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NITROGEN BALANCE IN INTENSIVE AGRICULTURE IN THE NORTH CHINA PLAIN

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Introduction

China is a country with large population and limited arable lands per capita (Zhu and Chen, 2002). To produce sufficient food to sustain the huge population, cropping practices often call for large applications of nitrogen fertilizer to maximize yields. However, the N applied is not all taken by crop; the efficiencies of N fertilizer use are very low, approximately 32%-35%. A large proportion is lost to the atmosphere by ammonia volatilization and denitrification, or leached into the ground or surface waters. This not only results in financial losses to farmers, but also has a detrimental impact on the environment. The object of this study is to quantitative estimates key aspects of the nitrogen cycle in order to develop effective strategies of N fertilizer management and to provide important parameters for the development of comprehensive N models to address issues of sustainable agriculture and environmental quality.

Materials and Methods

Experimental site

Key aspects of the nitrogen cycle mainly including N inputs (through fertilization, crop residue retained, irrigation and precipitation) and N outputs (N uptake, NH_3 volatilization, denitrification and nitrate leaching) were quantitatively examined in an approximate 1 ha farmland with a wheat-maize cropping system at the Luancheng Agro-ecosystem experimental station, Chinese Academy of Sciences. The station is located at 37.89°N, 114.67°E, and is 50.1m above sea level, where is in the east monsoon region, has a semihumid and warm temperature climate with a mean annual rainfall of 537 mm, most of which occur in summer. The soil was a moderately well drained loamy soil. Some properties of top soil (20 cm) were as follows: pH 8.5; bulk density 1.33 g cm^{-1}; organic matter 12-13 g kg^{-1}; total N, 0.8-0.9 g kg^{-1}.

Typical local farming practices were used in this study. Field was cultivated in early in October to a depth of about 20 cm with a rotovator, and seeded with winter wheat with a seeder. The wheat was harvested at the beginning of June. Summer maize was seeded just after wheat harvested and was harvested in the late of September. Residues of both wheat and maize were returned to field. During the experimental period the fertilization details were as follows: the basal fertilizer (150 kg N/ha) for wheat was surface applied just prior to ploughing and was immediately incorporated with rotovator to a depth of about 20cm. The top-dressing fertilizers were surface broadcast in April for wheat (100 kg N/ha) and in July for maize (170 kg N/ha), immediately following irrigation.

Measurement of ammonia volatilization

Micrometeorological gradient diffusion method in conjunction with a Bowen Ratio system (Hutchinson *et al.*, 1982; Denmead, 1983, 1994) was used to determine the actual NH_3 fluxes. The Bowen Ratio system was used to measure gradients of temperature and water vapor pressure, net radiation, soil temperature, soil heat flux, and wind speed. The devices including a vacuum pump, gas flow (rate and mass) meters, an acid trap, and a spectrophotometer were required for measuring the atmospheric NH_3 concentration. The net vertical flux density of NH_3 (F) was described by:

$$F = H(C_{z1} - C_{z2})/[\rho c_p(T_{z1} - T_{z2})] \quad (1)$$

where H is the flux density of sensible heat, ρ is the atmospheric density, c_p is the specific heat of moist air, C_{z1} and C_{z2} are NH_3 gas concentrations, and T_{z1} and T_{z2} are air temperatures at heights z_1 and z_2 at any given time.

Measurement of denitrification and N_2O emission

Denitrification loss and N_2O emission were measured using the acetylene inhibition method on intact soil cores (Ruz-Jerez et al. 1994, Chen et al. 1996). The sampling schedules were adjusted to focus on periods when N_2O emissions were most probable, that is, after irrigation or rainfall and fertiliser N applied. Denitrification and N_2O flux were measured every 2-3 days from the time of the N application, or after irrigation/heavy rainfall, for 10 days and then once a week for three weeks.

In addition, the measurements were conducted in three plots without N fertilizer, which was as control treatment (CK). The measurements both in the 1 ha experimental field and control plot were simultaneous.

Measurement of water drainage and nitrate leaching

Three soil profiles were dug to the depth of 200 cm in the 1 ha experimental field to install some monitoring instruments in order to monitor water drainage dynamic and take soil solution samples. In each point, ten suction cup samplers and ten tensiometers were installed with 20 cm interval along the two sides of the soil profile, respectively. An aluminum neutron access tubes were inserted to 200 cm depth close to each of the profiles. Tensiometer, neutron probe readings were taken once a week with additional reading once a day for 5 days after irrigation or significant rainfall (≥10 mm). Suction cup samplings were taken to analyze NO_3^--N content at least once every two weeks, with more frequent sampling after irrigation or significant rain (≥10 mm), and fertilizer applications.

Measurements required calculating water drainage and nitrate (NO_3^-) leaching below the root zone (1.8m) by the soil water balance (SWB) model (Heng et al. 2001) were conducted. The soil water balance was calculated on a daily time step for each of the three-instrumented experimental sites. The nitrate leaching losses were obtained from multiplying deep water drainage by nitrate concentration in the drainage samples (Magesan, 1996; Hu *et al*., 2002).

Results and Discussion

Ammonia volatilization

When the basal fertilizer was applied to the field just before sowing wheat in Oct. 2000, very little NH_3 volatilization occurred, with a peak of 0.52 kg N ha^{-1} d^{-1} on the fifth day after N application. The total NH_3 loss was only 1.78 kg N ha^{-1}, accounting for 1.2% of the applied fertilizer N during the wheat sowing period. During topdressing period under wheat in Apr. 2001, the NH_3 loss was 17.9 kg N ha^{-1} with peak of 1.91 kg N ha^{-1} occurred three days after N applied, totally accounting for 17.9% of N applied. Ammonia volatilization commenced very soon after the urea was surface broadcast to the maize field, the flux density reached a peak of 9.23 kg N ha^{-1} d^{-1} one day after urea was applied, but decreased to about zero thirteen days later (Fig. 1). The total NH_3 volatilization loss was 19.7 kg N ha^{-1} under wheat and 46.7 kg N ha^{-1} under maize, accounting for 7.9% and 27.4% of the applied N, respectively. Through NH_3 volatilization, there is about 66.3 kg N ha^{-1} N lost during maize-wheat rotation year, account for 16% of the total applied fertilizer N.

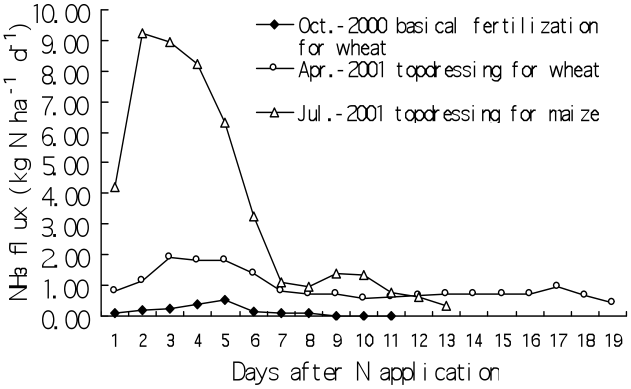

Fig. 1. Daily NH_3 volatilization after N-fertilizer application during maize-wheat rotation season.

Denitrification and N_2O emission

Denitrification rates and N_2O fluxes exhibited similar seasonal pattern. Under wheat, a slight burst of activity was triggered by irrigation and the basal urea application prior to sowing in October, with N_2O flux peak levels of 15.5±2.2 g N_2O-N ha^{-1} d^{-1}, while the peak of denitrification was 29.1±3.6 g (N_2O+N_2)-N ha^{-1} d^{-1} (Fig. 2). The values were within the range of 1.20-78.48 g N_2O-N ha^{-1} d^{-1} under wheat reported by Mahmood (1998). The second period of activity occurred in spring, following the top-dressing fertilization and irrigations in mid-April and the peaks value were slight higher than those observed at the sowing time. During the maize season, one brief burst of N_2O emission and denitrification occurred 2-4 days after N application and irrigation in mid-July 2000. The peak levels were 178.1±57.8 g N_2O-N $ha^{-1}d^{-1}$ and 323±82.9g (N_2O+N_2)-N ha^{-1} d^{-1} for N_2O emission and denitrification, respectively. In this study the increases in N_2O emissions followed N fertilization lasted about 6~7 weeks, similar to 6 weeks summarized by Mosier (1998). After this time, emission rates were reduced to fluctuate around a low base line level.

In the control treatment (CK), both of the denitrification rates and N_2O fluxes were much lower than those observed in the fertilized field. There were slight fluctuations after irrigation or heavy rainfall both for denitrification rates and N_2O fluxes (Fig. 2).

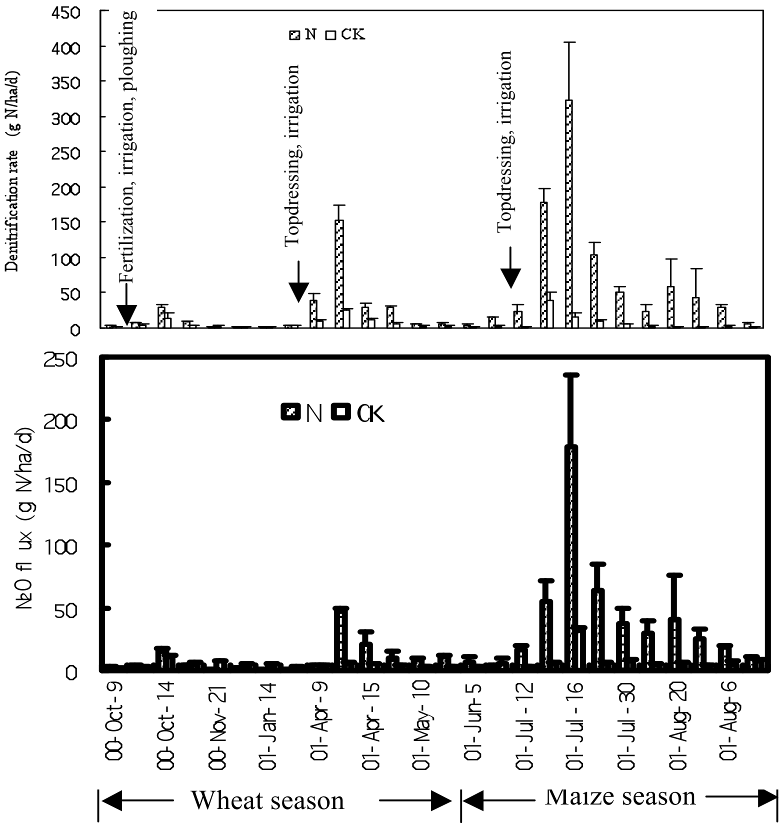

Fig. 2 Seasonal distribution of denitrification rates and nitrous oxide fluxes observed in the 1 ha experimental field from October 2000 to September 2001.

Since N_2O-emissions and denitrification rates were measured over the year, linearly interpolating data points and integrating the obtained curve could calculate the annual cumulative N loss through denitrification and N_2O emission. Loss through N_2O emission during the wheat season was 1.1±0.03 kg N ha^{-1}, while the denitrification loss was 2.5±0.4 kg N ha^{-1}. Under maize, the losses through N_2O emission and denitrification were 3.1±0.4 kg N ha^{-1} and 4.8±0.3 kg N ha^{-1}, respectively (Table 1).

The annual N_2O-emission fluxes (-C_2H_2) was 4.2 kg N $ha^{-1}y^{-1}$, representing 0.64% of the applied N. The values in this study are close to the global value published by Bouwman (1996), indicating an average fertiliser-induced N_2O emission of 1.25±1.0% of N applied. The annual denitrification loss was 7.3 kg N $ha^{-1}y^{-1}$, accounting for 1.02% of applied N. This is similar to the denitrification loss from fertilizer N applied to wheat-maize in China of 0.8-2.0%, as estimated by Cai (2002).

Table 1. N_2O emissions and denitrification losses from wheat-maize rotation system from October 2000 to September 2001

Period	Treatment	N_2O emission	Denitrification loss	Denitrification-nitrification loss
Wheat season	N	1.1±0.03	2.5±0.4	2.5~3.6
	CK	0.8±0.1	1.1±0.1	1.1~1.9
Maize season	N	3.1±0.4	4.8±0.3	4.8~7.9
	CK	0.7±0.03	1.9±0.9	1.9~2.6
Annual loss	N	4.2±0.43	7.3±0.7	7.3~11.5
	CK	1.5±0.1	3.0±1.0	3.0~4.5
	Percentage to N applied (%)	0.64	1.02	1.02~1.67

The relatively small difference between N_2O emissions and denitrification indicated that nitrification was an important source of the N_2O-producing process except when soil moisture content was high. During the present study, it was impossible to distinguish between nitrification and denitrification as the source of N_2O. The exact value could not be calculated since the contribution of nitrification was unknown. The annual N_2O emission from the C_2H_2 treated soil cores represents the minimum N-loss as this figure was based on the assumption that no nitrification-derived N_2O was emitted. On the other hand, the sum of the fluxes from soil cores with and without C_2H_2-amendment was only correct, representing the maximum N-loss through denitrification and nitrification, if the denitrification end product is N_2 rather than N_2O. N-losses (N_2O+N_2) from both nitrification and denitrification ranged was 7.3~11.5 kg N ha^{-1}, accounting for 1.02-1.67% of applied N in the crop year.

Water deep drainage and nitrate leaching loss

In this study area, under wheat-maize rotation field there are rare root actions below 180 cm soil depth (Zhang, 1999). It was assumed that water and nutrient absorbed by root below this depth would be a small and rare event and that NO_3-N leached below this depth would cause potential of groundwater pollution. Due to high spatial variability of soil profile structure and different initial water storages at the experimental starting, the temporal and spatial variability of deep drainage was great in this field. The average total drainage was 41 mm, ranging from 51 to 88 mm, accounting for 6% ~ 11% of total irrigation+rainfall (Table 2).

Since the concentration of NH_4-N in the drainage water was less than 1% of NO_3-N, NO_3-N losses from the soil profile can be regarded as good estimates of total N lost in drainage (Magesan, 1992). Nitrate leaching loss was calculated using the SWB method and NO_3^- concentrations of suction samples at depth of 180 cm when water deep drainage occurred (Table 2). The estimated amount of total NO_3-N leaching (including leaching loss of soil- and fertilizer-N) was 32±12 kg NO_3-N ha^{-1} under wheat and 24±18 kg NO_3-N ha^{-1} under maize, accounting for 7.6%~16.8% and 2.1%~22.5% of the applied N, respectively. The percentage loss of the applied N corresponding to the complete wheat-maize crop was 5.4%~19.1%. This significant N leaching was the consequence of the large amount of N fertilizer applied, 420 kg N ha^{-1}, and inappropriate and excessive irrigation (465mm).

Table 2. Soil water drainage and nitrate leaching losses calculated by soil water balance method and NO_3-N concentration of suction samples

Period	Crop	Precipitation (mm)	Irrigation (mm)	Eta[a] (mm)	Drainages (mm)	NO_3^--N leaching loss (kg N/ha)
1/10/2000~31/5/2001	Wheat	127	320	343	41±7	32±12
1/6/2001~30/9/2001	Maize	217	145	431	29±13	24±18
Total		344	465	774	70±19	56±30

[a] Measured by the weighing Lysimeter.

Nitrogen balance

Agricultural management, including fertilization, irrigation, tillage, crop rotation and stubble management, was recorded in the 1 ha experimental field for one crop rotation year from October 2000 to September 2001. The nitrogen contents in irrigation water, rainfall and crop residue were analyzed. The total N input for a crop rotation year by fertilization, irrigation, rainfall, and crop straw returned were shown in table 3. The amount of N input into the wheat-maize rotation system in a crop rotation year was 558.5 kg N ha^{-1}. The fertilizer N applied was the main item of the N inputs, accounting for 75% of the total N input.

Table 3. Amount of N input through applied N fertilizer, residue, irrigation and rainfall (kg N ha^{-1})

Period	Crop	Fertilizer	Residue	Irrigation	rainfall	Total input
1/10/2000~31/5/2000	Wheat	250	32	11.6	0.5	294.1
1/6/2000~30/9/2000	Maize	170	87	5.2	2.2	264.4
Total		420	119	16.8	2.7	558.5

Crop yields, including grain yield and straw yield, were measured at nine sites in the 1 ha experimental field and the N contents in biomass were analyzed. The N uptakes by plant above ground were calculated (Table 4). The total N uptakes by plant above ground, both from applied N fertilizer and soil N, were 359kg N ha^{-1} y^{-1}. The total N output, including N uptake by plant above ground and N loss, was 488.7~492.9 kg N $ha^{-1}y^{-1}$. N uptake by plant above ground was the main item of N output, accounting for about 73% of the total N output. The total N loss to the environment was 129.7~133.9 kg N $ha^{-1}y^{-1}$. Ammonia volatilization and nitrate leaching were the main pathways of fertilizer N loss, accounting for 49.5%~51.2% and 41.8%~43.2% of the total N loss, respectively, while denitrification loss was relatively low compared with ammonia volatilization and nitrate leaching. The results suggested that denitrification loss was not an important pathway in fertilizer N economy, but may have significant environmental impacts because N_2O is a potent greenhouse gas.

Table 4. Amount of N output through uptake by plant, nitrate leaching, NH3 volatilization and denitrification (kg N ha^{-1})

Period (m/y)	Crop	N uptake by plant	NO_3^--N leaching	NH_3 volatilization	Denitrification-nitrification loss	Total output
10/2000~5/2000	Wheat	162±8	32±12	19.7	2.5~3.6	216.2~217.3
6/2000~9/2000	Maize	197±17	24±18	46.7	4.8~7.9	272.5~275.6
Total		359±19	56±30	66.4	7.3~11.5	488.7~492.9

Conclusion

Substantial losses of N are not only financial losses for farmers but also serious environmental concerns. The N input was higher than the N output and the N balance was greatly surplus. To minimize the fertilizer loss and its adverse impact on the environment, precision in water and fertilizer management is necessary. A range of management options to mitigate N loss includes reducing N and water application rates, synchronizing N and water supply to plant demand, precision farming, and regulatory measures.

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