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# Evaluating Optimum Nitrogen Management Associated with Production and Environmental Load of Farm-Systems in the Dahuofang Reservoir Region

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**Abstract:** N budgets analysis model offers a new set of tools for evaluating the N cycling in Agricultural systems. Cycling Index (CI) is also a useful tool for estimating optimal N flows in farms and Application Index (AI) as a good indicator for characterizing the N flows in farms. Using these parameters, we analyzed all farm-systems to estimate the optimal N Management for safety N pollution in ground water and maximizing N export in the Dahuofang Reservoir region. It was clearly shown the critical N application rate (chemical fertilizer + manure) was 208.4 kg N $ha^{-1}$ $y^{-1}$. The critical inter-system input (application N, imported food and feed N and natural supplied N) was 422.5 kg N $ha^{-1}$ $y^{-1}$.

**Key words:** Agricultural systems, N balance, N Cycling index, N management

## INTRODUCTION

In order to meet the food products requires increasing the quantity demand people began to utilize chemical N fertilizers with high content of nitrogen (N) on a large scale in agricultural production. Such N application often exceeds crop N need. Agricultural land cannot withstand such high excess levels of N, which in turn becomes a burden to the environment (Bock, 1984; Nelson, 1985; Roy *et al*., 2002). As a result, leaching N followed by denitrification and ammonia volatilization, significantly increased with the increase in chemical N fertilizer.

At farm level, N imported into farm systems, through N cycling, N export and N loss occur from farm. The N loss is the major contributor to nitrate contamination of groundwater (Strebel *et al*., 1989; Fraters *et al*., 1998). To evaluate whether nitrate loss is sufficiently reduce, an indicator has to be defined, which is a nitrate concentration below $NO^{-}_{3}$ 50 mg $L^{-1}$ (equivalent to 11.3 mg N $L^{-1}$)_A(WHO, 1998). Therefore, water nitrate leaching below 11.3 mg N $L^{-1}$; minimizing N import and maximizing N export was considered the optimal N management at farm systems. This study is to offer a method of tracing N flow in farm systems to evaluate N management in the Dahuofang Reservoir region.

## MATERIALS AND METHODS

**Study area:** The study area is location at Dasuhe Forestry factory, Dahe Townships, Changsha village, Qingyuan Manchu Autonomous Country, Liao Ning province (N41°51', E124°54'), Southern 190 Km from Shenyang, the capital city of Liaoning province, China.

The information was obtained through the application of a questionnaire survey for crop species cultivated, cultivated areas, amounts of chemical fertilizer and manure applied for each arable, crop production, livestock species and population, amounts of feed consumed, livestock production, human population, amounts of food consumed, amounts of food and feed imported and amounts of products exported from arable and livestock products. There were 30 farms be surveyed in.

**N-flow estimation:** Figure 1 shows the farm scale N flow model used in this study. The model consists of external input and output and internal recycling flows. Input items of the system were biological $N_2$ fixation and atmospheric deposition in arable land, application (chemical fertilizer+

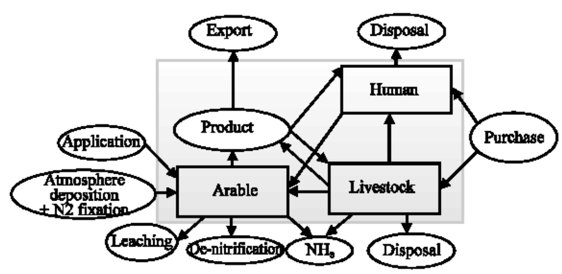


Fig. 1: N flow model for estimating the N budget flow

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manure) and purchased food and feed. Outputs of the system including N loss and N export, N loss (L) is described as L = ammonia volatilization + denitrification + leaching N + disposal N; N export is described as (E) is exported product from arable and livestock products. Internal cycling is described as (C) = human, livestock and arable land, via self-supplied (food and feed) and self manure application, N leaching N was defined as the difference between inputs and outputs in arable: the inputs include atmospheric deposition, biological $N_2$ fixation and application of chemical fertilizer and manure, whereas outputs are arable products, denitrification and ammonia volatilization.

The N flow was determined by multiplying the amount of organic matter, which is the import and export of food and feed applied into arable land, by the N content. For some livestock products and food, the N content was obtained from the Food Composition Table (RCSTA, 1982). Livestock excreta were calculated by subtracting the outputs from the inputs in the livestock; human excreta were calculated in the same manner.

In addition, the values for atmospheric deposition, biological $N_2$ fixation, denitrification and ammonia volatilization were obtained from reference values. Atmospheric deposition was calculated as 10 kg N $ha^{-1}$ $y^{-1}$ (Bouwman and van Vuuren, 1999). Biological $N_2$ fixation was 5 kg N $ha^{-1}$ $y^{-1}$ (Stewart *et al*., 1975) because of the absence of leguminous crops and hence non-symbiotic $N_2$ fixation. Denitrification was calculated as 18% of the amount of chemical N fertilizer applied (Pain *et al*., 1989). Ammonia volatilization was estimated to be 20% of human and livestock excreta N during handling and processing and 10% of manure N after application into arable lands (Javis and Pain, 1990). The above-mentioned calculation was performed for each farming family unit.

**Estimation of leaching N concentration in arable land:** The estimation of leaching N concentration was predicted by dividing the N leaching by the leaching water volume. N leaching was estimated as the difference between the N input (atmospheric deposition, biological $N_2$ fixation, chemical fertilizer and manure application) and the N output (crop production, $NH_3$ volatilization and denitrification) in regional scale:

$$\text{leaching N concentration} = \text{N leaching}/\text{leaching water volume} \quad (1)$$

**N Flow analysis methods:** Flow analysis techniques were originally borrowed from economic input-output analysis (Hannon, 1973; Finn, 1976). One may consider farm system to compose of separate homogeneous entities or components. Each component may receive input from the environment and donate output to the environment.

Throughflow is defined as the total system throughflow (TST) is described as TST = N application rate + imported and self-supplied food and feed N + naturally supplied N. Cycling may be defined as the fraction of throughflow, the cycling index (CI) for the entire system is defined as the fraction of total system throughflow.

$$\text{Total System Throughflow} = \text{Cycling} + \text{Export} + \text{Loss} \quad (2)$$

$$\text{Cycling Index} = \text{Cycling}/\text{Total System Throughflow} \quad (3)$$

Therefore, the loss index (LI) is also defined loss as the fraction of total system throughflow, the export index (EI) is defined export as the fraction of total system throughflow. The cycling index (CI) may vary from 0-1, zero meaning that there is no cycling at all. We use the method and improve it to analysis farm systems N flow.

## RESULTS AND DISCUSSION

**Farm-gate N balance and field surplus N balance at the farm scale:** Figure 2 shows the N balances of farm systems. Total input ranged from 276.1-629.3 kg N $ha^{-1}$ $y^{-1}$ of which N application (chemical N fertilizer + manure N) was from 202.4 -534.1 kg N $ha^{-1}$ $y^{-1}$, followed by food import (0-184.4 kg N $ha^{-1}$ $y^{-1}$) and others. N application was the major input, which occupied 83.1% of the total input in average. On the other hand, output ranged from 299.5 -739.5 kg N $ha^{-1}$ $y^{-1}$, of which leaching N was 31.0-255.6 kg N $ha^{-1}$ $y^{-1}$, followed by disposal N (2.0-188.4 kg N $ha^{-1}$ $y^{-1}$) denitrification (48.9-123.2 kg N $ha^{-1}$ $y^{-1}$) and ammonia emission (111.9-285.1 kg N $ha^{-1}$ $y^{-1}$). Disposal N and Leaching N accounted for 11.5 and 32.5% of the total output, respectively.

Figure 3 shows the N balances in arable land. Total input was estimated to be 273.0-650.8 kg N $ha^{-1}$ $y^{-1}$, with the average of 423.9 kg N $ha^{-1}$ $y^{-1}$. The major input component was N application rate of 344.1 kg $ha^{-1}$ $y^{-1}$ in average (ranging 202.4-534.1 kg N $ha^{-1}$ $y^{-1}$), which accounted for 81.2% (ranging 74.1-84.4%) of total input. The values varied among farms by as much as 2.1 times. Self manure N input ranged from 8.8 -113.6 kg N $ha^{-1}$ $y^{-1}$ and the average was 44.8 kg N $ha^{-1}$ $y^{-1}$. On the other hand, crop N products were 52.5-145.0 kg N $ha^{-1}$ $y^{-1}$ with 94 kg N $ha^{-1}$ $y^{-1}$ in average. Variability of crop N products was smaller than that of N application rate. The ratio

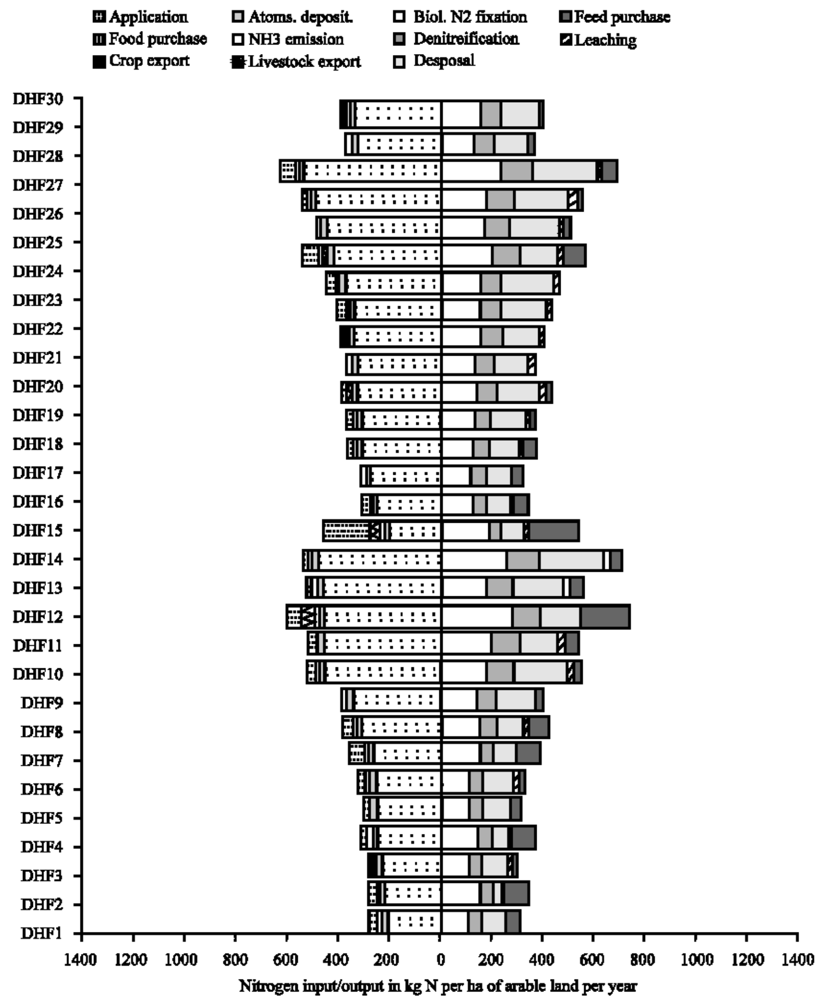


Fig. 2: Farm-gate Nitrogen Balance at farm scale

of crop N products to N application rate was 0.11-0.48 with 0.23 in average. Only third farms showed a ratio above 0.3. Denitrification N was 47.6-119.6 kg N $ha^{-1}$ $y^{-1}$ with 77.8 kg N $ha^{-1}$ $y^{-1}$ in average and ammonia volatilization was and 64.0-166.6 kg N $ha^{-1}$ $y^{-1}$ with 107.7 kg N $ha^{-1}$ $y^{-1}$ in average. Leaching N was 31.0-255.6 kg N $ha^{-1}$ $y^{-1}$, which accounted for 34.1% of the total input in average.

**The critical N Application Rate (NAR) in arable land:** Assuming the leaching water volume, the leaching water volume was estimated as the difference between precipitation and evapotranspiration. The precipitation of 700 mm and the mean annual evapotranspiration of 350 mm were measured and the drainage water volume was estimated as 350 mm for study region. The leaching N concentration in groundwater is predictable from the estimated amount of nitrate-N leaching. The WHO recommended maximum allowable concentration of nitrate in drinking water is $NO^{-}_{3}$ 50 mg $L^{-1}$ (equivalent to 11.3 mg N $L^{-1}$) (WHO, 1998). More recent studies have indicated the beneficial rather than threaten effects of nitrate-N (Lundberg *et al.*, 2004). Boink and Speijers (2001), however, suggested that consumption of drinking water with such high nitrate concentration for a prolonged period should be avoided. On the other hand, a half of the leaching volume discharged finally into Zhujiang River (Zheng *et al.*, 2003). Noted that the nitrate-N leaching possess undoubtedly environmental aspect. The excess NAR, which resulted in large nitrate leaching loss, can also be an economical loss (Neeteson *et al.*, 1999). In this study, employed temporarily the WHO (1998) recommended limit of 11.3 mg N $L^{-1}$ as the criteria for evaluating the magnitude of leaching N loss.

The Leaching N Concentration (LNC) was estimated to be significantly high in Dasuhe, N application rate

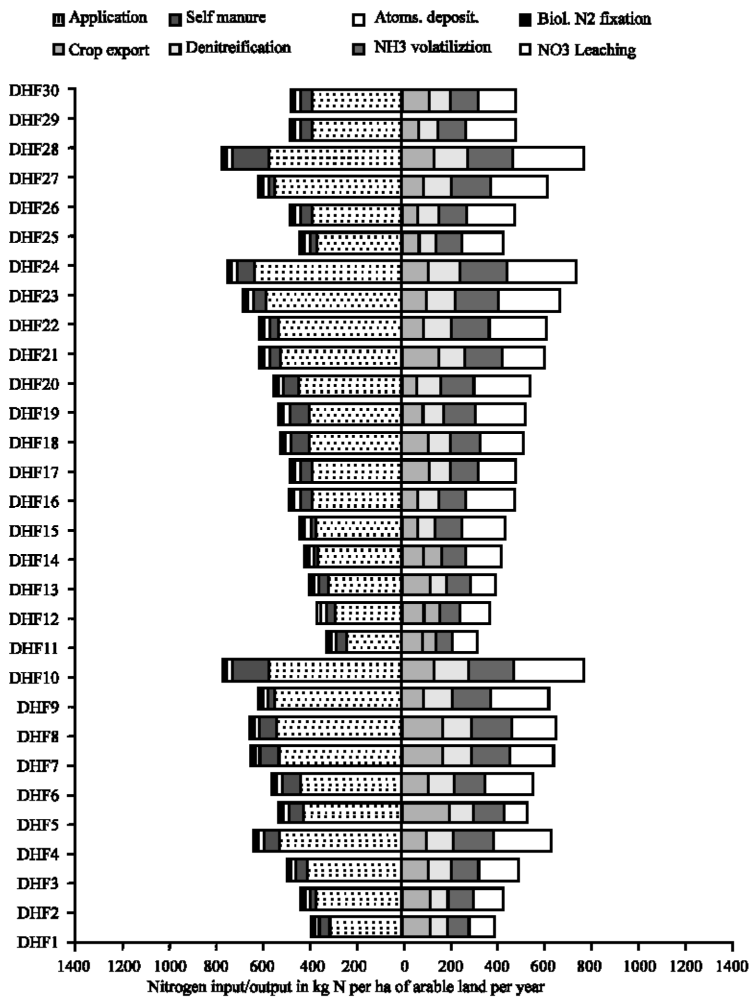


Fig. 3: Soil nitrogen balance at arable land

(NAR) explained the LNC = 0.13x - 15.8 ($R^2$ = 0.76, $p<0.05$) in Dasuhe (Fig. 4). The correlation equation indicates that LNC exceeds 11.3 mg N $L^{-1}$ at an N application rate of 208.4 kg N $ha^{-1}$ $y^{-1}$. However, the N application rate explained significantly amount of leaching N (Fig. 4), the correlation equation indicates that the N application rate of 208.4 kg N $ha^{-1}$ $y^{-1}$ produces leaching N of 54.4 kg N $ha^{-1}$ $y^{-1}$. Zebarth *et al.* (1999) showed that 50 kg N $ha^{-1}$ $y^{-1}$ of leaching N was the minimum value for maintaining optimal crop growth in Canada, which was similar to the present value in this study. Therefore, 208.4 kg N $ha^{-1}$ $y^{-1}$ for Dasuhe are the critical NAR in the regions.

**Estimate the optimal N Management in the Dasuhe:** CI is an indicator of the agricultural system stability by preventing overshoots due to external impact Vasconcellos *et al.* (1997). The CI increased with the maturity of farm systems. However, farm systems aim to obtain food products and thus, CI decreases the inevitably due to harvest and export of food. When all inter-system input N contributes to exported N, EI becomes 1 and both CI and LI become 0. But actual, products were gradually restricted with an increase in the NAR according to the law of diminishing returns and the law of minimum. Therefore, leaching N occurs inevitably in the farm systems and it is necessary to know optimal or critical N inputs which enhance for maximum production and ensure minimum N losses. In the present study, LNC of 11.3 mg N $L^{-1}$ of drinking water limit (WHO, 1998) was defined as the permissible upper range of N loss from the arable land. NAR to arable land consists mainly of chemical fertilizer and manure application. All human and animal excreta can be utilized for manure production in an ideal agricultural system. Therefore, the consumption of food for human and feed for livestock contributes to the

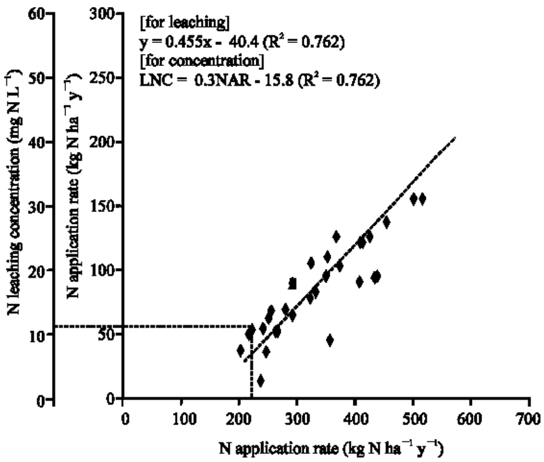


Fig. 4: Relationship between the N application rate and leaching N concentration, leaching N in leaching water from field

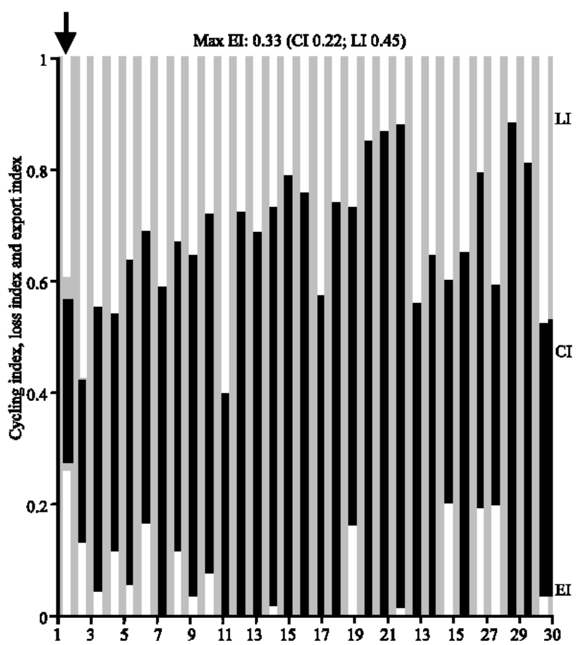


Fig. 5: Cycling index, loss index and export index of each farm

NAR and imported food and feed N can be the same as N application in farm system. As the TST is described as TST = NAR + imported and self-supplied food and feed N + naturally supplied N, NAR/TST indicates a degree of N application rate on farms, so it can be defined as the application index (AI).

The relationship between EI and CI + LI, EI and CI + EI was characteristically changed, where EI increased,

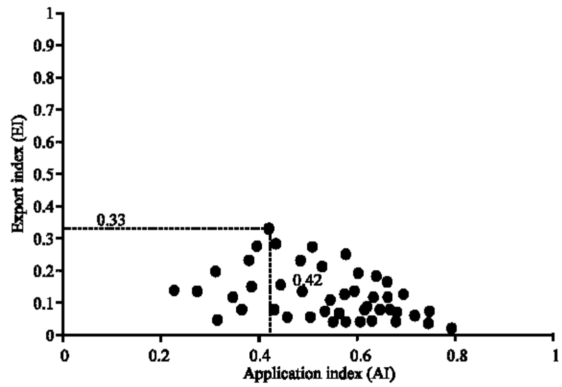


Fig. 6: Relationship between the export index and application index

CI+LI decreased. The highest EI value of 0.33 was shown in farm, which had CI of 0.22 and LI of 0.45 (Fig. 5).

The AI value of farms varied widely with a range of 0.22-0.78, the highest EI value of 0.33, the AI value is 0.41 in the farm of Dasuhe (Fig. 6). It can be determined as a critical value for optimal N cycling in the regions achieving the smallest N loss and the largest N export. We have estimated that 208.4 kg N $ha^{-1}$ $y^{-1}$ for Dasuhe are the critical N application rate, respectively. So we can estimate critical TST corresponding the critical NAR and AI. The critical TST was 541.7 kg N $ha^{-1}$ $y^{-1}$ in Dasuhe and also critical inter-system input (chemical fertilizer N, imported food and feed N and natural supplied N) can be estimated by using the TST and CI, the critical inter-system input in Dasuhe was 425.5 kg N $ha^{-1}$ $y^{-1}$.

## CONCLUSION

The minimizing N import which nitrate leaching below 11.3 mg N $L^{-1}$ and maximizing N export was considered the optimal N management at farm systems.

We analyzed Cycling index (CI), Loss index (LI) and export index (EI) based on CI + LI + EI = 1. Application index (AI) was also a good indicator for characterizing N flows on farms. All of the farms showed optimal AI which maximized EI and minimized CI + LI. The critical N application rate for maintaining optimal crop production and water quality might be determined from leaching N. Using these parameters, we can determine Optimum Nitrogen Management in Dasuhe that total system throughflow was 541.7 kg N $ha^{-1}$ $y^{-1}$; the critical N application rate (chemical fertilizer + manure) was 208.4 kg N $ha^{-1}$ $y^{-1}$; The critical inter-system input (application N, imported food and feed N and natural supplied N) was 422.5 kg N $ha^{-1}$ $y^{-1}$ in the Dasuhe.

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