertilizers – Lysimetric Experiment

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Abstract—Compost can influence soil fertility and plant health. At the same time compost can play an important role in the nitrogen cycle and it can influence leaching of mineral nitrogen from soil to underground water.

This paper deals with the influence of compost addition and mineral nitrogen fertilizer on leaching of mineral nitrogen, nitrogen availability in microbial biomass and plant biomass production in the lysimetric experiment. Twenty one lysimeters were filled with topsoil and subsoil collected in the area of protection zone of underground source of drinking water - Březová nad Svitavou. The highest leaching of mineral nitrogen was detected in the variant fertilized only mineral nitrogen fertilizer (624.58 mg m^{-2}), the lowest leaching was recorded in the variant with high addition of compost (315.51 mg m^{-2}). On the other hand, losses of mineral nitrogen are not in connection with the losses of available form of nitrogen in microbial biomass. Because lost of mineral nitrogen was detected in variant with the least change in the availability of N in microbial biomass.

The leaching of mineral nitrogen, yields as well as the results concerning nitrogen availability from the first year of long term experiment suggest that compost can positive influence the leaching of nitrogen into underground water.

Keywords—Nitrogen, Compost, Biomass production, Lysimeter.

I. INTRODUCTION

INTENSIVE agricultural management has brought economic and social development but it has also contributed to land degradation in terms of soil organic matter decline, soil erosion, biodiversity loss and water contamination by nutrients [6], [15]. Since nitrogen (N) is the most common limiting element for crop production, especially in long-term cultivated soils [21], [22], this has resulted in an increase in N fertilizers application [21]. A negative outcome of over-fertilization is pollution of water (underground and surface) [5].

The advantages of the use of organic wastes such as compost as fertilizers are evident. Their use would reduce the consumption of commercial fertilizers which need in their production high cost and energy [18]. Compost amendment improves physical, chemical and biological properties of soils,

in particular by increasing available nutrients mainly in the organic soil fractions [4], [7] and there is evidence that application of organic amendments to soils could also reduce soil mineral N [21]. Many studies have reported that addition of a high C, low N organic amendment to soil can stimulate microbes to take up the available N from their environment for their own growth, in a process known as immobilisation [1], [13], [21]. Also, the application of compost increases the plant cover and stimulates soil microbial growth and activity [17], [20]. On the other hand, if the compost is applied in high doses it can negatively influence desirable groups of microorganisms, reduce yield of crops, increase leaching of nutrients [9], [15].

Area of our interest is the protection zone of underground source of drinking water “Březová nad Svitavou” (further protection zone). This protection zone is located in the northern part of the Czech-Moravian highland and it is responsible for protection of underground source of drinking water against contamination by pollutants. Unfortunately, the function of this zone is ineffective which is indicated by increasing mineral nitrogen concentrations in the drinking water from this area [23].

Leaching of mineral nitrogen (consisting of $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$) from arable land is a major threat to the quality of drinking water from underground reservoirs in the Czech Republic [14]. The area is situated on the Bohemian Cretaceous basin and consists of a system of soil isolators and collectors. The isolators are made by impermeable soil. Conversely, collectors are filled with light soils. These soils allow infiltration of precipitation and water transfer. Unfortunately, most collectors are under agricultural land. Therefore, mineral nitrogen from arable land can quickly contaminate underground sources of drinking water there [8].

In the soil, the microbial activity is the key to stop the leaching of mineral nitrogen. Soil microorganisms have the ability to immobilize the mineral nitrogen in their bodies. Moreover, microorganisms help to restore SOM, if organic carbon (in compost) is added to the soil. SOM has a direct impact on the capacity of the soil for retaining mineral nitrogen and other nutrients [8], [19], [23].

The aim of this paper was to test the hypothesis that addition of compost can decrease leaching of mineral nitrogen

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while maintaining or increasing of plant production compared to using only mineral fertilization.

II. MATERIALS AND METHODS

A. Experimental Design

Effect of addition of different types of fertilizers was tested by pot experiment, previously detailed by [8].

Twenty one lysimeters have been used as experimental containers and located in the area. The experiment was conducted in the protection zone of underground source of drinking water Březová nad Svitavou, where annual climatic averages (1962-2012) are 588.47 mm of precipitation and 7.9°C mean of annual air temperature. The lysimeters were made from PVC (polyvinyl chloride). Each lysimeter was the same size and was filled with 25 kg of subsoil, 25 kg of topsoil (arable soil) and with compost in selected variants. See Fig. 1.

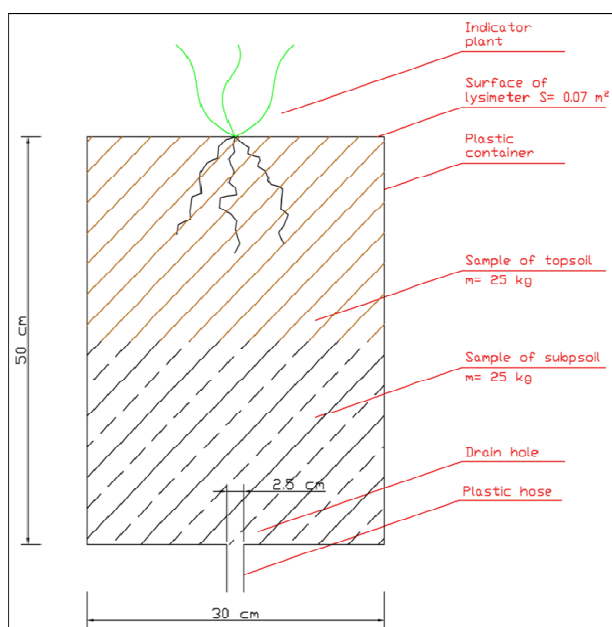


Fig. 1 Detail of experimental container – lysimeter according to [8]

Topsoil and subsoil were collected from a field in the area. Soil samples were sieved through a sieve (grid size of 10 mm) and homogenized. Topsoil and subsoil were prepared separately. Each lysimeter had one drain hole and PVC hose for collecting soil solution. Hose leads into the plastic bottle. All lysimeters were buried into the ground (Fig. 2). Collection of soil solution and monitoring of the lysimeters was carried out in the control shaft (Fig. 2). Lysimeters were completed and filled in October 2012. Winter wheat was used as a nodal plant to determine the effect of addition of different types of fertilizers, microbial activities and weather on plant production. Winter wheat (22 grains into each of lysimeters) was planted in the end of October.



Fig. 2 Detail of the lysimetric experiment and control shaft

Seven variants of the experiment were prepared, each one in three repetitions:

- C1 – arable soil with the addition of 100% of recommended dose of N,
- C2 – arable soil without the addition of fertilizers,
- K1 – arable soil with the addition of 100% of recommended dose of compost,
- K2 – arable soil with the addition of 100% of recommended dose of compost and 25% of recommended dose of N,
- K3 – arable soil with the addition of 100% of recommended dose of compost and 50% of recommended dose of N,
- K4 – arable soil with the addition of 100% of recommended dose of compost and 100% of recommended dose of N,
- K5 – arable soil with the addition of 200% of recommended dose of compost.

Information on the applied fertilizers: Compost (Černý drak) samples were taken from the Central Composting Plant in Brno and it is registered (under the Fertilizers Law) for agriculture use in the Czech Republic. Nitrogen was applied as a liquid fertilizer DAM 390. DAM 390 is a solution of ammonium nitrate and urea with an average content of 30% nitrogen (1/4 of nitrogen is in the form of ammonium, 1/4 is in the nitrate form and 1/2 is in the form of urea). One hundred liters of DAM 390 contain 39 kg of nitrogen. Recommended dose in Czech Republic of compost is 5 kg m⁻² per 5 years and of nitrogen is 140 g m⁻² per year for winter wheat.

B. Leaching of Mineral Nitrogen in Soil Solution

Leaching of mineral nitrogen (N_{min}) was measured using distillation-titration method by [16]. Ammonium nitrogen was determined by distillation-titration method in an alkaline solution after the addition of MgO. Nitrate nitrogen was determined in the same manner using Devard's alloy. Concentration of NH₄⁺-N and NO₃⁻-N was calculated:

$$\text{mg NH}_4^+ \text{ or NO}_3^- - \text{N} = \left(\frac{\text{normality of standart HCl}}{0.03571} \right) \times 0.5 \times \text{titration} \quad (1)$$

The value of N_{min} was calculated as the sum of the detected ammonium and nitrate forms.

Determination of N_{\min} was performed after each sampling of the soil solution and in each sample. The results obtained from the analyses of soil solution were expressed in mg of N_{\min} (NH_4^+-N and NO_3^--N) per m^2 ($mg\ m^{-2}$).

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 proportional 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 of waterlogged incubation at 40°C. Organic N from original microorganisms is mineralized during the incubation and accumulated as ammonia nitrogen (NH_4^+-N) [3].

20 g of field-moist soil sample from each variant was weighed into 125 ml incubation bottle. 50 ml of distilled water was then added into each bottle. The bottles were placed in an incubator at 40°C. After 7 days incubation 50 ml of 4 M KCl was added and filtration was performed. The ammonium was determined by distillation and titration method according [16].

The content of mineral nitrogen was estimated before the incubation. From each replication 20 g of soil sample was taken and it was shaken for 60 minutes with 2 M KCl. After shaking the determinations of ammonia and nitrate nitrogen (main compounds of mineral nitrogen) were made. This determination was performed using 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) was expressed in mg of $N_{\min}\ kg^{-1}$ and in mg of $NH_4^+-N\ kg^{-1}$ of soil.

D. Plant Biomass Production

In August 2013 aboveground biomass and grains of winter wheat were harvested. The obtained biomass and grains were dried at 60°C to constant weight.

E. Statistical Analysis

Potential differences in the values of plant biomass, leached mineral nitrogen in soil solution, nitrogen availability were analyzed by one-way analysis of variance (ANOVA) in combination with the Tukey's test. All analyses were performed using Statistica 10 software. The results were processed graphically in the program Microsoft Excel 2007.

III. RESULTS AND DISCUSSION

A. Leaching of Mineral Nitrogen in Soil Solution

From October 2012 to August 2013 soil solutions samples were taken for measuring of N_{\min} (sum of NH_4^+-N and NO_3^--N). Table I shows the leaching of N_{\min} in soil solution from seven variants of the experiment (with three replications).

TABLE I
CONCENTRATION OF AMMONIUM AND NITRATE NITROGEN IN SOIL SOLUTION

Variants	NH_4^+-N ($mg\ m^{-2}$)	$\pm SD$	NO_3^--N ($mg\ m^{-2}$)	$\pm SD$
C1	56.13	31.92	568.46	85.78
C2	21.10	8.31	405.90	34.11
K1	17.68	2.34	482.10	78.05
K2	14.69	2.86	508.89	72.03
K3	35.18	18.70	510.47	75.93
K4	28.75	12.60	576.09	65.23
K5	27.63	6.64	287.88	70.69

Leaching of ammonium nitrogen was not significant among treatments. On the other hand high addition of compost (variant K5) had a positive effect on concentration of nitrate nitrogen in soil solution. 200 % dose of compost in variant K5 significantly decreased leaching of N_{\min} compared with all variants.

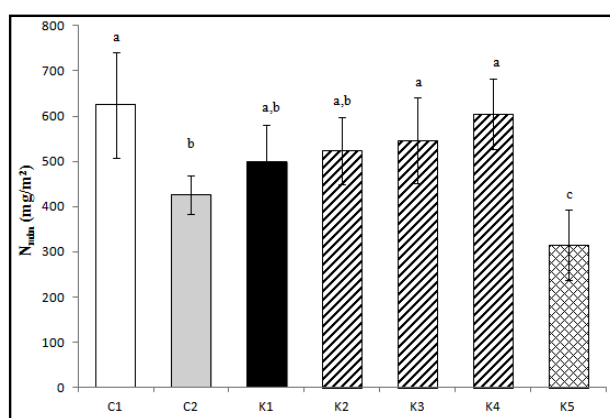


Fig. 3 Detection of mineral nitrogen in soil solution. Different letters indicate significant differences (ANOVA, $P < 0.05$)

Fig. 3 shows leaching of N_{\min} from soil. The highest concentration of N_{\min} was detected in variant C1 - with addition 100 % of recommended dose of nitrogen ($964.58\ mg\ m^{-2}$) and the lowest concentration of N_{\min} was detected in variant K5 - with addition of 200 % of recommended dose of compost ($315.51\ mg\ m^{-2}$).

Positive effect of compost addition on leaching of N_{\min} was confirmed by various scientific studies [7], [8], [10], [12], which confirm that C_{org} is a source of energy for soil microorganisms and its application in form of compost has a positive effect on microbial activities in soil.

B. Index of Nitrogen Availability

Ammonium N, which was determined in filtered extracts, indicates the amount of NH_4^+-N in the microbial biomass. The concept of soil nitrogen availability may represent the rate at which N is converted from unavailable to available forms within the rooting zone. The pool of N contained in microbial biomass is a major source of labile N in most soils [2].

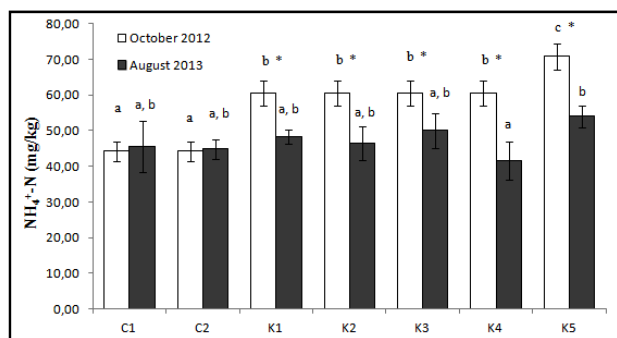


Fig. 4 Ammonium production during waterlogged period. Values are means and standard errors of three replications. Different letter indicate significant difference in one period (ANOVA, $P < 0.05$) and * indicate significant differences in one variant

Fig. 4 shows availability of NH_4^+ -N at the beginning of the experiment (October 2012) and after one year (August 2013). It is obvious that after one year in variants with compost addition (K1-K5) N availability decrease practically on the same level as the variants without the compost fertilization (C1-C2). On the other hand decreasing of availability it is not relating with leaching of N_{\min} , it means that the highest lost of mineral nitrogen are not in connection with the highest lost of available form of nitrogen in microbial biomass.

C. Biomass Production

In August of 2013 the indicator plant (winter wheat) was harvested and its production is the main indicator of effects of different types of fertilization. Fig. 5 presents the complete production of plant biomass for the first year of the experiment (October 2012 - August 2013).

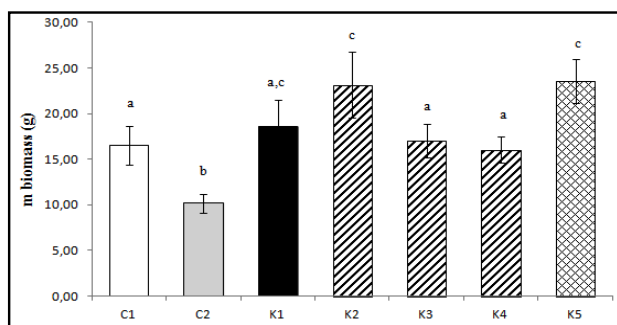


Fig. 5 Production of plant biomass. Values are means and standard errors of three replications. Different letters indicate significant differences (ANOVA, $P < 0.05$)

Consider the data in Table II. These data shows the percentage relationship between grain production and total biomass production (column %).

TABLE II
TOTAL BIOMASS PRODUCTION AND PRODUCTION OF GRAINS

Variants	grain production (g)	±SD	biomass production (g)	±SD	%
C1	16.54	3.02	57.07	4.66	28.98
C2	10.18	1.45	36.78	1.52	27.67
K1	18.52	4.22	69.14	3.01	26.79
K2	23.15	5.15	76.19	8.18	30.38
K3	17.02	2.59	67.67	0.66	25.16
K4	16.03	2.05	78.02	4.37	20.55
K5	23.58	3.39	70.28	5.44	33.55

The highest production of biomass and grains were detected in all variants with compost addition (K1-K5), but high addition of N fertilizer (in variant K3 and K4) significantly decrease production of biomass and grain.

In accordance to our hypothesis, the highest biomass and grain production with respect concentration of N_{\min} was found in variant K5. However, it is necessary to maintain the quality of the compost at the input to the soil. Inadequate management of the composting process may result in composts containing plant pathogens, weed seeds or toxic compounds which can cause damage to the crops. In contrast, well-managed composts can have the capacity to stimulate plant growth and to protect crops against diseases [10], [11].

IV. CONCLUSIONS

This contribution presents the first year results of a long-term lysimetric experiment. Based on the results, we can conclude that the high addition (200% of recommended dose) have a positive effect on microbial activity which is in connection with leaching of N_{\min} and plant biomass production.

Leaching of N_{\min} is not in connection with availability of nitrogen, because lower leaching of N_{\min} was observed in variants with initial higher index of nitrogen availability.

The obtained results will be necessary verified in the following years of the experiment.

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