Nitrogen balance and mineral nitrogen content in the soil in a long experiment with maize under different systems of N fertilization

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ABSTRACT

The effect of different systems of N fertilization on nitrogen balance and N transformation in the soil was studied in long-term stationary experiments (1991–2002) with successive growing of maize. Average dry matter yield for the control without fertilization in the period 1991–2002 was 11.67 t of dry matter per ha, which was by 2–2.9 t less than for fertilization treatments. Statistically significant differences between the control and fertilization treatments were determined for the first time in the 4th experimental year. Average nitrogen uptake by the aboveground biomass was 116 kg N/ha for the control, 162–170 kg N/ha for fertilization treatments. All experimental treatments had a negative balance of N inputs and outputs, and it was –1394 kg N/ha for the control (for 12 experimental years). After the application of mineral fertilizers, a lower content of total carbon and nitrogen was measured in the topsoil compared to the control and treatments with organic fertilization. The changes in the nitrogen regime of soil were characterized by the content of extractable nitrogen and carbon in extractions by 0.01M $CaCl_2$. With respect to the content of mineral nitrogen and easily extractable organic nitrogen and carbon in the topsoil the control was most stable followed by farmyard manure treatment. Soil lysimeters were installed in these experiments (depth 60 cm, size 0.2 m^2). For an eight-year period (1994/2002) 11.78 kg N-NO_3^-/ha were determined in lysimetric waters. These values for fertilization treatments ranged from 21.0 to 58.2 kg N-NO_3^-/ha. Straw application reduced nitrate contents in lysimetric waters.

Keywords: stationary experiment; maize; nitrogen fertilization; N transformation in soil; lysimeters

Maize is the most important annual forage crop in this country. Its production of dry matter and energy substances per unit area is high. It is a crucial crop for specialized dairy farms where intensive applications of farmyard manure and slurry are carried out and where it is grown for several successive years (Ammon et al. 1990). Maize belongs to the group of crops called consumers of organic matters (Škarda 1982) with negative impacts on soil productivity. This is the reason why nutrition experiments with successive growing of maize were established on plots of the Department of Agrochemistry and Plant Nutrition of Czech University of Agriculture in Prague.

The objective of our investigations was to determine changes in nitrogen balance and in the intensity of transformation of nitrogen and other nutrients in the soil under a negative management system, and changes in the parameters of soil productivity (Balík et al. 1995).

MATERIAL AND METHODS

Stationary experiments with successive growing of silage maize were established at an experimental station in Červený Újezd locality in 1990, belongs to the Agronomic Faculty of Czech University of Agriculture in Prague (height 405 m above sea level). The locality lies in a sugar beet production area. Average annual air temperature is 7.6°C, average annual precipitation amount is 549 mm. Average temperature for the growing season (months IV–IX) is 13.9°C, average precipitation amount for the growing season is 361 mm (Table 1). At the beginning of experiments the reserve of available P in topsoil was in the category high reserve, K good reserve, Mg high reserve (Mehlich II) and pH/KCl was 6.6 (Balík et al. 1995).

Maize hybrid CE 240 was grown in 1991–1993, Dea in 1994 and 1995, Romana in 1996 and 1997, Torena in 1998, Compact in 1999 and 2001, Etendard in 2002. Row spacing was 70 cm. Average stand density was 95 000 plants per 1 ha at the time of harvest. The size of experimental plot was 170 m^2 and that of harvest plot 25 m^2. Each treatment had four replications. Spring wheat was used as a maize forecrop. The last organic fertilization before the experiments were established was carried out in 1988. This paper presents the results of only five treatments that differed in the intensity and form of nitrogen fertilization (Table 2). Manure application rate was 40 t/ha, application rate of winter wheat straw was 5 t/ha. Straw was applied four times, manure five times in the years 1991–1998. The quality of manure (cattle manure + poultry droppings) was different in the years of observation, particularly its N content. Since 1999 straw (5 t/ha) and cattle manure (120 kg N/ha according to N content) have been applied every year. Mineral nitrogen fertilizers were

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Table 1. Precipitation amounts in the years 1991–2002 (September)

Period	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Calendar year (mm)	375.3	423.6	532.5	457.8	612.2	516.3	467.6	469.2	414.2	504.3	633.0	745.9
Growing season (mm)	243.1	258.0	316.0	285.9	449.3	392.6	364.6	293.0	256.8	239.9	435.6	478.5

Average annual precipitation amount 549 mm, and 361 mm for the growing season (months IV–IX)

Table 2. Experiment layout

No.	Treatment	Designation	kg N/ha	Time of application (month)
1	control	CON	–	–
2	ammonium sulphate	AS	120	XI
3	DAM	DAM	120	IV
4	DAM + straw	DAM + straw	120	straw XI, DAM IV
5	farmyard manure	manure	120*	XI

* in 1991/1998 – 40 t of manure 5×; in 1999/2002 – 120 kg N/ha in manure every year

applied every year. Neither liming nor P, K and Mg fertilization were used during the experiments.

The content of mineral N (N_{min}) was determined in extractions by 0.01M $CaCl_2$ (Houba et al. 1986), using a colorimetric method on a SKALAR plus SYSTEM apparatus. Total N in plants was measured after wet decomposition by concentrated H_2SO_4 with an addition of mixed catalyst at 420°C, in a KJELTEC AUTO 1030 ANALYZER. A LECO CNS 2000 apparatus was used to determine total content of nitrogen and carbon in the topsoil.

Soil lysimeters were installed in the spring 1992. Plastic troughs 0.2 m^2 in size (15 cm × 133.3 cm) were laid in the ground so that the upper edge of the trough would be at a depth of 60 cm. Lysimetric waters were collected into a receptacle at a depth of 90 cm. The water from the receptacle was pumped with a vacuum pump. The hose end was fixed at a depth of 35 cm outside of the lysimeter space. Such installation enabled to manage the plot without any hindrances. Neither was the lateral movement hindered during the application of soil moisture as it happens in all traditional filled-in lysimeters. Two lysimeters were installed for each treatment. Samplings of lysimetric waters were usually carried out at the beginning of April and after harvest (in September), in some cases only once a year after harvest.

RESULTS AND DISCUSSION

Table 3 shows average yields of dry matter for the whole experimental period. Average yield in the control was 11.67 t dry matter per ha; it was by 2–2.9 t less than in the fertilization treatments. Statistically significant differences between control and fertilization treatments were determined for the first time in 1994 (i.e. in the 4^{th} year of experiments). So it was confirmed that maize could efficiently utilize nitrogen from soil reserves released by mineralization in the months of May and June, and in the month of September. Therefore its response to nitrogen fertilization on fertile soils is relatively low (Horn 1990). Average yield in the control was 12.02 t/ha in 1991/1995, 10.09 t/ha in 1996/1998 and 11.54 t/ha in 1999/2000 (Figure 1). The variability of these results is quantified by standard deviation. Higher values of standard deviation are influenced by inter-year variability caused by a different hybrid that started to be grown, and particularly by weather conditions of the year concerned.

Ammonium sulphate was intentionally applied in treatment 2 in late autumn, on the same date as organic fertilization. The experimental station is situated in a drier area with the relatively deep soil profile without hazard of leaching losses, therefore this extreme case was chosen.

Table 3. Average annual dry matter yield, N content in plants and N uptake by crops in 1991 –2002

No.	Treatment	Dry matter yield (t/ha)	N content (%)	Uptake by crops (kg N/ha)
1	CON	11.67	0.996	116.2
2	AS	13.71	1.183	162.2
3	DAM	13.72	1.205	165.3
4	DAM + straw	14.15	1.174	166.1
5	manure	14.55	1.170	170.2

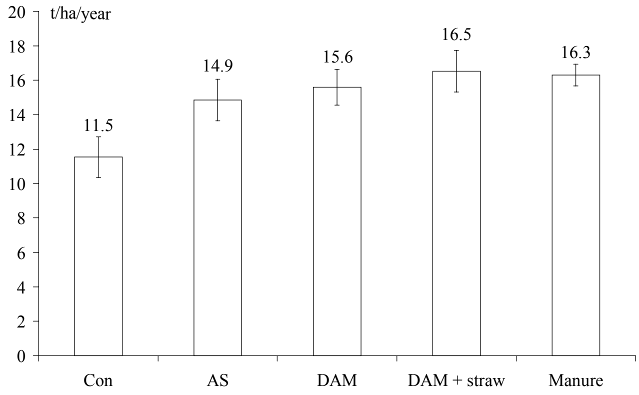

Figure 1. Dry matter yields of maize (average 1999–2002)

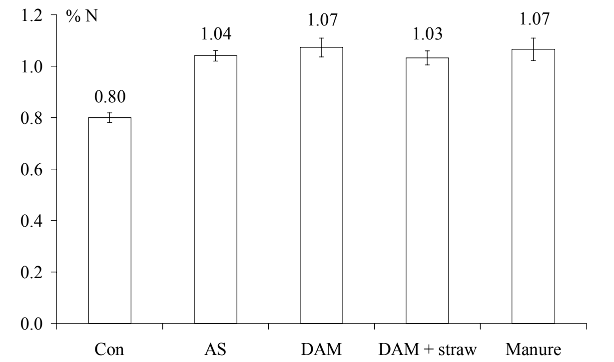

Figure 2. Nitrogen content in plant dry matter at harvest (average 1999–2002)

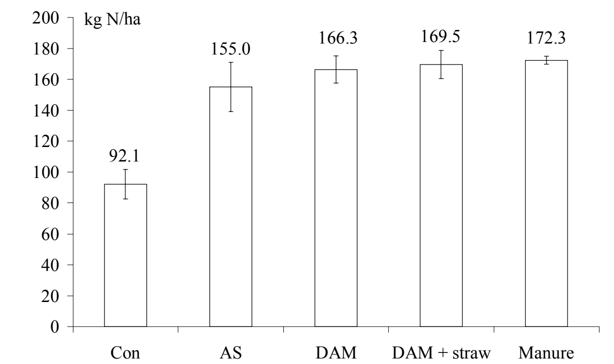

Figure 3. Nitrogen uptake by the aboveground biomass of maize (average 1999–2002)

In treatment 3, DAM in liquid form was applied just before sowing and subsequently incorporated into the soil. These two treatments had almost identical dry matter yields on the long-term average (AS – 13.71 t/ha, DAM – 13.72 t/ha). In the initial period, the yields were higher for AS treatment, currently DAM fertilization is more efficient.

Plants were harvested when their dry matter content was 30–34%. No statistically significant differences in dry matter content between the treatments were determined. However, the highest content of dry matter was always found in the control. The fertilization treatments did not differ from each other very much. In relative terms, dry matter content in the fertilization treatments was about 96–98% of the control.

Figure 2 shows N content in maize plants at harvest. The concentration of 1.09% N was measured in the control in 1991/1995, 0.95% in 1996/1998 and in 0.80% in 1999/2002. As N concentration in treatment 1 significantly decreased and because it remained at approximately the same level in the fertilization treatments, the differences between these treatments increased.

N uptake by the aboveground biomass of plants is a very important item of information (Figure 3). This characteristic shows variations in yield as well as variations in N concentration in plants. Average annual uptake in the control was 92.1 kg N/ha in the period of observation 1999/2002. This low value resulted from a low content of nitrogen in dry matter. In 1991/1995 average N uptake in the control amounted to 130.8 kg/ha, in the subsequent period the value lower by 29% was calculated, i.e. 93.5 kg/ha. Average N uptake in DAM + straw treatment was 169.6 kg/ha in the last period. The high intensity of long-term organic fertilization (treatment 5) was reflected in increased N uptake. In manure treatment the uptake was 172.3 kg N/ha, i.e. by 80.2 kg/ha more than in the control.

Table 4 shows the balance of N inputs and outputs in Červený Újezd locality for the eight-year experimental period. The inputs involve N in fertilizers only while atmospheric N is not included (dry and wet deposition, N from biological fixation). The outputs comprise only N uptake by the aboveground biomass of plants. Wet deposition was recorded in the years 1992/93 and it was about 9 kg N/ha/year (Balík et al. 1995). The results document negative balance in all treatments. N deficit in the control amounted to 1 394 kg/ha for the whole experimental period. In AS treatment the input was lower by 506 kg/ha than the uptake by plants, in DAM treatment, DAM + straw treatment and manure treatment it was less by 544 kg/ha, 415 kg/ha and 70 kg/ha, respectively.

Besides yield and N uptake the basic goal of these experiments was to study nitrogen transformations in the soil. Table 5 shows total contents of carbon and nitrogen in the topsoil after harvest in 2002. Data in this table document a statistically lower content of nitrogen for DAM treatment compared to the control. A decrease in carbon content is also obvious, but it is not statistically significant. A similar trend of a decrease in C_t and N_t content was measured for AS treatment. These results are consistent with the conclusions drawn by Collins et al (1992), who reported that the applications of mineral nitrogen fertilizers increased the mineralization of soil organic matters. The widest C/N ratio was found for DAM treatment. The results of Kubát et al. (1999) are confirmed that nitrogenous compounds of soil organic matter are

Table 4. N balance (kg/ha) in Červený Újezd locality for 1991–2002

No.	Treatment	Inputs (fertilization)	Outputs (uptake by crops)	Difference (inputs-outputs)
		kg N/ha		
1	CON	–	1394	–1394
2	AS	1440	1946	–506
3	DAM	1440	1984	–544
4	DAM + straw	1440 + 138	1993	–415
5	manure	1972	2042	–70

Table 5. Total content of carbon and nitrogen in the topsoil at maize harvest in 2002

No.	Treatment	C_t	N_t
		mg/100 g	
1	CON	1541	139.4
2	AS	1516	133.4
3	DAM	1504	127.4
4	DAM + straw	1610	139.9
5	manure	1900	162.9
d_{min} ($\alpha = 0.05$)		73	8.4

more susceptible to decomposition and mineralization than the components not containing nitrogen. It proves a hypothesis that nitrogen compounds are composed of the peripheral components of molecules of humic acids. As assumed, the manure treatment has a statistically significant increase in C_t and N_t content in comparison with treatments CON, AS, DAM and also DAM + straw. A statistically higher content of carbon was measured after straw application, but nitrogen content did not differ from the control significantly.

Figures 4 and 5 shows mineral nitrogen content in the topsoil at the time of harvest. As NH_4^+ content was mostly lower than 1 mg N/kg, the sum of N_{min} is given in this paper. Average values for the last 4 years are documented. The values of standard deviation illustrate relatively identical contents of N_{min} in the years of observation for the control, AS and manure treatments. On the contrary, high inter-year variability was determined for treatments with spring application of DAM (treatments 3 and 4). This graph also shows that the content of N_{min} was significantly higher for manure, DAM, DAM + straw treatments than for the control. The high contents of residual nitrogen in the topsoil after maize harvest can be a potential source of nitrogen losses and are an indicator for groundwater protection. When calculated for the topsoil layer of 25 cm, nitrate nitrogen is nearly 60 kg N/ha for DAM treatment and 73 kg N/ha for DAM + straw treatment. The contents of N_{min} at a level of 5–7 mg/kg appear to be residual ones, and the N_{min} reserve in the topsoil is not likely to decrease below this level at the time of harvest. This value can be taken into account for balances to define the criteria and fertilization recommendations based on N_{min} content in the soil.

The analytical equipment of our workplace made it possible to measure total content of nitrogen ($N_{min} + N_{org}$) and carbon in extractions by 0.01M of $CaCl_2$ solution (Houba et al. 1986). The values in Figure 6 document a substantially higher variability in carbon than in nitrogen. As assumed, the highest C contents were determined for manure treatment and the lowest for DAM treatment. Contrary to our expectations, on average lower C contents

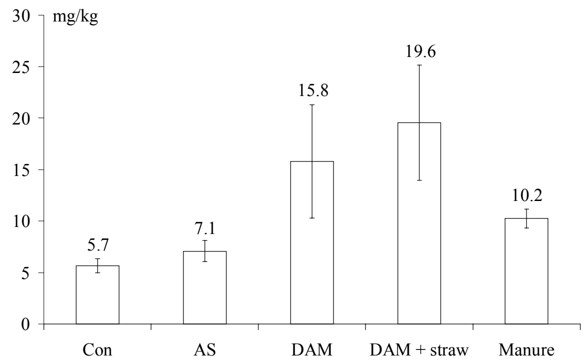

Figure 4. Mineral nitrogen content in the topsoil at maize harvest (average 1999–2002)

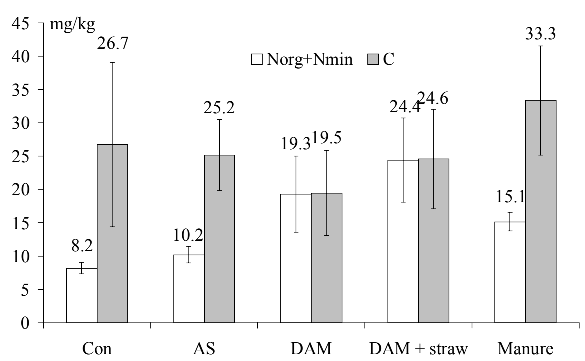

Figure 5. Nitrogen and carbon content in topsoil extractions by 0.01M $CaCl_2$ at maize harvest (average 1999–2002)

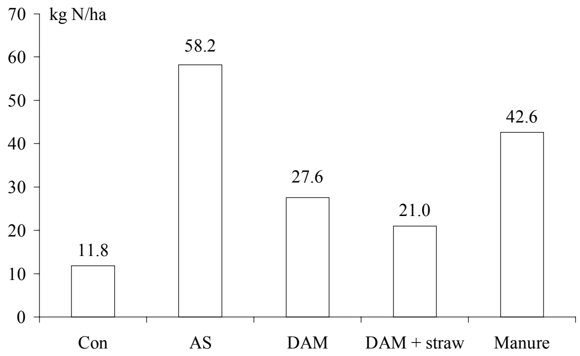

Figure 6. Total amounts of nitrates ($N\text{-}NO_3^-$) in lysimetric waters (17th October 1994–14th October 2002)

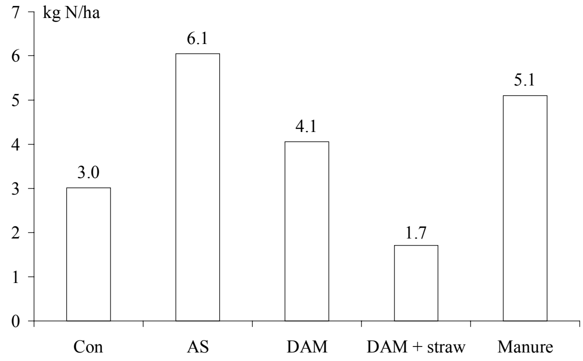

Figure 7. Total amount of organic nitrogen in lysimetric waters (17th October 1994–14th October 2002)

were measured for DAM + straw treatment than for the control. Besides absolute contents the carbon to nitrogen ratio is a very important criterion (Olfs 1992). The ratio of extractable C : N was 3.32 for the control and 2.20 for manure. This ratio was lowest for DAM treatment and for DAM + straw treatment (1.01). These results document quite different transformation processes of nitrogen and carbon taking place in the soil for all treatments. The control, and farmyard manure treatment, seem to be most stable from this aspect. It is to state that our results are consistent with the conclusions drawn by Vaněk et al. (2003), who accentuate the importance of farmyard manure application in the fertilization system as for the value of the potential of easily mineralizable nitrogen in the soil.

Figures 6 and 7 show nitrogen amount in lysimetric waters. Total nitrogen amount for the period from 17th October 1994 to 14th October 2002 is documented. The lysimeters were installed in spring in 1992. Only nitrate contents were measured in the first period (1st October 1992–17th October 1994); the amount of $N\text{-}NO_3^-$ intercepted by lysimeters was 1 kg N/kg for the control, 8.6 kg/ha for ammonium sulphate and 7.4 kg/ha for DAM. The values for DAM + straw treatment and for manure treatment were 6.2 and 6.4 kg/ha, respectively.

Nitrogen content in the form of nitrates and organic solutes was monitored in lysimetric waters since 1994. The highest measured values for an eight-year period were found for ammonium sulphate treatment where 58.2 kg $N\text{-}NO_3^-$/ha were leached. The losses in the control were 5× lower – 11.8 kg N/ha (Figure 6). In keeping with the conclusions drawn by Klasse and Werner (1986) our results also document potential losses of nitrogen through leaching after the application of organic fertilizers in autumn. It is obvious that it is a model case for ammonium sulphate not consistent with agronomic practice. On the other hand, this treatment can be compared with manure treatment (the same date of application). The organic form of nitrogen manifested itself in manure treatment and the losses were by 15.6 kg N/ha lower compared to AS. Although the treatments with DAM fertilizer (No. 3 and 4) had high contents of residual nitrogen at the time of harvest, the amounts in lysimetric waters were lower: 21.0 kg $N\text{-}NO_3^-$/ha for DAM + straw treatment and 27.6 kg $N\text{-}NO_3^-$/ha for DAM treatment. It was caused by the immobilization effect of applied straw.

Siemens and Kaupenjohann (2002) pointed out to potential leaching losses of nitrogen in organic forms on arable lands of Germany. The analytical equipment of our workplace enabled to measure also this form. Total amount of nitrogen in organic form was highest for ammonium sulphate treatment, 6.1 kg N/ha (Figure 7). The immobilization effect of straw manifested itself clearly in organic nitrogen and the amount of N_{org} in lysimetric waters was only 1.7 kg N/ha, which was less than in the control (3.0 kg N/ha).

It is to emphasize that these are not nitrogen losses by leaching. These values only document a certain movement of nitrogen. The root system of maize reaches to a depth of considerably more than 60 cm in the soil profile and nitrogen from the lower layers is taken up by plants; in addition, there is a movement of nitrogen towards the soil surface as a result of capillary rising of soil solution. On the other hand, these results accentuate a potential risk of nitrogen losses by leaching from fertilizers applied in autumn. On average 20.540 ml of solution per area of one lysimeter was intercepted in the period of observation. Total amount of precipitation was 4 286.2 mm. Only 2% of the total amount of precipitation infiltrated into a depth of 60 cm. It is interesting that a certain movement of nitrogen occurs in all fertilization treatments although the intensity of fertilization was much lower than nitrogen uptake by the aboveground biomass.

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ABSTRAKT

Bilance dusíku a obsah minerálního N v půdě ve stacionárním pokusu s kukuřicí při různých systémech N hnojení

V dlouhodobých stacionárních pokusech (1991 až 2002) s opakovaným pěstováním kukuřice byl sledován vliv různých systémů N hnojení na bilanci dusíku a transformaci N v půdě. Průměrný výnos sušiny na kontrolní nehnojené variantě za období 1991/2002 činil 11,67 t sušiny na ha, což bylo o 2–2,9 t méně než u hnojených variant. Statisticky významné rozdíly mezi kontrolní a hnojenými variantami byly poprvé stanoveny ve čtvrtém roce pokusů. Průměrný odběr dusíku nadzemní biomasou činil na kontrolní variantě 116 kg N/ha, u hnojených variant 162–170 kg N/ha. U všech pokusných variant byla negativní bilance mezi vstupy a výstupy N a na kontrole představovala celkem –1394 kg N/ha (za období 12 let pokusů). Po aplikaci samotných minerálních hnojiv byl nalezen nižší obsah celkového uhlíku a dusíku v ornici ve srovnání s kontrolní variantou a variantami s organickým hnojením. Změny dusíkatého režimu půdy byly dále charakterizovány obsahem extrahovatelného dusíku a uhlíku ve výluhu 0,01M $CaCl_2$. S ohledem na obsah minerálního dusíku a lehce extrahovatelného organického dusíku a uhlíku v ornici se jako nejstabilnější projevila varianta kontrolní a dále varianta hnojená chlévským hnojem. V pokusech byly rovněž instalovány půdní lyzimetry (hloubka 60 cm, plocha 0,2 m^2). Za období osmi let (1994/2002) bylo v lyzimetrických vodách nalezeno na kontrolní variantě 11,78 kg $N\text{-}NO_3^-$/ha. U hnojených variant byly stanoveny hodnoty 21,0–58,2 kg $N\text{-}NO_3^-$/ha. Po aplikaci slámy se v lyzimetrických vodách obsahy dusičnanů snížily.

Klíčová slova: stacionární pokus; kukuřice; hnojení dusíkem; transformace N v půdě; lyzimetry

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