Elimination of nitrate pollution of soil ground water by energy forest plantation

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Abstract

Nitrate ions can reach through their infiltration into deeper soil layers the ground water without any barrier, where they may cause serious contaminations. Regarding the leaching process it is totally unimportant, whether nitrate ions reached the soil through chemical fertilizers, manure, communal or agricultural wastewaters or such sewage sludge. The possibility of the microbial transformation of the nitrogen-containing material is even less parallel to the deeper soil layers.

At Gödöllő – Szárítópuszta (Hungary) long-term plant nutrition field experiments were carried out over 20 years on a Ramann-type ferruginous soil. Within this experiment the effect of different nitrogen fertilizer dosage (0-360 kg ha^{-1}) was investigated on the maize (*Zea mays L.*) production. During this period different, but significant amount of nitrate (due to different nutrient dosages of treatments) reached the deeper soil layers.

After the termination of the long-term experiment the plant nutrition experiment has been turned into an environmental protection one. In this environmental protection experiment our main aim is to dissolve and remediate these previous contaminations caused by intensive fertilization. At the first step we used alfalfa (*Medicago sativa L.*), that has a rather deep root zone, as test plant. During the production of alfalfa we realized, that the nitrate content of upper soil layers showed a decreasing tendency. For the re-cultivation of the deeper soil layers we planted energy wood – acacia (*Robinia pseudoacacia L.*) – after the first four year period.

Before and ten years after the plantation we measured the nitrate content of the soil profile each 20 centimetres till a depth of 3 metres. Measuring the nitrate content of the samples taken before the plantation from plots treated with higher fertilizer dosages we realized a significant nitrate accumulation in the layer deeper than 2 metres. Regarding the samples from 10 years later it can be stated, that this accumulation disappeared, or diffused to the upper layers due to the activity of nitrogen binding bacteria in the root tubers of pulses. Therefore the total nitrogen amount did not change, still the loading for the environment ceased. In addition, the heterogeneity between the plots treated with different fertilizer dosages also disappeared. This effect could be detected by modern precision remote sensing methods as well.

Keywords: Energy plant, nitrate leaching, bioremediation

Introduction

The intensive fertilization practise of the 70-80's was followed by a significant decrease in the applied fertilizer dosages. Despite this decrease in the amount the tendency, that the rate of nitrogen fertilizers increased within the total applied amount, was still going (Loch, 1999). Nitrogen supply plays a determining role in the amount of yield. Therefore the application of nitrogen fertilizers decreased less, although their prices are the highest and their application means the highest environmental risk in the production.

As a result of the treatments in a long-term experiment near Debrecen, Hungary, a lot of the soil properties (CEC, pH, hydrolytic acidity, plant available nutrient content) has changed (Kátai, 2006). A part of the nitrogen-content of the soil is lost through the leaching of nitrate ions into deeper soil layers. Generally, the leaching of nitrate occurs mainly in wet periods, the highest nitrogen amount is leached in the winter time (Loch and Nosticzius, 1992; Schilling, 2000). Nitrate ions are ones of the most mobile ions in the soil, because on the one hand they are highly soluble and on the other hand they cannot be bound on the soil colloids for their negative charge.

Trying to reveal the negative consequences of intensive fertilization the problems of nitrate leaching from the root zone, its accumulation in the deeper layers and its migration towards the ground water came to the front. Models dealing with the description of the process range from the simplest (based on mass balance calculation) to the most complicated (based on theoretical assumptions) mathematic simulations (Addiscott et al., 1991; Czinkota and Füleky 1994; Németh, 1996).

Due to the intensive fertilization practise of the 1970's and '80s a significant plant nutrient stock has been accumulated in our soils. From these plant nutrients the nitrogen migrated towards the deeper soil layers as a form of nitrate-ions, it is moving on towards the ground water and therefore it means a risk for the quality of the drinking water. It is only the question of time, how fast the nitrogen – under the biologically active soil layer – enters the ground water and confined aquifers. Therefore it has been investigated, how the nitrate in the deeper soil layers can be eliminated using plants with deep root zones

In a maize monoculture experiment on a Ramann-type ferruginous soil in Gödöllő, Hungary in the upper 3 m soil layer nitrate-N amounts between 130 and 2050 kg ha^{-1} (depending on the treatment) were accumulated between 1969 and 1986 (Füleky and Debreczeni, 1991). In other long-term experiments in the country similar NO_3-N accumulation has been observed (Németh and Buzás, 1991). Finding such an extent of NO_3-N accumulation we came to the idea that a plant with a deeper root zone that the previous plant – like alfalfa or even agricultural forest – could utilize the nitrogen in the deeper layers. The state of the plants could as well be followed and evaluated by using remote sensing methods (Erdeiné et al., 2009).

Materials and methods

The effect of different nitrogen fertilizer dosages on maize production was investigated within the confines of a 20-years long-term experiment on a Ramann-type ferruginous soil, in Gödöllő Szárítópuszta, Hungary.

The physical properties of the experimental soil are the following: the upper 60 cm layer is sandy, underneath that there is a sandy loam layer and the 200-300 cm layer under surface is clay-loam. The width of the layer that contains humus is 35 cm. $CaCO_3$ occurs in a depth of 60 cm. The humus content of the ploughed layer is 1.3 %, underneath that this value is less than 1 %. The groundwater level lays under 4 m. In some parts of the soil profile there is a limestone layer in a depth of about 2 m.

Since the autumn of 1969 increasing nitrogen fertilizer dosages were applied at a range from 0 to 90, 180, 270 and 360 kg N ha^{-1} resp. Parallel to the increasing nitrogen dosages the amounts of the applied phosphorous and potassium fertilizer were also enhanced (Füleky-Kovács, 1994). During the autumn of 1989 fertilization was finished and alfalfa has been planted. We measured the hay yield and the nitrogen content of these plants each year.

In 1994 and 2003 we took soil samples each 20 cm in a total depth of 3 m, so that we could reveal the changes in the soils of 4 treatments with high N-fertilizer dosages from the total 12 treatments.

The studied samples were taken from the plots treated each year with the fertilizer dosages in Table 1.

Table 1. Codes of the investigated treatments and the per year applied N-dosages (kg ha^{-1})

Treatment code	1	9	10	11	12
N dosage	0 kg ha^{-1}	90 kg ha^{-1}	180 kg ha^{-1}	270 kg ha^{-1}	360 kg ha^{-1}

After the mechanical preparation (sieving, chopping) and the drying of the samples we made soil extracts using 1.0 % KCl and 1 hour shaking time. The soil suspensions were filtered and their NH_4^+-N and NO_3^--N contents were measured by a Parnas-Wagner water steam distillation equipment.
The changes in the previous period and the effect of the former treatments on the depth distribution of nitrogen have been evaluated with a 3-way (Sváb, 1981) ANOVA. For the calculations we used our own computer program – written in Excel Macro – just as we did in our former studies (Tolner, 2008; Vágó, 2008).

Results and discussion

The fertilization experiment is a single factor (12 fertilizer stages) experiment with 4 replications and a random block design. We took soil samples from the total depth only in 5 selected treatments and on each 2 plots. The evaluation was executed for the total mineral nitrogen (NH_4^+-N + NO_3^--N mg kg^{-1} soil) content according to the 3 factor-random block design. The factors were the followings:

- Factor A: soil depth (15 soil layers: each 20 cm, until the depth of 3 m),
- Factor B: the former fertilizer treatment (5 dosages: 0, 90, 180, 270, 360 kg N ha^{-1}),
- Factor C: time (2 levels: 1994, 2003).

Upon the results of the evaluation and the table of variance, following important statements can be concluded and statistically confirmed:

1. The interaction between soil depth and time (A x C) was significant (F-rate: 1.8*). That means that the distribution of soil nitrogen content in the soil profile changed between the first and second sampling period (9 years). It can be followed on Figure 1., that in the depth of 240-300 cm the in 1994 detected N accumulation could not be traced any more in 2003. This confirms that it is possible to eliminate the nitrate accumulation, leached until 3 m soil depth, by planting forests. A significant N accumulation was measured in the upper 20 cm layer in both sampling periods. The extent of this accumulation was significantly more expressed in 2003, than in 1994. This effect can be attributed to the N-binding effect of the – with acacia, as a legume host plant – symbiotic Rhizobium bacteria.

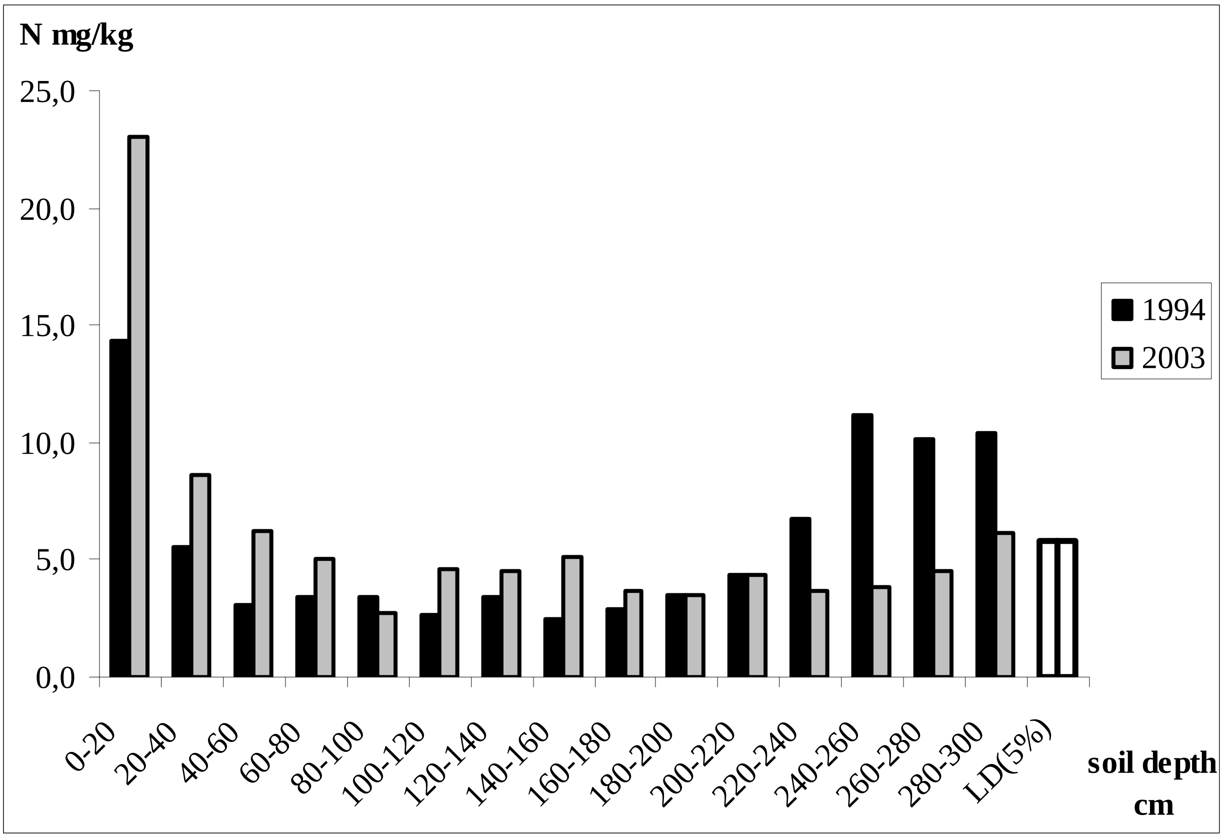

Figure 1. Depth distribution of soil N in the years 1994 and 2003 in the average of the fertilizer treatments

2. The interaction between fertilizer treatments and time (B x C) was also significant (F-rate: 2.5*). This means that differences in soil N-content – originating from the previous differences in the applied fertilizer dosages – changed during the 9 years between the two sampling periods. It is evident from Figure 2., that in 1994 the soil nitrogen content was increased by the increasing fertilizer dosages, although this effect cannot be revealed between the sequential steps. In 2003 a significant difference can be detected only between the control and the 270 kg ha^{-1} N treatments. It can be stated that the effect of the former fertilization decreased during the surveyed 9 years.

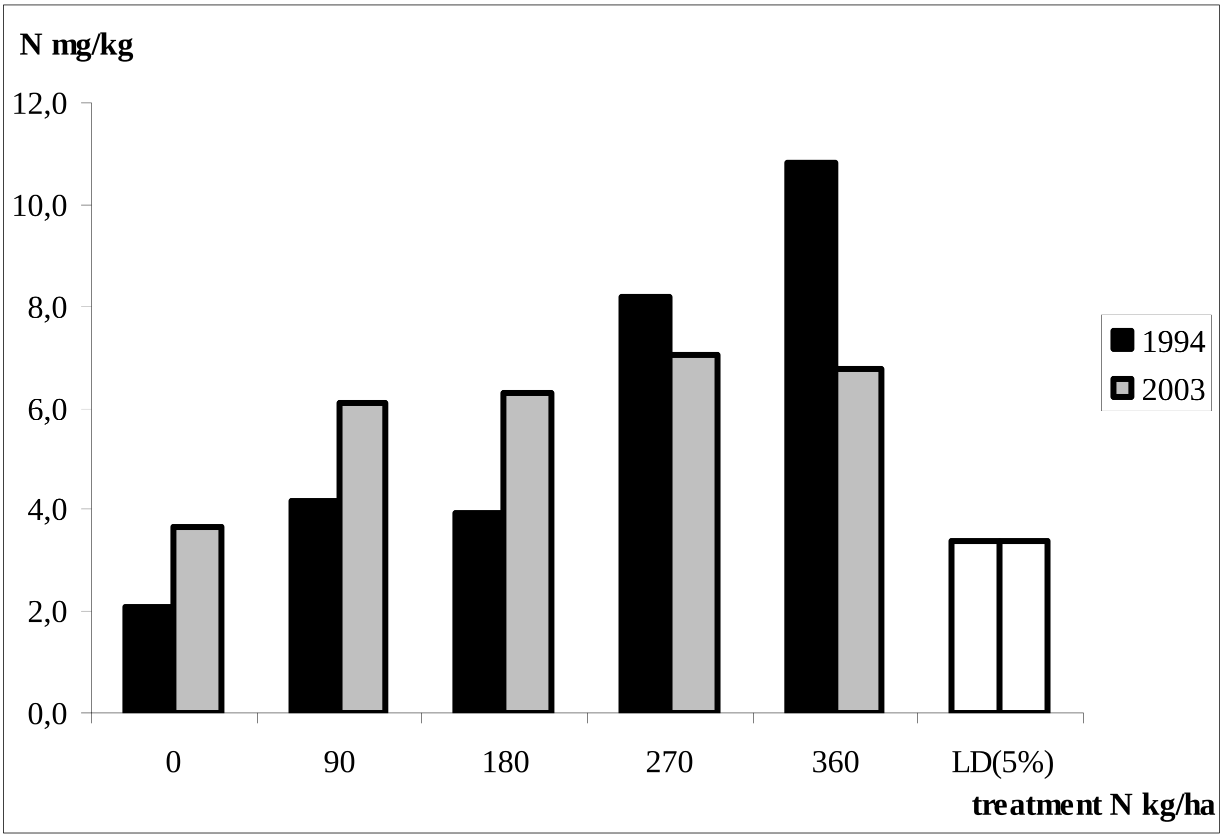

Figure 2. Differences in soil N-content as affected by N fertilization in the years 1994 and 2003, in the average of the factor soil depth

As an effect of forest planting the former heterogeneity of the experimental plots decreased significantly. It can be stated also from the satellite picture from the 30th June 2009 that the steady forest does not show any effect of the former soil heterogeneity.

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