NITORGEN TURNOVER OF CHERNOZEM MEADOW SOIL IN A LONG-TERM MINERAL FERTILISATION TRIAL

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The elaboration and introduction of an environment-friendly N fertilisation system requires studies on the soil N regime, and on NO_3-N accumulation and leaching under field conditions. The present work aimed to provide data on the soil N balance and on the depth distribution and leaching of NO_3-N in chernozem meadow soil, based on the results of an 18-year long-term mineral fertilisation experiment. The soil contained 3.0-3.2 % humus and had good N-supplying ability. Averaged over 18 years, the plant N uptake on plots without N fertilisation was 126 kg $ha^{-1}year^{-1}$. At the 80 kg ha^{-1} N rate the soil N balance was negative, with a mean plant N uptake of 170 kg $ha^{-1}year^{-1}$ and a low rate of NO_3-N leaching was observed. At 160 kg ha^{-1} N the accumulated N balance was only slightly negative. In 7 of the 18 years plant N uptake vas below 160 kg ha^{-1}. Under the given experimental conditions, considering the natural N-supplying capacity of the soil, the 160 kg ha^{-1} N fertiliser rate proved to be excessive, surpassing the N requirements of the potential crop yield in most years and resulting in NO_3-N leaching. The N regime data indicated that the 240 kg ha^{-1} N rate represented over-fertilisation in the given location.

Key vords: N fertilisation, N turnover, NO_3-N leaching, long-term trial

INTRODUCTION

The minimisation of environmental pollution from N fertilisation, the need to adjust N fertilisation to plant requirements and the elaboration of a precision recommendation system for N fertilisation all require the N regime and N-supplying ability of various soils to be estimated as accurately as possible under various ecological and technological conditions.

The mean N pollution (mineral fertiliser + farmyard manure N) of Hungary's agricultural land over the last two decades did not represent a high environmental risk, but this does not mean that there are no areas in the country which are at risk of N pollution due to incorrect N management in agriculture. Hungary applies the EU Nitrate Directive and has elaborated the necessary regulatory and monitoring systems, but it is still necessary to examine all the factors which need to be harmonised in order to reduce the N pollution of the environment.

The soil N regime and the accumulation and leaching of NO_3-N are influenced by numerous factors, such as N fertilisation practice, plant N uptake, the N-supplying ability of the soil, ecological factors, cultivation technology, and farming and soil use methods (Jung, 1972, Németh 1996, Kirchmann et al. 2002).

The results of numerous long-term experiments confirmed that N accumulation and NO_3-N leaching are primarily due to N fertilisation in excess of plant demands (Kádár and Németh 1993, Ruzsányi et al. 1994, Hansen and Djurhuus 1996, Németh and Kádár 1999, Izsáki and Iványi 2005), though this may be considerably modified by soil structure, soil tillage, crop sequences, the root depth and N demands of the crop, the quantity and C/N ratio of stubble and crop residues, the plant cover, the time and distribution of N fertilisation, water supplies and irrigation (Hansen and Djurhuus 1996, Delphin 2000, Icher et al. 2003, Nakamura 2004). Long-term fertilisation experiments are ideal for examining these complex effects.

The present work evaluated the effects of N fertilisation, crop sequences and water supplies on the N balance, N-supplying ability, NO_3-N accumulation and leaching in a chernozem meadow soil, based on the results of 18 years of a long-term mineral fertilisation experiment, in order to elaborate an environment-friendly, location-specific system of N fertilisation.

Materials and methods

The long-term mineral fertilisation experiment was set up at the Experimental Station of the Institute of Agricultural Sciences in Szarvas, in the Southern Great Plain Region of Hungary, in 1989. The soil of the experimental area is a chernozem meadow soil, calcareous in the deeper layers, with the following main properties at the beginning of the experiment: depth of the humus layer 85–100 cm, pH_{KCl} of the ploughed layer 5.0–5.2, humus content 3.0–3.2%, $CaCO_3$ content 0%, upper limit of plasticity according to Arany (K_A) 50, clay content 32%, and good phosphorus and potassium supplies. The mean groundwater depth was 300–350 m and the surface of the experimental area was completely flat.

The mineral fertiliser treatments involved all possible combinations of four levels each of N, P and K, giving a total of 64 treatments, laid out in three replications in a split-split-plot design with a sub-sub-plot size of 4×5 m. One aim of the experiment was to examine the effect of N fertilisation on plant nutrient uptake and yield, the mineral N content and N-supplying capacity of the soil, and NO_3-N leaching. The investigations reported here were carried out on selected plots where the N fertilisation rates were 0, 80, 160 and 240 kg ha^{-1} $year^{-1}$, applied in the form of ammonium nitrate (34% N).

The crop sequence in the various N regime cycles was as follows: 1990–1993: sugar beet *(Beta vulgaris* L.*)*, soybean *(Glycine max* L.*)*, fibre hemp *(Cannabis sativa* L.*)*, canary grass *(Phalaris canariensis* L.*)*; 1994–1997: maize *(Zea mays* L.*)*, soybean, linseed *(Linum usitatissimum* L.*)*, naked oat *(Avena nuda* L.*)*; 1998–2000: broad bean *(Vicia faba* L.*)*, fibre hemp, sorghum *(Sorghum bicolor* L. Moench.*)*; 2001–2003: maize, broad bean, fibre hemp; 2004–2007: sorghum, maize, soybean, fibre hemp.

In order to calculate the soil N balance (N applied – N uptake), measurements were made on the yield and N uptake per plot. Samples of whole aboveground plant organs were taken for N analysis immediately before harvesting from 2×1 m per plot. The N content of the plant organs was determined using the macro-Kjeldahl method. In order to monitor the migration of NO_3-N, the soil NO_3-N content in the N_0, N_{80}, N_{160} and N_{240} treatments was recorded to depths of 200 and 300 cm in 1993, 1997, 2000, 2003 and 2007. Soil samples were taken every 20 cm from three drillings per plot, after which the samples for each level were united. The NO_3-N content was then determined from a 1 N KCl extract using the colorimetric method. In order to evaluate the N supplies of the soil, the mineral N content of the 0–60 cm layer was determined each year prior to sowing in spring and after harvest in autumn.

Results and discussion

When calculating N balances it is assumed that the N uptake of the crop is derived from fertiliser N. When no mineral fertiliser is applied or the N fertiliser does not cover the plant uptake the N balance is negative, indicating a decrease in the original N supplies of the soil. Research results have proved, however, that under field conditions 40–80% of the fertiliser N is taken up by the plants in the first vegetation period. Unabsorbed nitrogen is subjected to various transformation processes, but in the long term the majority of this N form is either taken up by the crop or is leached.

The estimated N balance of the experiment is presented in the Table 1.

In the first experimental cycle (1990–1993), when the sequence included sugar beet, soybeans, fibre hemp and canary grass, the plants took up 558 kg ha^{-1} nitrogen in plots without N fertilisation, which was indicative of the good N-supplying ability of the soil.

At N rates of 80 and 160 kg ha^{-1} the N balance was negative, and only at the 240 kg ha^{-1} rate was a positive N balance recorded. When the balance of N-fertilised plots is compared with that of the control plots (soil $balance_{Tr}$ – soil $balance_{Ct}$) the difference provides information on the extent to which the soil was "enriched" with nitrogen in excess of plant N uptake. At N rates of 160 and 240 kg ha^{-1} the soil N supplies increased theoretically by 307 and 612 kg per hectare, approximately 80% of which could be detected in NO_3-N form (soil NO_3-N_{Tr} – soil NO_3-N_{Ct}) in the 200 cm soil profile. NO_3-N leaching was first detected at the 160 kg ha^{-1} N rate, and became pronounced at the highest rate.

During the second experimental cycle (1994–1997), when the crop sequence consisted of maize, soybean, linseed and naked oats, the plant N uptake was only 341 kg ha^{-1} without N fertilisation, while the N uptake over the whole eight years reached a value of 899 kg ha^{-1}. The N balance was negative at an N fertiliser rate of 80 kg ha^{-1}, while the balance was close to equilibrium at 160 kg ha^{-1}, with a value of –50 kg ha^{-1}. At the highest level of N supplies the N balance became strongly positive. In this cycle, when some of the crops had lower N requirements and there were two dry years with unfavourable rainfall distribution, the yields were low and the N reserves of the soil (soil $balance_{Tr}$ – soil $balance_{Ct}$) increased in all the N-fertilised treatments.

In the eighth year of the experiment the curves illustrating the soil distribution of NO_3-N were clearly distinct in layers below 100 cm, and the profile of NO_3-N accumulation gave a good characterisation of N supply levels. The maximum N accumulation was recorded at a depth of 140–180 cm, irrespective of the N supplies.

Table 1 Estimated N balance of experiment, kg ha^{-1}
(Szarvas, 1990-2007)

Items in the balance	N application rate kg ha^{-1} year^{-1}			
	0	80	160	240
	1997 (at the end of the 8th year) kg ha^{-1}			
N applied	-	640	1280	1920
N uptake	899	1192	1330	1294
Soil balance (N applied-N uptake)	-899	-552	-50	626
Soil balance$_{Tr}$ - soil balance$_{Ct}$	-	347	849	1525
NO_3-N in the soil (0-2 m)	205	384	530	690
Soil NO_3- N_{Tr} - soil NO_3-N_{Ct} (0-2 m)	-	179	325	485
	2000 (at the end of the 11th year) kg ha^{-1}			
N applied	-	880	1760	2640
N uptake	1126	1595	1747	1806
Soil balance (N applied - N uptake)	-1126	-715	13	834
Soil balance$_{Tr}$ - soil balance$_{Ct}$	-	411	1139	1960
NO_3-N in the soil (0-2 m)	115	117	304	359
Soil NO_3- N_{Tr} - soil NO_3-N_{Ct} (0-2 m)	-	2	189	244
NO_3-N in the soil (0-3 m)	214	256	466	603
Soil NO_3-N_{Tr} - soil NO_3-N_{Ct} (0-3 m)	-	42	252	389
	2003 (at the end of the 14th year) kg ha^{-1}			
N applied	-	1120	2240	3360
N uptake	1523	2139	2343	2441
Soil balance (N applied-N uptake)	-1523	-1019	-103	919
Soil balance$_{Tr}$ - soil balance$_{Ct}$	-	504	1420	2442
NO_3-N in the soil (0-2 m)	118	211	265	606
Soil NO_3- N_{Tr} - soil NO_3-N_{Ct} (0-2 m)	-	93	147	488
NO_3-N in the soil (0-3 m)	221	388	493	842
Soil NO_3- N_{Tr} - soil NO_3-N_{Ct} (0-3 m)	-	167	272	621
	2007 (at the end of the 18th year) kg ha^{-1}			
N applied	-	1440	2880	4320
N uptake	2273	3054	3309	3435
Soil balance (N applied-N uptake)	-2273	-1614	-429	885
Soil balance$_{Tr}$ - soil balance$_{Ct}$	-	659	1844	3158
NO_3-N in the soil (0-2 m)	76	128	235	254
Soil NO_3-N_{Tr} - soil NO_3-N_{Ct} (0-2 m)	-	52	159	178
NO_3-N in the soil (0-3 m)	153	235	380	427
Soil NO_3-N_{Tr} - Soil NO_3-N_{Ct} (0-3 m)	-	82	227	274

Tr= treated; Ct= control

Over the course of the 11 years (1990-2000) the plants absorbed a total of 1126 kg N ha^{-1}, averaging 102 kg ha^{-1}, without N fertilisation. At a fertiliser rate of 80 kg N ha^{-1} the N balance was negative, reaching an approximate equilibrium at 160 kg ha^{-1} and becoming positive in the case of over-fertilisation with N (240 kg ha^{-1}). The increase in soil N content compared with the control (soil balance$_{Tr}$ – soil balance$_{Ct}$) amounted to 411, 1139 and 1960 kg ha^{-1} at increasing N fertiliser rates, but only 10, 22 and 20%, respectively, of this could be detected in NO_3-N form in the 300 cm soil profile. This high rate of N leaching could be explained by the fact that 1999 was extremely wet (847 mm), with a total of 207 mm rainfall in November and December, with the result that the groundwater was close to the soil surface from late autumn to early spring. Due to the extremely dry weather during the 2000 vegetation period, the groundwater dropped to a depth of 300 cm by late September, taking with it a substantial quantity of NO_3-N.

In the fourth experimental cycle (2001–2003), when the sequence was maize, broad beans and fibre hemp, the plant N uptake was 397 kg ha^{-1} without N fertilisation. By the end of the 14th growing season plant N uptake on the control plots had reached 1523 kg ha^{-1}, an average of 109 kg ha^{-1} N supplies a year. The N balance was negative at an N rate of 80 kg ha^{-1} (–1019 kg ha^{-1}) and still slightly negative at 160 kg ha^{-1} (–103 kg ha^{-1}), becoming positive at 240 kg N ha^{-1} (919 kg ha^{-1}). In terms of changes in the N content compared with the control over the full 14-year period (soil $balance_{Tr}$ – soil $balance_{Ct}$), the theoretical N enrichment of the soil at rising rates of N fertilisation amounted to 504, 1420 and 2442 kg ha^{-1}, of which 33, 19 and 25% could be detected in the 300 cm soil profile in the form of NO_3-N.

In the fifth experimental cycle (2004–2007), sorghum, maize, soybean and fibre hemp were included in the crop sequence. Three of these years (2004–2006) had favourable water supplies, while 2007 was an average year for rainfall. The better water supplies favoured higher yields and N uptake. Thus, without N fertilisation plant N uptake over the four years amounted to 750 kg ha^{-1}, an annual average of 188 kg ha^{-1}, while in the N-fertilised treatments (80, 160, 240 kg ha^{-1}) the N uptake was 915, 966 and 994 kg ha^{-1}, respectively, with the result that over this 4-year cycle the N balance was negative for all the N fertiliser levels.

The combined N balance data for the 18 years of the experiment indicate that without N fertilisation plant uptake amounted to 2273 kg ha^{-1}, equivalent to 126 kg ha^{-1} a year on average. It can be seen from the soil N balance that at the 80 and 160 kg ha^{-1} N fertiliser rates this balance was negative (–1614 and -429 kg ha^{-1}, respectively). The N balance became positive (885 kg ha^{-1}) at the 240 kg ha^{-1} N rate. A comparison of the N balances for the N-fertilised and unfertilised plots (soil $balance_{Tr}$ – soil $balance_{Ct}$) revealed that the theoretical increase in soil N content at rising rates of N fertilisation (80, 160 and 240 kg ha^{-1}) amounted to 659, 1844 and 3158 kg ha^{-1}, respectively, 12, 12 and 9% of which could be detected in the 300 cm soil layer in the form of NO_3-N. Over the 18-year experimental period the mean N uptake of the plants at N fertilisation levels of 80, 160 and 240 kg ha^{-1} amounted to 170, 184 and 191 kg ha^{-1}. Taking into consideration the mean 126 kg ha^{-1} N-supplying ability of soil given no N fertiliser, the N-supplying capacity of the soil at an N fertiliser rate of 80 kg ha^{-1} could be put at 206 kg ha^{-1}, which was in excess of the plant N uptake values recorded at N fertiliser rates of

160 and 240 kg ha^{-1}. This indicates that, over the average of many years, fertilisation with 80 kg ha^{-1} N is sufficient to satisfy plant N requirements in combination with the good N-supplying capacity of this soil. This was confirmed by yield analysis, as there was no significant increase in yield in any year at rates of 160 or 240 kg ha^{-1} compared with the 80 kg ha^{-1} rate.

Acknowledgements

This research was fundad in part by grants T-034436 and T-048816 from the National Scientific Research Fund.

References

Delphin, J-E. (2000): Estimation of nitrogen mineralization in the field from an incubation test and from soil analysis. *Agron. Sustain. Dev.*, **20,** 349-361.

Hansen, E. M., Djurhuus, J. (1996): Nitrate leaching as affected by long-term N fertilization on a coarse sand. *Soil Use and Management*, **12,** 221-228.

Ichir, L. L., Ismaili, M., Hofman, G. (2003): Recovery of ^{15}N labeled wheat residue and residual effect of N fertilization in a wheat-wheat cropping system under Mediterranean conditions. *Nutrient Cycling in Agroecosystems*, **66**, 201-207.

Izsáki, Z., Iványi, I. (2005): Effect of mineral fertilization on NO_3-N leaching on clay soil. *Comm. Soil. Sci. Plant Anal.*, **36,** 383-391.

Jung, J. (1972): Factors determining the leaching of nitrogen from soil, including some aspects of maintenance of water quality. *Plant Foods for Human Nutrition*, **21,** 343-366.

Kádár, I., Németh, T. (1993): Nitrát bemosódásának vizsgálata műtrágyázási tartamkísérletben. (Study on nitrate leaching in long-term fertilization trial.) *Növénytermelés*, **42,** 331-338.

Kirchmann, H., Johnston, A. E. J., Bergström, L. F. (2002): Possibilities for reducing nitrate leaching from agricultural land. AMBIO: *J. Human Environ.*, **31,** 404-408.

Nakamura, K., Harter, T., Hirono, Y., Hirono, H., Mitsuno, T. (2004): Assessment of root zone nitrogen leaching as affected by irrigation and nutrient management practices. *Vadose Zone J.*, **3,** 1353-1366.

Németh, T. (1996): *Talajaink szervesanyag-tartalma*. (Organic matter content of Hungarian soils.) MTA Talajtani és Agrokémiai Kutató Intézete, Budapest.

Németh, T., Kádár, I. (1999): Nitrát bemosódásának vizsgálata és a nitrogénmérleg alakulása egy műtrágyázási tartamkísérletben. (Studies on nitrate leaching and changes in the nitrogen balance during a long-term mineral fertilization experiment.) *Növénytermelés*, **48,** 377-386.

Ruzsányi, L., Pepó, P., Sárvári, M. (1994): Evaluation of major agrotechnical factors in sustainable crop production. *Agrokémia és Talajtan*, **43,** 335-343.