Evaluating Nitrogen Management of Farm Systems in the Steep-mountainous KARST Region

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In Qibainong, the steep-mountainous KARST region, Southwest China, self-contained societies have long sustained, although increasing socio-economic liberation resulted in their structural change of the societies rapidly, environmental deterioration and exhaustion of resources have become problematic issues. Therefore, we conducted interviews analyze and estimated the optimal N management for safety N pollution in ground water and maximizing N export in the region. It was clearly shown the critical N application rate (chemical fertilizer + manure) was 297.1 kg N ha⁻¹ y⁻¹. The critical inter-system input (application N, imported food and feed N, and natural supplied N) was 551.5 kg N ha⁻¹ y⁻¹ which groundwater nitrate leaching below 11.3 mg N L⁻¹; minimizing N import and maximizing N export in the steep-mountainous KARST region.

Key Words: Agricultural systems, KARST region, N balance, N Cycling index, N management

Introduction

In the steep-mountainous KARST region, Southwest China, sustain a self-contained society during over 600 years, although increasing socio-economic liberation resulted in their structural change of the societies rapidly in recent. Consequently, environmental deterioration and exhaustion of resources have become problematic issues. 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 NO₃⁻ 50 mg L⁻¹ (equivalent to 11.3 mg N L⁻¹) (WHO, 1998). Therefore, groundwater 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 paper is to offer a method of tracing N flow in farm systems to evaluate N management in the steep-mountainous KARST region.

Materials and methods

Study site.

The study area is located in Qibainong, Dahua County, Zhuangzu autonomous region of Guangxi Province, southwestern China (N 23°3’ E 107°59”). A large karst terrain forms topographical characteristics in this
region: there are 1124 cavities (called Doline) with level planar areas of 100–300 m diameter, surrounded by 3570 steep mountains with elevations of 600–1000 m above sea level and steep slopes of 30–40°. About 16,000 persons reside in this region, near approximately 300 Doline. The region is in a subtropical monsoon climate zone. The average annual temperature is 19.5°C and the average annual precipitation is 1566 mm. The annual potential cultivation period is more than 300 days; mainly maize, soybeans, and sweet potatoes are cultivated throughout the year. In this study, we targeted the farms of four villages in Qibaimong: Nongshi-tun, Nongli-tun, Patan-tun, and Waixian-tun.

The information was obtained through the application of a questionnaire survey for 1) crop species cultivated; 2) cultivated areas; 3) amounts of chemical fertilizer and manure applied for each arable; 4) crop production; 5) livestock species and population; 6) amounts of feed consumed; 7) livestock production; 8) human population; 9) amounts of food consumed; 10) amounts of food and feed imported; and 11) amounts of products exported from arable and livestock products. There were 46 farms be surveyed in Qibaimong.

**N-flow estimation**

![N flow model for estimating the N budget flow.](image)

Fig. 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+ 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, 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, 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 drainage water volume. N leaching was estimated as the difference between the N input (atmospheric deposition, biological
N fixation, chemical fertilizer, and manure application) and the N output (crop production, NH volatilization, and denitrification) in regional scale.

Eq. (1): leaching N concentration = N leaching/ drainage water volume

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.

Eq. (2): Total System Throughflow = Cycling + Export + Loss

Eq. (3): Cycling Index = Cycling Total System Throughflow

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 zero to 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

Fig. 2: Farmgate Nitrogen Balance at farm scale in Nongshi-tun (NS01-16), Nongli-tun (NL01-08), Patan-tun (PT01-12), Waixian-tun (WX01-10), in Qibainong, southeastern China.
Fig. 2 shows the N balances of farm systems. Total input ranged from 148 to 1196 kg N ha\(^{-1}\) y\(^{-1}\) of which N application (chemical N fertilizer+ manure N) was from 113 to 1123 kg N ha\(^{-1}\) y\(^{-1}\), followed by food import (0–184 kg N ha\(^{-1}\) y\(^{-1}\)) and others. N application was the major input, which occupied 83% of the total input in average. On the other hand, output ranged from 113 to 1189 kg N ha\(^{-1}\) y\(^{-1}\), of which leaching N was 11–856 kg N ha\(^{-1}\) y\(^{-1}\), followed by disposal N (25–254 kg N ha\(^{-1}\) y\(^{-1}\)) denitrification (21–202 kg N ha\(^{-1}\) y\(^{-1}\)) and ammonia emission (0–86 kg N ha\(^{-1}\) y\(^{-1}\)). Leaching N and disposal N accounted for 60 and 19% of the total output, respectively.

Fig. 3: Nitrogen Balance at arable land in Nongshi-tun (NS01-16), Nongli-tun (NL01-08), Patan-tun (PT01-12), Waixian-tun (WX01-10), Qibainong, southeastern China.

Fig. 3 shows the N balances in arable land. Total input was estimated to be 132–1170 kg N ha\(^{-1}\) y\(^{-1}\), with the average of 453 kg N ha\(^{-1}\) y\(^{-1}\). The major input component was N application rate of 399 kg ha\(^{-1}\) y\(^{-1}\) in average (ranging 112–1123 kg N ha\(^{-1}\) y\(^{-1}\)), which accounted for 87% (ranging 74–97%) of total input. The values varied among farms by as much as 10 times. Self manure N input ranged from 0 to 132 kg N ha\(^{-1}\) y\(^{-1}\), and the average was 38 kg N ha\(^{-1}\) y\(^{-1}\). On the other hand, crop N products were 51–173 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 of crop N products to N application rate was 0.08–0.89 with 0.29 in average. Only three farms showed a ratio above 0.5. Denitrification N was 20–202 kg N ha\(^{-1}\) y\(^{-1}\) with 76 kg N ha\(^{-1}\) y\(^{-1}\) in average, and ammonia volatilization was and 0–13 kg N ha\(^{-1}\) y\(^{-1}\) with 4 kg N ha\(^{-1}\) y\(^{-1}\) in average. Leaching N was 11–856 kg N ha\(^{-1}\) y\(^{-1}\), which accounted for 59% of the total input in average.

The critical N application rate (NAR) in arable land

Assuming the drainage water volume, the leaching N concentration in groundwater is predictable from the estimated amount of nitrate-N leaching. Based on the water balance measured in this study area, the drainage volume was estimated to be 900mm (Hatano et al., 2002). Spring water (groundwater) as well as rainwater is the major drinking water sources, depending on the geological condition of karst mountainous region. 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 (Addiscott and Benjamin, 2004; 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 via subterranean pathway in this karst region (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 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 Qibainong. N application rate (NAR) explained the LNC = 0.0518x - 4.09 (R\(^2\) = 0.94, P<0.05) in Qibainong (Fig. 4). The correlation equation indicates that LNC exceeds 11.3 mg N L\(^{-1}\) at an N application rate of 297.1 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 297.1 kg N ha\(^{-1}\) y\(^{-1}\) produces leaching N of 101.7 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, 297.1 kg N ha\(^{-1}\) y\(^{-1}\) for Qibainong are the critical NAR in the regions.

Estimate the optimal N Management at the Qibainong

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 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, 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 A1 value of farms varied widely with a range of 0.23 to 0.78, the highest EI value of 0.33, the A1 value is 0.42 in the farm of Qibainong (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 297.1 kg N ha\(^{-1}\) y\(^{-1}\) for Qibainong are the critical N application rate, respectively. So we can estimate critical TST corresponding the critical NAR and A1. The critical TST was 707.1 kg N ha\(^{-1}\) y\(^{-1}\) in Qibainong, 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 Qibainong was 551.5 kg N ha\(^{-1}\) y\(^{-1}\).

**Conclusion**

The minimizing N import which groundwater 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 drainage water quality might be determined from leaching N. Using these parameters, we can determine Optimum Nitrogen Management in Qibainong that total system throughflow was 707.1 kg N ha\(^{-1}\) y\(^{-1}\) and the critical inter-system input was 551.5 kg N ha\(^{-1}\) y\(^{-1}\) in the steep-mountainous KARST region.

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