# Monitoring of Nitrogen cycling and balance in maize monoculture agro-ecosystem in northeast China black soil

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***Abstract*—Research the nitrogen cycling in agricultural ecosystem and quantitative analysis of the sources and destinations of nitrogen are important for the reasonable application of nitrogen fertilizer and promotion of the agricultural sustainability. The trial was aimed to monitor and assess nitrogen cycling and balance in maize monoculture agro-ecosystem in northeast China black soil. Ammonia volatilization, denitrification, nitrate leaching and crop nitrogen (N) uptake were measured in field experiments under different N applications, and nitrogen budget was quantitatively evaluated. Results showed that the N input was 30.56 ~ 330.56 kg ha $^{-1}$ and the N output was 124.9 ~ 225.5 kg ha $^{-1}$ in this black soil agro-ecosystem. The N input was mainly through chemical fertilizer, rainfall, biological fixation and seeds in maize monoculture agro-ecosystem, among which chemical N fertilizer contributed to 83.1%~88.2% of total N input. Meanwhile, nitrogen was removed from this agro-ecosystem primarily through crop uptake, ammonia volatilization and denitrification. Crop N uptake accounted for 90.3% ~ 95.2% of total N removal. With the increase of N fertilization application, N loss through ammonia volatilization and denitrification increased markedly. Ammonia volatilization is an important way of nitrogen loss in this agro-ecosystem, and N loss from ammonia volatilization was observed to be 5.38 ~ 18.85 kg ha $^{-1}$ yr $^{-1}$, which occupied 3.17% ~ 4.49% of the applied N fertilizer. The loss rate of fertilizer nitrogen caused by denitrification was only 0.08% to 0.23%. Compared with the northern wheat-maize rotation system, nitrogen loss from ammonia volatilization and denitrification in the maize monoculture system is lower, only equivalent to nitrogen loss from winter wheat season in the wheat-maize rotation system. There was a N deficiency in 3.05 ~ 94.34 kg ha $^{-1}$ yr $^{-1}$when N input was less than 150 kg ha $^{-1}$ yr $^{-1}$ in this agro-ecosystem. However, there was a 124.57 kg ha $^{-1}$ yr $^{-1}$N surplus in this agro-ecosystem when farmer conventional fertilization was 300 kg ha $^{-1}$ yr $^{-1}$. Under N application of 225 kg ha $^{-1}$ (two times of application) and optimized N application of 225 kg ha $^{-1}$ (three times of application), there was a 51.36 and 30.06 kg ha $^{-1}$ yr $^{-1}$N surplus, respectively. Therefore, intensifying N management associated with increasing ratios of top dressing N to basal N fertilizer and times of top dressing might be a useful measure to reduce the N surplus and N loss, and maintain a positive nitrogen cycling and balance in maize monoculture agro-ecosystem.**

***Keywords—Agricultural ecosystem monitoring; Nitrogen cycling and balance; Black soil; Maize monoculture***

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## I. INTRODUCTION

The nitrogen cycles of the agro-ecosystems are driven not only by natural behavior also by human behavior, which is the biggest difference compared with those in the ecosystems of wetlands, grasslands and oceans. For instance, atmospheric nitrogen deposition is the main source of nitrogen in wetland ecosystems [1], biological nitrogen fixation is the important input of nitrogen in grassland ecosystems [2], and denitrification is the dominant nitrogen loss process in the ocean ecosystems [3]. However, chemical fertilizer is a main source of nitrogen input and crop N uptake is the important output of nitrogen in the agro-ecosystems. In this system, excessive use of nitrogen fertilizer is the common phenomenon to obtain higher yield. Excessive input of nitrogen to this system would reduce the fertilizer utilization rate and meanwhile result in a series of environmental problems such as water pollution and $N_2O$ emission by leaching and denitrification loss [4-5]. Therefore, the nitrogen cycles of the agro-ecosystems have been paid more attention than those in other natural ecosystems. The more detailed information on the N cycles can be provided by integrating atmosphere-soil N process into the total N balances. But it is not easy to determine accurately each component of N input and output in relation to atmosphere-soil N process.

The northeast black soil, the north wheat-maize rotation system and the middle-lower Yangtze plains are three major grain producing areas in China. The nitrogen cyclings and balances in the North wheat-maize rotation systems and the middle-lower Yangtze plains have been researched recently [6-7]. But there are few published reports on the nitrogen cycling and balance in the northeast black soil. Maize monoculture system is a typical planting pattern in the northeast China black soil. The maize annual yield in this region contributed 27.60 % of the total maize production in China and its amount of N fertilizer application accounted for 29.79% of the total N fertilizer amount[8]. Excessive use of N fertilizer and the unreasonable fertilization such as base fertilizer applied only once without top-dressing fertilizer are common problems in the maize monoculture system. An investigation found that the farmer conventional fertilization was 300 kg N $ha^{-1}$. It's obvious that such high N rates exceed the N requirements of maize and would cause N losses. The fertilizer utilization rate was only 30% ~ 35%, and fertilizer average loss rate was about 45% in this region. The losses of nitrogen mainly were caused from ammonia volatilization, denitrification and leaching losses due to improper fertilization practices.

Quantitative analysis of the sources and destinations of nitrogen are useful tools for minimizing environmental pollution and promotion of the agricultural sustainability. Integrated research on nitrogen cycling and balances was essential to understand N behavior and reasonably use nitrogen fertilizers in this specific black soil system. Therefore, a field study was undertaken to monitor and assess nitrogen cycling and balance in maize monoculture agro-ecosystem in northeast China black soil. Ammonia volatilization, denitrification, nitrate leaching and crop nitrogen (N) uptake were measured under different N applications, and nitrogen budget was quantitatively evaluated.

## II. MATERIALS AND METHODS

*Experimental site*

A field experiment was conducted for one year (April – October, 2014) on the field of Heilongjiang Academy of Agricultural Sciences（45.41°N, 126.37°E）, Harbin, Heilongjiang Province. The cropping system is maize monoculture. The study area belongs to temperate continental monsoon climate, its annual average temperature is 3.6°C, and effective accumulated temperature of growing season is 2757.8°C. The average annual precipitation is 523.3mm. The study area is black soil and its organic C from 0～20cm deep soil profile is 20.14 g $kg^{-1}$, total N is 1.14 $gkg^{-1}$, Olsen P is 43.1$mgkg^{-1}$, available K is 251.8 mg $kg^{-1}$, soil bulk density is 1.40$gcm^{-3}$and pH is 6.8.

*The experimental design and fertilizer treatments*

The plots, each 6m×20m in size, were arranged in a randomized complete block experimental design with three replicates. Maize cultivar is Tunyu 88 with the planting density of 60000 plants $ha^{-1}$. An investigation in maize monoculture system found that the farmer conventional fertilization was 300 kg N $ha^{-1}$ with 50% base fertilizer and 50%jointing fertilizer or base fertilizer applied only once. The yield of the farmer conventional fertilization is 9545 $kgha^{-1}$ and the yield of the unfertilized plot is 7000 kg $ha^{-1}$ in this region. Supposing that the objective yield is 1.1 times the yield of the farmer conventional fertilization, the optimal amount of nitrogen application was about 225 kg N ha-1, based a formula that (objective yield- the unfertilized plot yield) * 2.6 /(0.4 * 100). Nitrogen use efficiency is 0.4 and nitrogen uptake of 100kg grain is 2.6.

Based on the above survey and calculation, the experimental design included 5 nitrogen treatments: 1) $N_0$ treatment, as an unfertilized control , 2) $N_1$ treatment, 150 kg N $ha^{-1}$with 50% base fertilizer and 50%jointing fertilizer, 3) $N_2$ treatment, 225 kg N $ha^{-1}$ with 50% base fertilizer and 50%jointing fertilizer, 4) $N_3$ treatment (the farmer conventional fertilization), 300 kg N $ha^{-1}$with 50% base fertilizer and 50%jointing fertilizer, 5) $N_4$ treatment (the optimized N application), 225 kg N $ha^{-1}$ with 33% base fertilizer, 33% jointing fertilizer and 33% booting fertilizer.

Nitrogen, phosphorus and potassium fertilizers were urea (46.4% N), calcium superphosphate (l7%$P_2O_5$) and potassium chloride (60%$K_2O$), respectively. The amounts of P and K applied to the experimental plots were.60 kg $P_2O_5$ $ha^{-1}$ and 60kg$K_2O$$ha^{-1}$, which were applied for maize monoculture system as basal fertilizer.

*The N input factors*

The nitrogen input from the fertilizers and the seeds were directly calculated by the amount of the fertilizer and the seeds and their corresponding nitrogen content. Atmospheric wet deposition from the study area was referred in the nitrogen input from precipitation. The nitrogen input from precipitation were estimated on the base of the product of the average annual precipitation (523.3mm) and the nitrogen concentration of monthly average precipitation(N2.78$mgL^{-1}$).The nitrogen input from Non-symbiotic nitrogen fixation was about 15kg N $ha^{-1}$, which referenced from the report about the non-symbiotic nitrogen fixation amount of Maize in China[9].

*Nitrogen output from grain and straw*

Maize was harvested at randomly selected 10 $m^2$ sites in each field and separated into grain and straw. The grain and straw yields were calculated by measuring dry matter weight. The grain and straw were also analyzed the N content to calculate total plant N uptake by Kjeldahl determination.

*Ammonia volatilization loss*

Ammonia volatilization losses from maize monoculture system were determined by sponge absorption method[10].Ammonia was absorbed by 15cm diameter and 20cm height PVC collectors with a phosphoglycerol soaked sponge. The samples were collected daily for 21 d after the N fertilizer application. The samples collected in the phosphoglycerol soaked sponge was taken away at 8 am, in the same time the new phosphoglycerol soaked sponge was put into PVC collectors. The samples collected immediately immerged in 300 ml of 1.0 mol $l^{-1}$ KCl solution in 500 ml containers and were shaken for 1h. At last the extracted solutions of ammonia nitrogen were analyzed using Flow Injection Analysis (FOSS, FIASTAR5000).

*Denitrification loss*

Denitrification losses from maize monoculture system were measured by using the intact soil core-acetylene ($C_2H_2$) inhibition technique [5]. The 6 soil cores were randomly taken from the different treatments by the PVC collectors (32 mm diameter and 170 mm deep) and then were put into soil using the gas-tight PVC incubator (150 mm deep). Each incubator lid was fitted with a rubber stopper for $C_2H_2$ addition and gas sample withdrawing. $C_2H_2$ was injected to the incubator and then the volume ratio of $C_2H_2$ to gas in the tank was adjusted to 10%.After the lid was closed, the incubators were kept for 24 h in a hole at 150 mm deep experimental plots and covered with a thin layer of soil. After 24 h, a 20mL gas sample was taken into the glass bottle. The samples of $N_20$ were analyzed using a gas chromatograph (Agilent, 7890A). Samples were taken on 3rd, 7th and 14th d after each N application and at longer intervals of 14d in other growing season.

*Nitrate accumulation*

Soil samples were taken once per 20cm in 0 cm to 100 cm depth soil core at seeding, jointing, booting and post-harvest stages. Soil samples was added 1 mol $l^{-1}$ KCl and were shaken for 1h. The nitrate-N contents were determined using Flow Injection Analysis (FOSS, FIASTAR5000).

*Statistical analysis*

Statistical analysis was accomplished by Microsoft Excel and variance and mean values were compared at the 5% level by the SAS software package.

## III. Results

*The N input factors*

The N input in maize monoculture agro-ecosystem was mainly through chemical fertilizer, rainfall, biological fixation and seeds. Fertilizer is the main source of nitrogen input in this system, which accounted for 83.1%～88.2% of total nitrogen input. The N amount from the precipitation is 14.80 kg N $hm^{-2}$ and seeds nitrogen uptake was 0.76 kg N $hm^{-2}$, which were not the main source of nitrogen input in the maize monoculture system. The non-symbiotic nitrogen fixation was about 15kg N $ha^{-1}$, which referenced from the research on the non-symbiotic nitrogen fixation amount of Maize [9]. The nitrogen input from organic fertilizer, irrigation and straw were neglected because this agro-ecosystem is a rain-fed agriculture system without organic fertilizer application and straw returning.

*Nitrogen output from grain and straw*

Nitrogen was removed from this agro-ecosystem mainly through grain and straw in harvest. The amount of nitrogen in the grain was harvested from 75.91 to 130.40 kg N $hm^{-2}$., and the amount of nitrogen in the straw from 42.94 to 81.76 kg N $hm^{-2}$(Table 1). With the increase of N fertilization application, the N concentration in grain and straw increased. The farmer conventional fertilization ($N_3$) and optimized nitrogen application ($N_4$) maintained the higher grain yields and above-ground maize nitrogen uptake, which resulted in the higher amount of N output.

*Ammonia volatilization loss*

In maize monoculture system, N loss from ammonia volatilization was observed to be 5.38 ~ 18.85 kg N $ha^{-1}$, which occupied 3.17% ~ 4.49% of the applied N fertilizer (Table 2). The ammonia volatilization was significantly increased by the application of N fertilizer. Ammonia volatilization from N free treatment ($N_0$) was 5.38kg N $ha^{-1}$, and ammonia volatilization from the farmer conventional fertilization ($N_3$) was 18.85 kg N $ha^{-1}$, which is the largest in all treatments. Optimized nitrogen application ($N_4$) can significantly reduce the ammonia volatilization loss. Its ammonia volatilization was 12.52kg N $ha^{-1}$, which is significantly lower than ammonia volatilization of the northeast farmers conventional fertilization (N3) and its equivalent nitrogen treatment ($N_2$).

*Denitrification loss*

In maize monoculture system, denitrification loss of farmland ($N_0$) was 667.45g N $ha^{-1}$.The denitrification loss increased with the increase of N fertilizer application. The denitrification loss from the conventional fertilization ($N_3$) was 1883.67g N $ha^{-1}$, which is the largest in all treatments. Its Loss ratio of fertilizer N was 0.24% (Table2).Optimized fertilization ($N_4$) can also significantly reduce the N losses by denitrification. Its denitrification loss is 819.47g N $ha^{-1}$, which is significantly lower than denitrification loss from the northeast farmers conventional fertilization ($N_3$) and its equivalent nitrogen treatment ($N_2$).Compared with the ammonia volatilization loss, denitrification loss was very low in maize monoculture system. Fertilizer N losses rate caused by denitrification was only 0.08% ~ 0.24% (Table2). It seemed that denitrification was not the main way of nitrogen loss in this agro-ecosystem.

*Leaching loss*

Nitrogen leaching loss was not directly measured. Its potential risk of N leaching was assessed by analyzing the nitrate accumulation in soil profile. More than 90% of maize roots distributed in 0~100 cm soil layer in this agro-ecosystem. Therefore, it was usually assumed that the N leaching loss mainly happened outside 0~100 cm soil layer. During three weeks after basal application of N fertilizer, the rainfall was 20 mm and water filled pore space (WFPS) in soil was 21.74%～28.70%, and the nitrate accumulation from 60 ~ 80 cm soil layer was 6.67～9.79kg N $ha^{-1}$(Fig.1a).During three weeks after top-dressing N fertilizer at jointing stage, the rainfall was 12 mm and WFPS in soil was 21.04%～34.05%, and the nitrate accumulation from 60 ~ 80 cm soil layer was 6.35～8.26kg N $ha^{-1}$(Fig.1b). At booting stage, more than 95% of the nitrate was mainly distributed in 0 ~ 60cm soil layer, and the nitrate accumulation from 60 ~ 80 cm soil layer was only 1.75～2.12 kg N $ha^{-1}$(Fig.1c). The accumulation of nitrate nitrogen in 80 ~ 100cm soil profile was too low to not be detected in the entire growth period, except for $N_3$ treatment at harvest period (Fig.2). Based on previous data of the nitrate accumulation, the risk of nitrate leaching was rather low in the maize monculture system. Therefore, the nitrogen leaching loss was ignored in calculating nitrogen balance.

*Nitrogen balance in the maize monoculture system*

There was a nitrogen deficiency in 3.05 ~ 94.34 kg N$ha^{-1}$ when N input was less than 150 kg $ha^{-1}$ $yr^{-1}$ in this agro-ecosystem (table3). However, there was a 124.57 kg N $ha^{-1}$ surplus in this agro-ecosystem when farmer conventional fertilization was 300 kg $ha^{-1}$ $yr^{-1}$. Under N application of 225 kg $ha^{-1}$ (two times of application) and optimized N application of 225 kg $ha^{-1}$ (three times of application), there was a 51.36 and 30.06 kg N $ha^{-1}$ surplus (table3), respectively. It means that the optimized N application ($N_3$) effectively reduced N surplus in this agro-ecosystem.

**Table 1 N uptake by plant above ground**

| Treatments | Grain yield (kg $hm^{-2}$) | Straw yield (kg $hm^{-2}$) | Grain N (kg N $hm^{-2}$) | Straw N (kg N $hm^{-2}$) | Total N (kg N $hm^{-2}$) |
|---|---|---|---|---|---|
| $N_0$ | 7272c | 8066b | 75.91b | 42.94b | 118.85c |
| $N_1$ | 8541b | 9437ab | 101.87b | 70.47ab | 172.34b |
| $N_2$ | 8619b | 9959a | 109.24b | 79.52a | 188.76ab |
| $N_3$ | 9025a | 10727a | 110.53ab | 75.43a | 185.96ab |
| $N_4$ | 9121a | 11514a | 130.40a | 81.76a | 212.16a |

Note: No significant difference among the mean values with the same letter in the column ($p < 0.05$)

**Table2 $NH_3$ volatilization and denitrification losses in the maize monoculture system**

| Treatments | $NH_3$ volatilization | | Denitrification | |
|---|---|---|---|---|
| | N loss kg$hm^{-2}$ | Loss ratio of fertilizer N (%) | N loss kg$hm^{-2}$ | Loss ratio of fertilizer N (%) |
| $N_0$ | 5.38e | — | 667.45d | — |
| $N_1$ | 10.47d | 3.39 | 801.67c | 0.23% |
| $N_2$ | 14.56b | 4.08 | 884.92b | 0.18% |
| $N_3$ | 18.85a | 4.49 | 1183.67a | 0.24% |
| $N_4$ | 12.52c | 3.17 | 819.47c | 0.08% |

Note: No significant difference among the mean values with the same letter in the column ($p < 0.05$.)

**Table3 Nitrogen cycling and balance in maize monoculture system (kg $hm^{-2}$)**

| Items | $N_0$ | $N_1$ | $N_2$ | $N_3$ | $N_4$ |
|---|---|---|---|---|---|
| **N input** | | | | | |
| Fertilizer | 0 | 150 | 225 | 300 | 225 |
| Precipitation | 14.80 | 14.80 | 14.80 | 14.80 | 14.80 |
| Seeds | 0.76 | 0.76 | 0.76 | 0.76 | 0.76 |
| Non-symbiotic N fixation | 15 | 15 | 15 | 15 | 15 |
| **Total N input** | 30.56 | 180.56 | 255.56 | 330.56 | 255.56 |
| **N output** | | | | | |
| Crop uptake | 118.85 | 172.34 | 188.76 | 185.96 | 212.16 |
| NH3 volatilization | 5.38 | 10.47 | 14.56 | 18.85 | 12.52 |
| Denitrification | 0.67 | 0.80 | 0.88 | 1.18 | 0.82 |
| $NO_3^-$-N leaching loss | * | * | * | * | * |
| **Total N output** | 124.9 | 183.61 | 204.2 | 205.99 | 225.5 |
| **N balance** | -94.34 | -3.05 | 51.36 | 124.57 | 30.06 |

* meant that $NO_3^-$-N leaching loss was not detected in maize monoculture system.

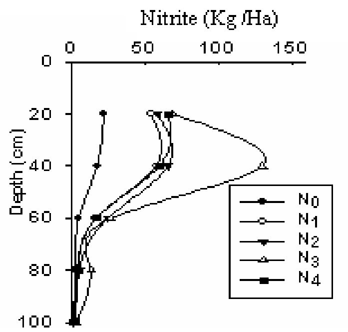


**Fig. 2 The distribution of $NO_3^-$-N in soil profiles at harvest period under different level nitrogen treatments**

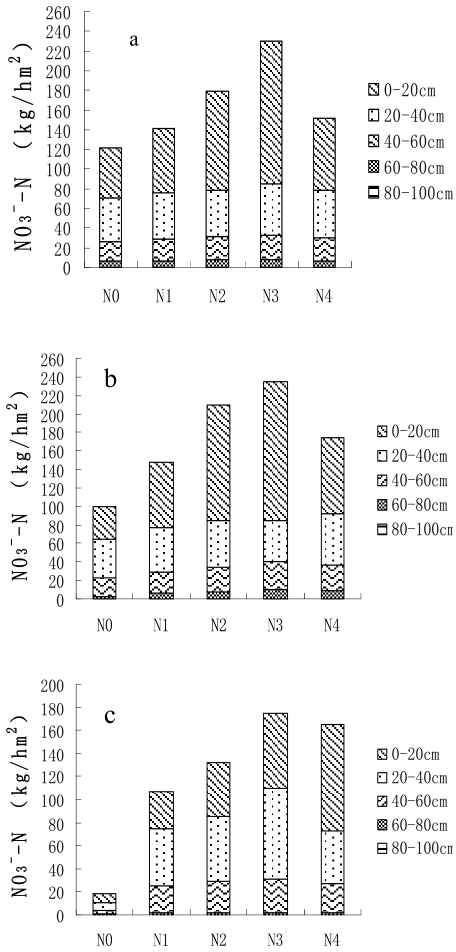


**Fig.1 $NO_3^-$-N accumulation in soil profiles during three periods of N fertilizer application**

(a, first application period of N fertilizer;
b, jointing stage after top-dressing of N fertilizer;
c, booting stage after top-dressing of N fertilizer)

## IV. DISCUSSION

The nitrogen cycle of the farmland ecosystem is a complex and dynamic process which is influenced by each component of N input and output. The positive regulation of various factors affecting nitrogen cycling can promote the reasonable flow of nitrogen in farmland, improve the fertilizer utilization rate, and reduce the loss of nitrogen. Nitrogen fertilizer is the first important factor affecting the nitrogen cycling in the agro-ecosystem. Not only nitrogen fertilizer is the main way of nitrogen input but also it has a direct impact on the each component of the nitrogen output in farmland ecosystem, such as crops nitrogen uptake, ammonia volatilization, denitrification and leaching loss. In the northeast maize monoculture system, there was a N deficiency in 3.05 ~ 94.34 kg N $ha^{-1}$when N fertilizer was less than 150 kg N $ha^{-1}$. Long time nitrogen deficient will seriously reduce soil nitrogen pool capacity and soil fertility, which might be a good explanation for the decline of organic matter in the northeast of China. When N fertilizer was used excessively (such as the farmer conventional fertilization of 300kg N $ha^{-1}$), it did not show a yield increasing effect (Table1), but caused a large number of surplus (124.57 kg N $ha^{-1}$, table 3), which resulting in a serious waste of N fertilizer resources and the potential risk of environmental pollution. Compared with $N_3$ and $N_4$ treatments in maize monoculture system, increasing the frequency of top-dressing fertilizer and reducing the fertilizer amount ($N_4$, the optimized N application) can obtain the higher yield and reduce the surplus nitrogen (Table3) and the potential environmental risk caused by the excess input of fertilizer nitrogen.

Inorganic nitrogen is the most active element in soil nitrogen pool. It can cause the nitrogen loss through ammonia volatilization, denitrification and leaching, and cause environmental pollution problems by $N_2O$ emission and $NO_3^-$-N leaching[11]. In present study, the nitrogen loss from ammonia volatilization and denitrification were significantly increased with increasing of N fertilizer in the Northeast corn monoculture system (Table 2). Despite the leaching losses of nitrogen did not occur in this region, the accumulation of $NO_3^-$-N in the 60-80cm deep soil significantly increased (Fig.1 and Fig.2).Ammonia volatilization and denitrification losses from farmer conventional fertilization ($N_3$) were the largest in all treatments, and the optimization fertilization ($N_4$) with three times of application reduced the nitrogen loss from ammonia volatilization and denitrification (Table 2). Therefore, intensifying N management associated with increasing ratios of top dressing N to basal N fertilizer and times of top dressing might be a useful measure to reduce the N surplus and N loss, and maintain a positive nitrogen cycling and balance in maize monoculture agro-ecosystem.

Comparison of nitrogen cycling and balance among the northeast maize monoculture system, north wheat-maize rotation system[4,6] and the middle-lower Yangtze plains[7] can find that N fertilizer is the main approach of the nitrogen input and crop N uptake is the main approach of the nitrogen output in three regions. As far as the nitrogen cycling characteristics in the northeast maize monoculture system was concerned, ammonia volatilization is an important way of nitrogen loss in this agro-ecosystem, which occupied 3.17% ~ 4.49% of the applied N fertilizer. Compared with the northern wheat-maize rotation system and the middle-lower Yangtze plain, nitrogen loss from denitrification in the maize monoculture system is very low, only equivalent to nitrogen loss from winter wheat season in the wheat-maize rotation system and half of nitrogen loss from one rice season in the middle-lower Yangtze plains.


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## REFERENCES


[1] D. Whitalla, B. Hendricksonb and H. Paerlb, “Importance of atmospherically deposited nitrogen to the annual nitrogen budget of the Neuse River estuary, North Carolina”, Environ. Int. vol. 29, pp. 393–399, June 2003.

[2] V. V. S. R. Gupta, S.J. Kroker , M. Hicks, C.W. Davoren , K. Descheemaeker and R. Llewellyn, “Nitrogen cycling in summer active perennial grass systems in South Australia: non-symbiotic nitrogen fixation”, Agron. Crop. Sci. vol. 65, pp. 1044–1056, May 2014.

[3] B. B. Ward, A.H. Devol, J.J. Rich, B.X. Chang, S. E. Bulow, H. Naik, A. Pratihary and A. Jayakumar , “Denitrification as the dominant nitrogen loss process in the Arabian Sea”, Nature, vol. 461, pp. 78–81, July 2009.

[4] X.T. Ju, C.L. Kou, F.S. Zhang and P. Christie, “Nitrogen balance and groundwater nitrate contamination: Comparison among three intensive cropping systems on the North China Plain”, Environ. Pollut. vol.143, pp.117–125, September 2006.

[5] B. Cao, F.Y. He, Q.M. Xu,B, Yin and G.X. Cai, “Denitrification Losses and $N_2O$ Emissions from Nitrogen Fertilizer Applied to a Vegetable Field”, Pedosphere, vol. 16, pp.390–397, February 2006.

[6] X.J. Liu, X.T. Ju, F.S. Zhang, J.R. Pan, and P. Christie, “Nitrogen dynamics and budgets in a winter wheat–maize cropping system in the North China Plain”, Field Crops Res. vol.83, pp.111–124, August 2003.

[7] C. Liu, M. Watanabe and Q. Wang, “Changes in nitrogen budgets and nitrogen use efficiency in the agroecosystems of the Changjiang River basin between 1980 and 2000” , Nutr. Cycl. Agroecosys. vol.80, pp.19–37, January 2008.

[8] Editing Committee of China Agricultural Yearbook, China Agricultural Yearbook, Agriculture Press: Beijing, 2013, pp.148–149.

[9] Z.L. Zhu, “Soil nitrogen in China”, Acta Pedologica Sin. vol.45, pp.778–783, September 2008.

[10] J. Xu, S. Peng, S. Yang and W. Wang, “Ammonia volatilization losses from a rice paddy with different irrigation and nitrogen managements”, Agr. Water Manage. vol.104, pp.184–192, February 2012.

[11] H.C. Lin, J.A. Huber, G. Gerl and K.J. Hülsbergen, “Nitrogen balances and nitrogen-use efficiency of different organic and conventional farming systems”, Nutr. Cycl. Agroecosys. vol.105, pp.1–23, May 2016.