ACCUMULATION AND DEPLETION OF FERTILIZER ORIGINATED NITRATE-N AND AMMONIUM-N IN DEEPER SOIL LAYERS

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Abstract

The leaching process of nitrate was studied in a long-term field experiment at Gödöllő on a brown forest soil started in 1969. 0, 90, 180, 270, 360 kg ha^{-1} y^{-1} N doses have been broadcasted as basal fertilization in the form of ammonium-nitrate for 16 years. The test plant was maize in monoculture. In autumn 1989 fertilization was discontinued and alfalfa was sown on the experimental area. In 1995 pseudoacacia was planted into the field. In 1986, 1989, 1994 and 2003 the soils of the treatments were sampled in 6 replications from 0 to 3 meters depth at every 20 cm. The nitrate-N and ammonium-N content of the sample was determined.

Increasing the dose of nitrogen fertilization nitrate content in the soil profile increased, as well. About the half of fertilizer nitrogen can be found in the 3 meter layer of the soil profile after 16 years fertilization. Using deep rooting plants the accumulated nitrogen could be used to prevent the leaching losses.

Results prove the necessity of a suitable technology preventing nitrate losses. As the experiment shows 100 kg N ha^{-1} fertilizer nitrogen enough for the maximum crop yield in this area. The amount of nitrate-N exceeding plant demand could be leached into 1-3 meter depth of soil or into deeper horizons.

Keywords: ammonium-N, fertilizer, field experiment, nitrate-N, soil

Introduction

Nitrate leaching was studied for a winter leaching period in a layered calcareous silt loam with tile-drains at about 1-m depth. Measured NO_3 leaching was 11 kg N ha^{-1} y^{-1} in the relatively dry, winter leaching period 1991-1992 (De Vos et al., 2000). Paramasivam et al. (2001) evaluated NO_3-N distribution in soil solution at various depths in the vadose zone, and N leaching below the root zone for two cropping seasons. The treatments included 112, 168, 224, and 280 kg N ha^{-1} y^{-1}. At the 60- or 120-cm depths, the NO_3-N concentrations occasionally peaked at 12 to 100 mg L^{-1}, but at 240 cm NO_3-N concentrations mostly remained below 10 mg L^{-1}. The careful irrigation management, split fertilizer application, and timing of application contributed to the low leaching of NO_3-N below the root zone. Calculated NO_3-N leaching losses below the rooting depth increased with increasing rate of N application and the amount of water drained, and accounted for 1 to 16% of applied fertilizer N. Results showed that well and moderately well drained fields had consistently higher ground water NO_3 compared to more imperfectly drained fields receiving comparable N inputs (Young and Briggs, 2007).

A long-term (1982-2004) field experiment was conducted to investigate the effects of nitrogen fertilizers on accumulation of nitrate-N in the soil profile (0-210 cm). Annual applications of N fertilizer and manure for 23 successive years had a marked effect on NO_3-N accumulation in the 0-210 cm soil profile. Accumulation of NO_3-N in the deeper soil layers with application of N fertilizer and manure is regarded as a potential danger, because of pollution of the soil environment and of groundwater (Yang et al., 2006).

The magnitude of nutrient accumulation and its distribution in the soil profile varies with soil-climatic conditions. The objective of the study was to determine loading and distribution of manure-derived nitrogen in the soil profile as influenced by repeated manure applications.

DOI: 10.18380/SZIE.COLUM.2014.1.2.7

Lower crop removal and reduced leaching of NO_3-N due to drier conditions contributed to greater accumulation of nitrate-N in the top 60 cm. At large manure rates, excess N from the balance estimates could not be accounted for in soil organic N and was assumed to be lost from the soil-plant system. At the Dixon LHM site, deep leaching of NO_3-N was observed at the excessive rate up to the 150 cm depths compared to the control. To prevent loading, rates of applied manure nitrogen should be reduced when crop N removal potential is diminished by high frequency of drought (Stumborg et al., 2007).

A long-term fertilizer experiment on dry land of the Loess Plateau, northwest China, has been conducted since 1984 to study the distribution and accumulation of NO_3-N down to a depth of 400 cm in the profile of a coarse-textured dark loess soil after continuous winter wheat cropping. Annual N and P (P_2O_5) rates were 0, 45, 90, 135 and 180 kg ha^{-1}. After 15 successive cropping cycles, the soil samples were taken from each treatment for analysis of NO_3-N concentration. The application of fertilizer N alone resulted in higher NO_3-N concentration in the soil profile than the combined application of N and P, showing that application of P could greatly reduce the NO_3-N accumulation. With an annual application of 180 kg N ha^{-1} alone, a peak in NO_3-N accumulation occurred at 140 cm soil depth, and the maximum NO_3-N concentration in the soils was 67.92 mg kg^{-1}. The amount of NO_3-N accumulated in the soil profile decreased as the cumulative N uptake by the winter wheat increased (Fan and et al., 2003).

Nitrate leaching occurs when there is an accumulation of NO_3-N in the soil profile that coincides with or is followed by a period of high drainage. Therefore, excessive nitrogen fertilizer or waste effluent application rates or N applications at the wrong time (e. g. late autumn) of the year, ploughing pasture leys early in the autumn or long periods of fallow ground, can all potentially lead to high NO_3-N leaching losses. N returns in animal urine have a major impact on NO_3-N leaching in grazed pastures (Di and Cameron, 2002).

Nitrate leaching from agricultural soils can increase groundwater nitrate concentrations. Ammonium nitrate was applied only to the percolation lysimeters. Leachate from the lysimeters was extracted from a depth of 2.1 m and soil samples were collected from field plots in 0.3 m depth increments to 2.1 m on a periodic basis. Determining accurate yield expectations under deficit irrigation conditions, correct scheduling of irrigation and the use current best management practices for N management can help minimize nitrate losses in leachate (Tarkalson et al., 2006).

Very low NO_3 concentrations were found in the rooting zone at most sample positions, indicating that crop demand during recent growing seasons matched or exceeded supply. Accumulations of NO_3 below the rooting zone indicated that deep percolation of NO_3 has been an important process over the longer term throughout the upper and mid slope positions of the landscape. A lack of NO_3 accumulation in one lower-toe position and the depression indicated that excess NO_3 in these profiles may have been leached into the groundwater and/or removed via denitrification or simply may not have accumulated (Whetter et al., 2006).

A long-term (1982 to 2000) field experiment was conducted - under wheat - wheat-corn rotation to determine the effects of N, P, and K chemical fertilizers and farmyard manure accumulation on nitrate (NO_3-N) in the soil profile (0-180 cm).

Fertilizers (N, NP, and NPK) led to NO_3-N accumulation in most subsoil layers. Combined applications of fertilizers and manure reduced soil NO_3-N accumulation in soil compared with fertilizers alone. In conclusion, the findings suggest that it is important to use balanced application of chemical fertilizers and manure at proper rates in order to protect soil and underground water from potential

NO_3-N pollution while also sustaining high crop production (Yang et al., 2003).

Four variants of a leaching experiment were conducted at 2 sites to parameterise and check the theory. The experiment involved the application of ammonium chloride to an area of 25 m^2, and then from 6 days to 5 months taking soil samples at 200 mm intervals down to 2 m depth and analysing them for chloride, ammonium, and nitrate. Background concentrations were obtained by contemporaneous sampling nearby. In one variant of the experiment 353 mm of rain in 6 days moved nearly half the applied nitrogen to below 400 mm depth (Banabas et al., 2008).

Drainage and nitrate leaching were simulated using the Water and Nitrogen Management Model (WNMM). Nitrate concentrations in the drainage water and nitrate leaching increased with increasing N application rate. Annual leaching losses ranged from 21.1 to 46.3 kg N ha^{-1} (9.5-16.8%) for inputs between 0 and 150 kg N ha^{-1}. Growth of oilseed rape decreased the nitrate concentration in the drainage water, but growing N fixing peanuts did not. Rainfall had a greater impact on nitrate leaching than crop uptake. The loss of nitrate was low during the dry season (October-February) and in the dry year (rainfall 17% below average) mainly as a result of reduced drainage (Sun et al., 2008).

Under fertilizer treatment, larger quantities of NO_3-N were present in the upper soil layer (0-40 cm) at 7 days after fertilization. From 7 to 37 days after fertilization, NO_3-N decreased, obviously because of the heavy rainfall together with the increase in the capacity of maize to accumulate N in this period and a significant decrease in NO_3-N stock was observed. There was a significant positive correlation between the quantity of NO_3-N stock decrease and the nitrogen fertilizer application rates during this period. And there was more NO_3-N accumulated in the lower layers under fertilization treatment at 76 days after N fertilizer application. Nitrogen fertilizer application increased NO_3-N concentration and stock in 0-100cm soil profile and changed NO_3-N distribution during maize cropping season. Nitrogen fertilizer application promoted movement of NO_3-N down the soil profile and increased N loss (Yin et al., 2007).

Numerous studies have shown that 54-72% of mineral nitrogen fertilizer applied is taken up by the plant, 8—21% is bound in the soil organic matter, 2—18% is lost to the atmosphere by denitrification and only 2-8% is lost by leaching (Owen and Jürgens-Gschwind,. 1986). In their opinion the major source of leached nitrate is the nitrogen mineralised from the soil organic reserves. However these values are valid at careful fertilizer application. In general, nitrate movement in the soil follows water movement. Increased leaching loss of nitrate can be resulted by rainfall, and irrigation between the growing seasons when soils are without plant cover. Less water percolates through heavy soils than through light soils, resulting in lower nitrate leaching losses from heavy soils. On average, nitrate leaching losses are 30-40 kg ha^{-1} from sandy soils and 20-30 kg N ha^{-1} from loamy soils. In the absence of a crop leaching losses are extremely high. High groundwater level also favours nitrate leaching from the soil. With very high fertilizer nitrogen application rates the proportion of the applied nitrogen taken up by the plant decreases, and the residual fertilizer nitrogen in the soil will be vulnerable to leaching. Approximately 300 mm annual drainage water at 100 kg N $ha^{-1}y^{-1}$ fertilizer rate has only little effect on nitrate leaching loss, but at higher fertilizer rate more than 100 kg N $ha^{-1}y^{-1}$ is the leaching loss from a sandy soil. Application of nitrogen fertilizer in spring rather than in autumn avoids leaching of fertilizer nitrogen.

The N_{min} method (Wehrmann and Scharpf, 1979) is based on observations that cereals utilise the mineral nitrogen contents of deeper soil levels. To start with, the mineral nitrogen content of the 0-90 cm soil level was taken into account when applying nitrogen head dressing in spring. Later, wide-ranging studies proved that winter wheat is capable of efficiently utilising the mineral nitrogen content of the soil to a depth of 150 cm (Kuhlmann, Barraclough and Weir, 1989). The utilisation of the mineral nitrogen present in deeper soil layers was also confirmed in the case of other crops (barley, sugar beet, maize) (De Willigen and Van Noordwijk, 1987). These nitrogen sources were found to be used by maize varieties with nitrogen requirements in the shoot and large root density in the soil layers (Wiesler and Horst, 1994). The uptake of nitrate-N leached into deeper soil layers is taken into consideration by crop models and nitrogen submodels (SOILN) (Jansson et al., 1991).

Under the climatic and soil conditions in Hungary, the annual application of 100 kg/ha N fertiliser (2000 kg/ha/20 years) does not result in any great increase in the nitrate-N content. At higher rates, however, depending on the climatic and soil conditions, there is an exponential rise in the nitrate-N content in the 0–3 m soil layer, both in the 1 m root zone and in the 1–3 m layer below it.

Nitrate-N migration towards the deeper soil layers can be clearly characterised by the depth of maximum nitrate-N accumulation in the profile, which was determined using a Gauss distribution curve. The nitrate-N concentrations recorded every 20 cm in the 0-3 m soil layer were plotted as a function of depth, after which a Gauss curve was fitted. Linear correlation analysis was applied to determine the correlation between the depth of maximum nitrate-N accumulation and the soil texture or rainfall migration.

The depth of maximum nitrate-N accumulation after various rates of mineral fertilisation was closer to the surface in heavier soils. The depth of maximum nitrate-N accumulation did not exhibit a close correlation with the rainfall. There was, however, a clear tendency for higher quantities of rainfall to cause the nitrate-N to move to deeper layers and accumulate there (Füleky, 2009).

The objective of this study is to monitor nitrate-N and ammonium-N distribution in the deeper soil layers of a brown forest soil effected by annual nitrogen fertilizer application for the 1969-2003 period.

Materials and methods

The experiment was set up on a brown forest soil at the experimental station of GödölIő University of Agricultural Sciences at Szárítópuszta in 1969. The physical soil type in the top 60 cm was sand, fol1owed by sandy loam, loam and, at a depth of 200-300 cm, clay or clayey loam. The thickness of the humus layer was 35 cm, with $CaCO_3$ appearing at a depth of 60 cm. The humus content was 1.3 % in the ploughed layer and less than 1 % in lower layers. The parent material was loess, the groundwater level was below 4 m, with a layer of limestone in the soil profile at a depth of around 2 m.

Nitrogen fertilizer was applied in the experiment from autumn 1969 onwards at rising rates of 0, 90, 180, 270, and 360 kg Nha^{-1} in the form of ammonium-nitrate. Phosphorus and potassium fertilizers were applied together in the rates of 0, 60, 120, 240 kg P_2O_5 $ha^{-1}y^{-1}$ and 0, 50, 100, 150, 200 kg K_2O $ha^{-1}y^{-1}$, respectively. The experiment was not irrigated except of 3 years when 100 mm of water were applied yearly. Maize was sown on the area in a monoculture for 20 years. Yields and the nitrogen content of stalk and grain were measured. Average corn yields were 3.7, 5.1, 5.2, 5.0, 4.6 tha^{-1}, respectively. In autumn 1989 fertilization was discontinued and alfalfa was sown on the experimental area. In 1995 pseudo-acacia was planted into the field. Each year the hay yield and the nitrogen content of alfalfa were recorded. In 1986, 1989, 1994 and 2003 soil samples were taken every 20 cm in 6 replications to a depth of 3 m from the various fertilizer treatments. Nitrate and ammonium content of the soil samples were determined.

Table 1. Nitrogen fertilizer rates and the amount of accumulated NO_3-N in 1986, 1989, 1994 and 2003, respectively

Nitrogen application rate, N kg $ha^{-1}y^{-1}$	0	90	180	270	360
Total amount of fertilizer nitrogen, N kg ha^{-1}	0	1440	2880	4320	5760
Total N uptake by the maize crops, N kg ha^{-1}	852	1436	1561	1574	1512
Nitrogen balance in 1986 N kg ha^{-1}, after maize	-852	+2	+1319	+2746	+4248
NO_3-N in 3 m soil layer, N kg ha^{-1}	134	298	1125	1189	2051
NO_3-N in 1 m soil layer, N kg ha^{-1}	41	43	205	198	235
NO_3-N in 3 m soil layer in the % of nitrogen balance	-	>100	85	43	48
Nitrogen balance in 1989 N kg ha^{-1}, after maize	-1070	+14	+1666	+3432	+5294
NO_3-N in 3 m soil layer, N kg ha^{-1}	288	628	933	1634	1787
NO_3-N in 1 m soil layer, N kg ha^{-1}	82	132	256	424	397
NO_3-N in 3 m soil layer in the % of nitrogen balance			56	48	34
Nitrogen balance in 1994 N kg ha^{-1}, after alfalfa	-1710	-791	+842	+2525	+4371
NO_3-N in 3 m soil layer, N kg ha^{-1}	90	183	381	625	885
NO_3-N in 1 m soil layer, N kg ha^{-1}	56	61	85	87	95
NO_3-N in 3 m soil layer in the % of nitrogen balance			45	25	20
Nitrogen balance in 2003 N kg ha^{-1}, after forest	Not calculated				
NO_3-N in 3 m soil layer, N kg ha^{-1}	183	223	195	359	324
NO_3-N in 1 m soil layer, N kg ha^{-1}	88	124	117	117	133

Results and discussion

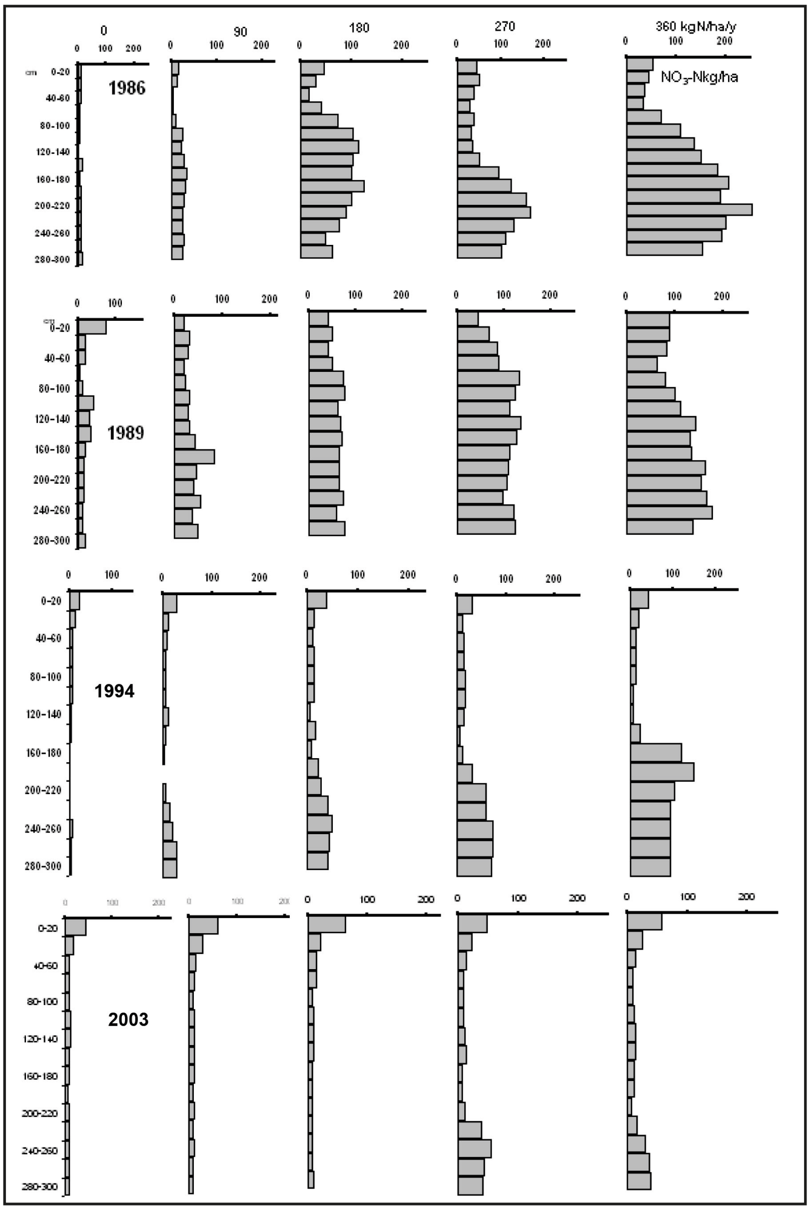
In a long-term fertilization experiment set up in 1969 on a brown forest soil in Gödöllő, the 0-3 m soil layer under a maize monoculture had accumulated a total of 130-2050 kg nitrate-N by 1986 (Table 1.) depending on the rates of nitrogen applied (Füleky and Debreczeni, 1991). Between 1986 and 1989 the quantity of nitrate-N in the soil continued to increase due to the application of unchanged fertilizer rates. In long-term experiments in other parts of the country a similar extent of nitrate-N accumulation was observed (Németh and Buzas, 1990).

Considering the fact that the Gödöllő soil also contained several hundred kg nitrate-N, it was a natural thought to sow alfalfa, which is more deeply rooted than the crops previously used, and has a high nitrogen requirement, in order to utilise the nitrate-N to be found in the deeper layers of the soil. The vertical distribution of nitrate-N is shown in Figure 1.

In the control plot the amount of nitrate-N is only a few kg N ha^{-1} in the 3 meter soil layer. Increasing the rate of nitrogen fertilization the amount of nitrate-N in the soil profile increases. The maximum of nitrate accumulation is found at about 2 meter. Nitrate distribution usually has a minimum at 40-80 cm depth. Nitrogen uptake of plants usually effects of the nitrate shift by 100 cm depth. Nitrate being in deeper horizons practically is lost for plant uptake and moves downwards with water movement. However further significant nitrate enrichment can be expected below 3 meter at 180 kg N ha^{-1} or higher rates of nitrogen fertilization.

Nitrate accumulation shown in Figure 1. can be compared to the nitrogen uptake of maize plants. Yield and nitrogen concentration of grain and stalk are given in Table 1. Data for nitrate accumulation in the soil can be seen in Table 2. Crop yield was found to be increased by90 kg N ha^{-1} in the field. Additional fertilizer rates increased only the N content of grain and stalk but not the yield. In the control treatment and uptake by stalk and grain together was about 53 kg yearly. In other treatments this is fluctuated about 100 kg N ha^{-1}. In control plots than only source of nitrate-N is nitrogen mineralised from the soil organic reserves

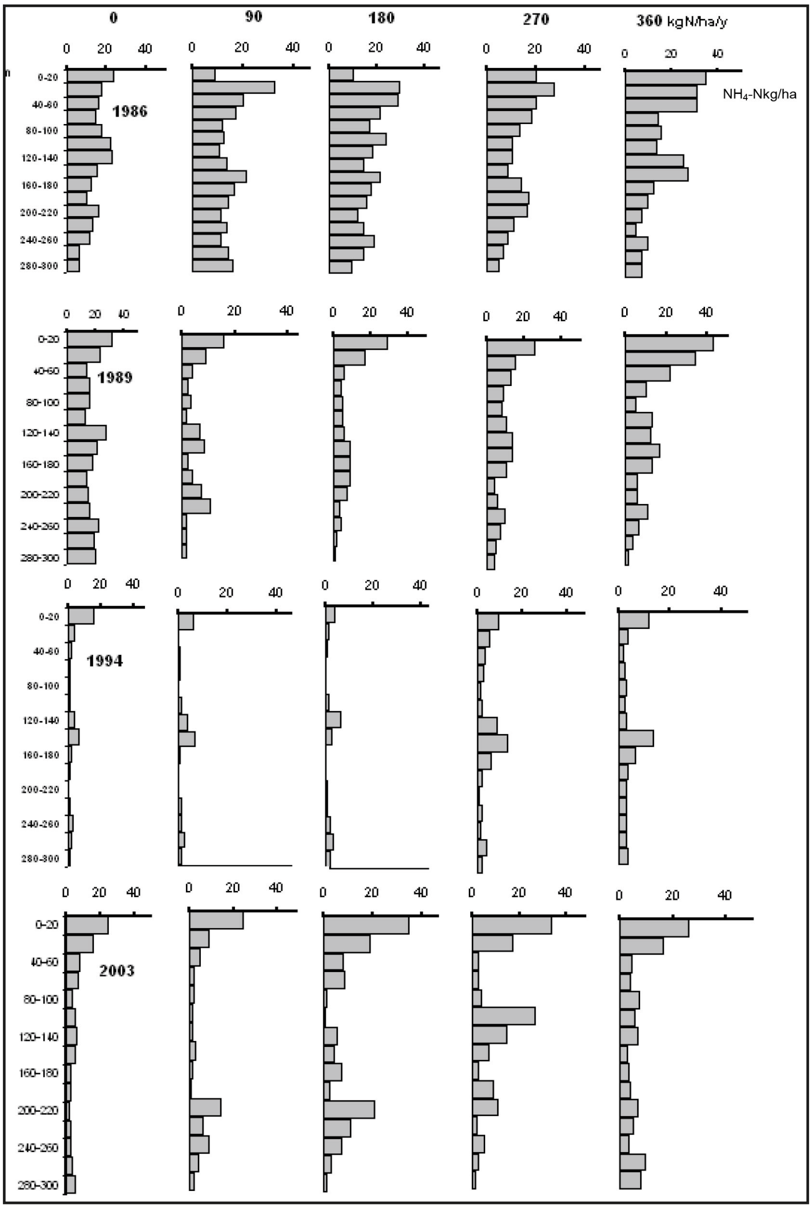
Figure 1. The vertical distribution of NO_3-N in 1986, 1989, 1994 and 2003, respectively



(852 kg N ha^{-1} in 16 years). As it can seen from the nitrogen balance at 90 kg N ha^{-1} fertilizer rata the amount of nitrogen taken up by crop is equal to the nitrogen added in 15 years. Nevertheless, the 3 meter layer of soil profile has remarkable nitrate content (298 kg N ha^{-1}). For this the downwards movement of both the mineralised and fertilizer originated nitrate can be responsible. At 180 kg N ha^{-1} and higher fertilizer rates N balance becomes more positive so a considerable amount of fertilizer nitrogen has to remain after each harvest in the soil. Data for vertical distribution show very significant amount of nitrate accumulation in the 3 meter layer of soil$_1$ at higher fertilizer rates. At 0, 90, 180, 270, 360 kg N ha rates 134, 298, 1125, 1189, 2051 kg nitrate-N ha^{-1} are found in 3 meter soil 1ayer. From these amounts only 41, 43, 205, 198, 235 kg N ha^{-1} are in the upper 1 meter layer which is available for the plant roots. These data suggest that a big amount of nitrate practically lost for plant uptake and its fate is the leaching. The annual rainfall surplus is 116 mm in the average of 16 years and it is enough for leaching the nitrate not taken up by plants.

DOI: 10.18380/SZIE.COLUM.2014.1.2.7

Figure 2. The vertical distribution of NH_4-N in 1986, 1989, 1994 and 2003, respectively



Regarding the nitrate content of 3 meter soil layer in relation to the total amount of applied fertilizer nitrogen, the 20-40% of fertilizer nitrogen can be found in this soil layer. If the amount of nitrate accumulated in the 3 meter 1ayer is related to the “nitrogen balance” .data, at 90 kg N ha^{-1} fertilizer rate the whole amount of nitrogen balance, at 180 kg N ha^{-1} rate 85%, at 270 and 360 kg N ha^{-1} rates 43 and 48% of the “nitrogen ba1ance” can be found in the 3 meter soil layer. As it can be seen in Figure 1 this nitrogen loss is probably not caused by nitrogen volatilization to the atmosphere but by leaching downwards with the drainage water into the deeper soil layers.

At increasing nitrogen rates nitrate accumulation in soil is due to the fact, that at higher fertilizer rates plants take up nitrogen mainly from the fertilizer, so nitrate mineralised from soil organic reserves is exposed to leaching. Application of nitrogen fertilizer in autumn also can be contributory factor tor nitrate leaching into deeper soil horizons.

Table 2. Nitrogen balances and the amount of accumulated NH_4-N in 1986, 1989, 1994 and 2003, respectively

Nitrogen balance in 1986 N kg ha^{-1}, after maize	-852	+2	+1319	+2746	+4248
NH_4-N in 3 m soil layer, N kg ha^{-1}	224	244	285	219	260
NH_4-N in 1 m soil layer, N kg ha^{-1}	90	103	130	110	138
Nitrogen balance in 1989 N kg ha^{-1}, after maize	-1070	+14	+1666	+3432	+5294
NH_4-N in 3 m soil layer, N kg ha^{-1}	288	82	117	150	204
NH_4-N in 1 m soil layer, N kg ha^{-1}	101	35	61	69	114
Nitrogen balance in 1994 N kg ha^{-1}, after alfalfa	-1710	-791	+842	+2525	+4371
NH_4-N in 3 m soil layer, N kg ha^{-1}	40	25	24	65	66
NH_4-N in 1 m soil layer, N kg ha^{-1}	21	7.2	5.1	22	22
Nitrogen balance in 2003 N kg ha^{-1}, after forest	Not calculated				
NH_4-N in 3 m soil layer, N kg ha^{-1}	95	85	133	140	112
NH_4-N in 1 m soil layer, N kg ha^{-1}	58	42	69	60	58

Compared to the average 588 mm precipitation measured over many years, there was a deficiency of 199 mm in 1989-1990, 13 mm in 1990-1991 and 197 mm in 1991-1992, while a surplus of 55 mm was recorded in 1993-1994. Due to this water deficiency and the extremely high water requirements of alfalfa, the available quantity of water was presumably insufficient to allow a greater quantity of nitrate-N to migrate downwards, so the decline in the nitrate-N quantity in the lower soil layers after 4 years of alfalfa production can be attributed to the nitrogen uptake of the alfalfa. As shown by the data on the nitrate-N content of the 3 m soil layer, presented in the Table 1., there was a substantial decrease by 1994 compared with the 1989 figures. In the control treatment the nitrate-N quantity, which was initially already small, decreased to below a value of 10 kg N/ha/20 cm throughout the profile (Figure 1.). In plots previously given rates of 90 and 180 kg N/ha the nitrate-N quantity dropped below 10 kg N/ha/20 cm up to a depth of 220 cm, while this reduction was observed up to 200 cm in the 270 kg N/ha treatment. In the 360 kg N/ha treatment there was a substantial decline in the soil nitrate-N content up to 160 cm. In addition a considerable reduction in the nitrate-N level could be observed throughout the soil profile during the production of alfalfa. In the course of 4 years the alfalfa removed between 550 and 823 kg/ha N from the soil, depending on the original nitrogen rates. At the same time, the loss of nitrate-N content from the 3 m soil layer ranged from 215 to 1040 kg N/ha. In the control plot the available nitrate-N was insufficient to satisfy N requirement of alfalfa, while in plots previously given lower rates of nitrogen fertiliser the quantity of nitrate-N removed from the 3 m soil layer over the 4-year period was roughly equivalent to the quantity of nitrogen absorbed by the alfalfa. In the case of the highest nitrogen fertiliser rates the reduction in the nitrate-N content of the soil exceeded the nitrogen uptake of the alfalfa plants. This fact, observed chiefly in the deepest soil layers after a very large accumulation of nitrate-N, suggests the further migration of nitrate-N to still deeper layers. This is confirmed by examinations on deep-lying roots, showing that alfalfa roots could be found up to a depth of 180 cm, though with a great reduction in mass at lower levels. A gradual reduction in root density is in agreement with the depth of the nitrate-N exhaustion zones previously established. The pseudoacacia trees growing between 1995 and 2003 furthered reduced the quantity of nitrate-N accumulated in the deeper layers. The depletion recorded to a depth of 2 m after alfalfa continued to 2.40 m, and there was also a decline in the nitrate-N quantity in even deeper layers. The ammonium-N quantity in the 3 m profile exhibited a slightly different picture to that of nitrate.

In 1986 largely identical quantities of NH_4-N could be found in the 3 m soil profile in all the mineral fertiliser treatments (Figure 2). In the upper layers there was an average of 20 kg N/ha in each 20 cm soil layer, while at lower depths only half this quantity was detected. The total ammonium-N quantity in the 3 m soil profile was around 200 kg. By 1989 this had decreased considerably to 100 kg N/ha, except for the non-fertilised control plot and plots receiving the highest rate of N fertiliser, both of which still had around 200 kg N/ha in the 3 m profile. The depth distribution of NH_4/N was completely different in the two treatments, however, being fairly uniform with depth in the control plot, but with a tendency to decrease with depth at the highest fertiliser rate (Table 2).

In 1994, after the alfalfa crop, hardly any NH_4-N could be detected in the 3 m soil profile, partly due to the lack of mineral fertilisation and partly due to the nitrogen uptake of alfalfa. The pseudoacacia trees grown on the area between 1995 and 2003, however, led to the reappearance of NH_4-N in the profile, though not in large quantities. In all the treatments the quantity of NH_4-N was greatest in the upper 40 cm, derived from the substantial N content of the falling leaves. In deeper soil layers NH_4-N was probably formed via the decomposition of dead roots, and in the surface layers by the mineralisation of the leaves. The soil did not contain sufficient nitrate-N to satisfy the requirements of the trees, so they were forced to supply their needs through nitrogen fixation, the result of which could be detected in the NH_4-N content of lower soil layers.

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