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Fertigation Use in Agriculture and Biosorption of Residual Nitrogen by Soil Microorganisms

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***Abstract*—**Present work deals with the possible use of fertigation in agriculture and its impact on the availability of mineral nitrogen (N_{min}) in topsoil and subsoil horizons. The aim of the present study is to demonstrate the effect of the organic matter presence in fertigation on microbial transformation and availability of mineral nitrogen forms. The main investigation reason is the potential use of pre-treated waste water, as a source of organic carbon (C_{org}) and residual nutrients (N_{min}) for fertigation. Laboratory experiment has been conducted to demonstrate the effect of the arable land fertilization method on the Nmin availability in different depths of the soil with the usage of model experimental containers filled with soil from topsoil and podsoil horizons that were taken from the precise area. Tufted hairgrass (*Deschampsia caespitosa*) has been chosen as a model plant. The water source protection zone Brezova nad Svitavou has been a research area where significant underground reservoirs of drinking water of the highest quality are located. From the second half of the last century local sources of drinking water show nitrogenous compounds increase that get here almost only from arable lands. Therefore, an attention of the following text focuses on the fate of mineral nitrogen in the complex plant-soil. Research results show that the fertigation application with C_{org} in a combination with mineral fertilizer can reduce the amount of N_{min} leached from topsoil horizon of agricultural soils. In addition, some plants biomass production reduces may occur.

***Keywords*—**Fertigation, fertilizers, mineral nitrogen, soil microorganisms.

I. Introduction

MINERAL nitrogen losses from agricultural soils are of a great challenge for the farmers and the country inhabitants. The reason is based on the influence of mineral nitrogen (N_{min}) on agricultural soils fertility and on quality of a groundwater along with surface water. On N_{min} addition plants respond with a lush growth, but N_{min} amendment to plants is desirable only to the extent that prevents its losses from the soil [1]. Human activity leads to an excessive input of so-called locally non-native nitrogen or reactive nitrogen compound (N_r). Reference [2] defines N_r as the reactive form of nitrogen that represents its oxidized (NO, NO_2, NO_3), reduced (NH_4^+, NO_3^-) and organic forms (proteins, amines etc.).

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The continuous N_r concentration increase in the soil can lead to a situation where the soil will reach its maximum capacity of nitrogenous compounds immobilization. Subsequently, plant or microbial community is not able to immobilize excessive nitrogen that enters further into the soil. Resulting condition is called soil saturation by nitrogen compounds. Thus saturated soil poses a risk to groundwater contamination by nitrogen and especially by nitrates. The reason is based in the negative affinity of soil sorption complex to the negatively charged particles (NO_3^-) and groundwater sources restore by precipitation percolation through saturated soil profile. It occurs mainly because of the leaking water that carries nitrates into deeper layers of the soil, which is unable to hold back soil sorption complex.

Apart from the negative impact of soil saturation by N_r farmers in Czech Republic have to face another problem that is recurrent drought periods and declining quality and quantity of humic substances in topsoil horizon. The solution of these problems may be the use of pre-treated waste water suitable for agricultural land irrigation. Moreover such fertigation can supply the soil not only with essential nutrients (NPK) but also with very important for the microorganisms organic substances such as available organic carbon (C_{org}).

Nitrogen along with carbon, oxygen and silicon are ranked among the most common elements that occur in the compounds that are necessary for the life appearance on our planet. Although a problem may lay in their natural availability, for example great amount of nitrogenous compounds are located in the earth's crust, rocks and soil. In addition lithosphere contains over 98% of all Earths nitrogen which is mainly unavailable for plants [3], [4].

Total nitrogen content can be expressed as nitrogen total (NT) and within the topsoil layer of Czech Republic's soil it reaches 0.1-0.2%, further it can be calculated that in the topsoil layer is about 3000 – 9000 kg N per ha^{-1}. From this amount only 1-2% of nitrogen is available for plants in the forms of ammonium (NH_4^+,) and nitrate nitrogen (NO_3^-) or nitrates. For sufficient plant nutrition is necessary an access of mentioned N_{min} forms or adding them into the soil. Another solution may concern the problem of nitrate leakage into the deeper parts of the soil profile and subsequently into the groundwater. Significant influence on the limitation of soil N_{min} leakage from agro-ecosystems has the quantity and the quality of soil organic matter (organic carbon), the soil sorption complex condition, the amount and the type of applied fertilizers, the arrangement of crop rotation and the tillage method.

The activity of soil microorganisms plays a key role in the

N_{min} retention and its enable for plant nutrition use. The actual activity of the microorganisms is dependent on many factors. Among the most important is the presence of a sufficient amount of water and organic matter as the main energy source of organic carbon, which is proved by [5] that proper organic carbon application can positively affect soil geobiochemical part of the nitrogen cycle in a way to minimize its leakage from agricultural soils. In the first half of the 90s [6] drew attention to the fact that exist recurrent and lengthening periods of dryness. Furthermore, farmers cannot ensure for cultivated crops not only sufficient moisture regime, but also C_{org} supply on the biggest parts of arable land in Czech Republic in cases where steadily decreasing production of manure and other organic substances occur. Therefore, importance of fertilizing irrigation grows in geomorphological appropriate areas such as South Moravia.

Sufficient C_{org} amount in the soil leads to the microbial biomass development. Subsequently, increasing soil microbial activity has a positive effect on soil capacity increasing for N_r retention in the soil. The main N_r retention mechanism in the soil is called bio-sorption. Reference [7] describes bio-sorption as an intake of inorganic and organic matter by soil microorganisms, which can be done either passively or actively. The most important for nutrients maintaining in the soil is an active bio-sorption, which is the result of individual microorganism's metabolic activity (bacteria, fungi, yeast, etc.).

Due to the harsh conditions concerning surface water availability it appears to be very applicable a waste water pre-purifying, which can provide plants with the necessary moisture amount and with biogenic nutrients such as N_{min} and P. Researchers [8]-[10] recommend to use sewage or municipal wastewater for fertigation. Reference [9] draws attention to the fact that for this purpose are suitable primarily waste waters from towns and villages without extensive industry and with prevailing residential development. The reason is based on less contamination risk from industrial sources and less composition variability with relatively continuous quantity. Some authors recommend to perform mechanical treatment of municipal wastewater before its using, it comes about the nutrient content reduce [10]. On the other hand prepared such way irrigation water is suitable for application by means of so-called localized irrigation.

Apart from the pre-treated wastewater from conventional (mechanical-biological) industrial water treatment, exists an alternative waste water use from the root and domestic purifications or ground filters. The problem of wastewater smaller sources is in quantity and continuity of wastewater supply for an irrigation purposes. According to [9], [11], [12] and the others irrigation by the wastewater has significant effect on chemical and physical properties of the soil that can be of positive or negative influence. The main negative effect may deal with a soil erosion increase and nutrients leaching into underground drinking water sources. Negative irrigation influence can be frequently associated with an imperfect irrigation planning that is poorly set plants water demand, irrigation norm etc. and consequently poorly executed implementation. The most important positive influence concerning N_{min} release is of humus creation support (increase of organic matter content in the soil) and support of microbial activity in the soil. The irrigation water quality is regulated by CSN ISO 75 143 (CSN - Czech Technical Standard).

Soil organic matter is an indispensable source of available decomposable carbon which serves as an energy source for N_2.biological fixation. Natural ecosystems take advantage of the natural atmospheric nitrogen fixation for balance maintaining of nutrients intake and their expenditure. Moreover, nitrogen fixation plays a key role in agro-ecosystems, as an alternative source of nitrogenous substances in a combination with a proper crop rotation, incorporation of organic matter into the soil etc. [3], [4], [13].

II. Material and Methods

A. Experimental Design

Fertigation use in agriculture and bio sorption of mineral nitrogen by soil microorganisms have been tested by a container experiment set up in a growth box. Twenty seven containers from PVC have been used for this experiment. Equal size lysimeters (see Fig. 1) have been filled with 3 kg of topsoil and 7.5 kg of subsoil. Experimental soil has sampled from the area Březová nad Svitavou. Soil sampling has been done on the 10th of October 2014 in accordance with CSN ISO 10 381-6. Soil samples have been sieved through a sieve (grid size of 2 mm) before the using. In addition, soil samples have been preincubated at laboratory temperature for 30 days before their application. *Deschampsia caespitosa* has been used as a model plant (1 plant per container). Experimental containers with an indicator plant have been kept in phytotron at 24°C day temperature, 20°C night temperature, 65 % humidity (for 24h) with a day length of 12 h during the whole experiment (Fig. 2). Light intensity is 380 $\mu mol \cdot m^{-1} \cdot s^{-1}$ [14].

Five variants of the fertilizers treatment have been prepared (V1–V5): V1 is a control variant without addition of fertilizers; variants V2–V5 have been fertilized by fertigation which has been prepared from fertilizers Lignohumate and GSH according to [15]: Lignohumate - 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 (NPK) is a common mineral fertilizer containing N, P, K and S in the ratio 10:10:10:13.

The doses of the above applied fertilizers were dissolved in 600 ml of distilled water for each variant. Fertilizers irrigation has been applied twice a week. These variants have been prepared in a way: V2 – application of 90 g m^{-2} of GSH (representing 100% of recommended dose); V3 – application of 50 ml m^{-2} of LG B (representing 100% of recommended dose); V4 – application of 50 ml m^{-2} of LG B and 45 g m^{-2} of GSH (representing 50% of recommended dose); V5 – application of 150 ml m^{-2} of LG B (representing 300% of recommended dose) and 45 g m^{-2} of GSH. Used fertilizers are registered (under the Fertilizers Law) for agriculture use in the Czech Republic.

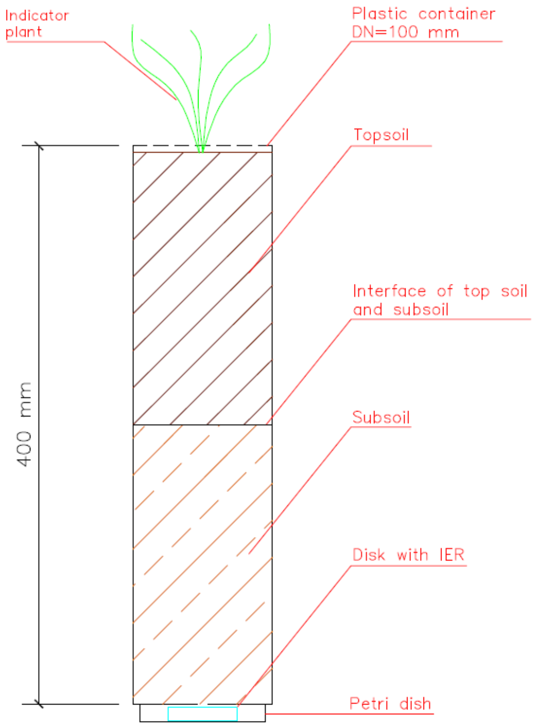

Fig. 1 Experimental container

Fig. 2 Location of experimental containers in a growth chamber container

B. Measurement of Mineral Nitrogen Leaching

Measurement of mineral nitrogen (N_{min}) leaching have been performed according to [16], [17]: the loss of N_{min} has been measured using Ion Exchange Resins (IER), which have been placed into plastic PVC discs situated under each experimental container (see Fig. 1). The discs are made from plastic (PVC) tubes. Each disc has 75 mm diameter and is 5 mm thick. Nylon mesh is glued (grid size of 0.1 mm) from the both sides of each disc. Mixed IER (CER – Cation Exchange Resin and AER – Anion Exchange Resin in ratio 1:1) have been placed into the inner space of an annular flat cover. After an exposition in and under the experimental containers, discs have been dried at laboratory temperature 18.5°C for seven days. N_{min} has been extracted from IER (individual discs) using 100 ml of 1.7 M NaCl. Distillation-titration method has been used for the determination of released N_{min} according to [18]. Obtained results are expressed in mg of N_{min} per m^2 (surface of experimental containers).

C. Statistical Analysis

Potential differences in values of N_{min} leaching and plant biomass production have been analyzed by one-way analysis of variance in a combination with the Fischer LSD test. All analyses are performed using Statistica10 CZ software. The results are processed graphically in the program MS Excel.

III. Results and Discussion

A. Mineral Nitrogen Loss from Topsoil and Subsoil

Nitrogen (N) is a key element for all living organisms because it is an essential component of proteins and nucleic acids. Although the element nitrogen is extremely abundant, making up 78% of the Earth's atmosphere, it exists mainly as unreactive di-nitrogen. Reactive nitrogen forms are needed to be useable by most plants and animals. These include oxidized and reduced nitrogen compounds such as nitric acid, ammonia, nitrates, ammonium and organic nitrogen compounds. All of these substances are normally scarce in the natural environment. The most important form of reactive nitrogen in the soil is the mineral nitrogen which is formed by nitrate and ammonium nitrogen [19]. Leaching of mineral nitrogen has been expressed as the detection of ammonium and nitrate forms on the Ion Exchange Resin (mg of N_{min} per m^{-2} of soil surface).

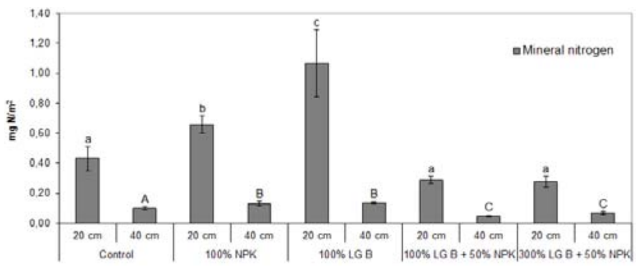

Fig. 3 N_{min} loss (sum of nitrate and ammonium nitrogen) from topsoil (0 – 20 cm) and subsoil (20 – 40 cm); (mean values ± SD, n = 3, different letters indicate significant differences)

Figs. 3 and 4 present capture values of two basic N_{min} forms leached from the topsoil and subsoil horizons that is the nitrate (NO_3^--N) and the ammonium nitrogen (NH_4^+-N). The highest value of N_{min} leaching has been found in variant V4 (100% LG B; from top soil). Moreover the lowest value has been observed in variant V5 (combined dose of LG B and NPK). The highest decrease of mineral nitrogen leaching has been found by the simultaneous applications of soluble humic substances and mineral compounds to soil samples (V4 and V5; combined dose of LG B and NPK), about 200% in comparison with the control variant. Application of these compounds also supports microbial activity and nitrogen immobilization fixed by the lowest values of N_{min} loss.

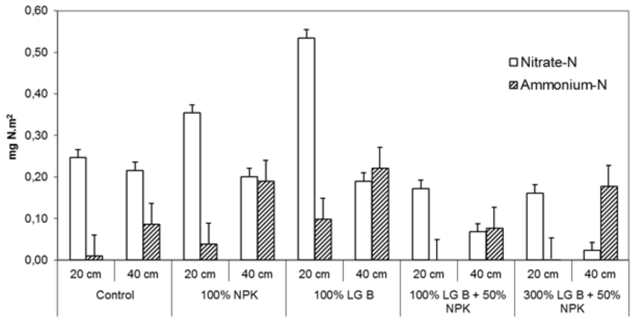

Fig. 4 N_{min} loss from topsoil (0 – 20 cm) and subsoil (20 – 40 cm) in a form of ammonia and nitrate nitrogen

Data presented in the Fig. 4 indicate significant differences in the leaching of ammonium-N and nitrate-N in particular variants, where only mineral NPK or LG B has been applied. The highest loss of ammonium-N has been found in variant V2 and V3. These values are significantly (ANOVA, $P<0.05$) higher in comparison with other variants.

The sum of captured ammonium and nitrate ions (N_{min}) in ion exchange resins is directly proportional to the ability of retention given key nutrient in its own environment [19]. Therefore, we conclude that application of combined doses of LG B and NPK positively influences development of organic-mineral soil complex, which is necessary for uptake and utilization of nitrogen in the soil.

Nitrogen leaching from arable land is said to be a diffuse source of nitrogen and therefore some difficulties may occur with its measuring. Nitrate has always been leaching out of soils but in pristine conditions before agriculture was industrialized, there were many spots in the landscape acting as natural retention spots for nitrate e.g. lakes, wetlands and mires. The amount of nitrate that is leached out from an agricultural soil depends on abiotic factors such as soil type characteristics, soil water content and precipitation patterns. Nitrate movement in a field creates a complex system although the rate of nitrate flow is higher in a sandy soil than in a clay soil [20]. Nitrogen amount balancing is needed for optimum plant growth while minimizing the NO_3^--N transported to ground and surface waters remains a major challenge for everyone attempting to understand and improve agricultural nutrient use efficiency [21].

The above results of N_{min} leaching confirm that N_{min} loss has significantly decreased by fertitigation which contained C_{org} (from LG B) and N_{min} (from GSH). Variant with an applied combined dose of LG B and GSH has showed lower amount of N_{min} (both forms) compared to the control variant. The effect of nitrogen fertilization method on N_{min} leaching increase from an arable soil has been confirmed by [22].

B. Production of Plant Biomass

Indicator plant (*Deschampsia cespitosa* L.) has been grown 180 days in grow box and its production is the main indicator of phytotoxicity and soil fertility in each variant. Production of biomass is illustrated in the Fig. 5.

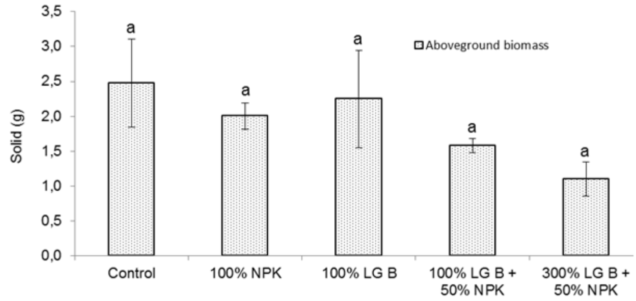

Fig. 5 Production of plant biomass (mean values ± SD, n = 3, different letters indicate significant differences)

Fig. 5 shows that the fertigation have not influenced positively or negatively plant biomass production. Reason for this may be related to a short duration of the laboratory experiment.

IV. Conclusion

Based on the obtained results, we may conclude that the fertigation with LG B and NPK has a positive effect on microbial activity and on decrease of mineral nitrogen leaching from the soil. This investigation presents the part of results of a long-term laboratory experiment and therefore these results have to be interpreted with a caution. From this contribution it can be concluded that one of the areas for the fertigation use may be an area with a risk of underground water contamination by the nitrates (N_{min}). These findings give support to new methods of fertilization, such as an application of new organic substances. The experiment has been conducted in specific laboratory conditions and it is planned to be repeated in a future as a field experiment.

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