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Nitrogen discharge pathways in vegetable production as non-point sources of pollution and measures to control it

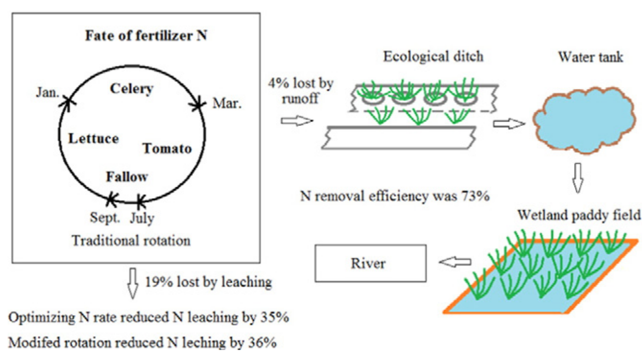
Ju Min, Weiming Shi *

State Key Laboratory of Soil and Sustainable Agriculture, Institute of Soil Science, Chinese Academy of Sciences, Nanjing 210008, China

HIGHLIGHTS

- N loss pathway and quantity from vegetable field are different from paddy field.
- Total N in leaching and runoff were 20 and 5 times above threshold, respectively.
- Providing whole course control measures to reduce N pollution without yield loss.
- Our measures reduced annual leaching and runoff by 36 and 73%, respectively.

GRAPHICAL ABSTRACT



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ABSTRACT

Discharge of nitrogen (N) from fertilizers applied to vegetables is becoming a serious environmental problem. In a field experiment involving a celery-tomato-fallow-lettuce rotation, leaching was the primary pathway of N loss (56.1 ± 0.4% of the total), followed, in descending order, by runoff (11.7 ± 0.3%), N_2O emissions (1.6 ± 0.1%), and volatilization of ammonia (0.5 ± 0.1%). Decreasing the traditional dose of N by 40% in each growth season decreased N leaching by 22.3 ± 4.5, 39.8 ± 6.7, 40.3 ± 2.9 and 27.4 ± 3.6% in celery, tomato, fallow and lettuce seasons, respectively, without any yield loss, and modifying the rotation to include a leguminous crop reduced the N leaching by 72 ± 2, 40 ± 3, 24 ± 2 and 13 ± 1% in each season, respectively, without any economic impact. These measures decreased annual N leaching by 36 ± 4%. A combination of the eco-ditches and wetland paddy fields adjacent to the vegetable plot led to annual N removal efficiency of 73 ± 6% in runoff.

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1. Introduction

In China, 57% of the nitrogen (N) entering water courses were from agriculture (MEP, 2010). In recent years, the farmland traditionally used for rice is being increasingly used for vegetables instead, because they fetch far higher prices. The area under vegetables had increased to 21.3 million ha by 2015 and accounted for 13.5% of the total cultivated area in China (Huang et al., 2016). At present, intensive vegetable production in China is marked by high doses of fertilizers, multiple crop index, and growing the same crop repeatedly, which is significant different from the rice-wheat rotation. Although examining the pathways of N loss can help in developing suitable measures to reduce such pollution, there has been little research on changes in N loss following the conversion of rice paddies into vegetable fields in China. Loss of N from rice paddies has been studied extensively (Tian et al., 2007; Zhao

* Corresponding author.
E-mail address: wmshi@issas.ac.cn (W. Shi).

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et al., 2012a). Earlier studies of intensive vegetable production were mostly short-term observations focused only on identifying the pathways of N loss from fertilizers (He et al., 2007; Song et al., 2009; Zhang et al., 2013) and not on comprehensive analyses of such pathways. In general, runoff from a vegetable field does not discharge into sources of surface water directly but is usually passed through a drainage ditch, and the transport loss factor of discharged N through the ditch is not well documented. The vegetable cultivation was significant influenced by climate, such as in a continental monsoon climate the vegetable crop index was one or two, but in a sub-tropical monsoon climate the crop index was three or above, and one-third of the vegetable cultivation area was in sub-tropical in China (National Bureau of Statistics of China, 2015). Vegetable cropping systems using unheated polytunnel greenhouses with three vegetable crops per year, e.g. celery, tomato and lettuce, are widespread in southern China of such sub-tropical monsoon climate. Therefore, to study the N non-point source pollution control measures in intensive vegetable production, the multiple vegetable growth seasons should be considered. Site-specific N management, precise drip fertigation, and slow-release fertilizers are reported to reduce N loss from vegetable fields (He et al., 2007; Shrestha et al., 2010). However, the effect of these practices was studied separately, and the studies were limited to a single vegetable species or a single season. What we need is a set of practical measures to reduce N from non-point sources of pollution in whole course and in each season that is part of an annual rotation.

The present experiment was therefore designed to measure N loss from a system of intensive cultivation of a sub-tropical monsoon climate region in China, where high doses of N are coupled with high summer precipitation. The specific objectives of this study were (1) to monitor the fate of N from its uptake to its division into residual N, N lost through leaching, runoff N, its volatilization as ammonia, and its emissions in the form of N_2O over one year and (2) to decrease such loss in each season by (a) lowering the traditional dose of N to an optimum level without any loss in yield, (b) devising a rotation to include a legume, and (c) using a combination of eco-ditches and the wetland paddy fields to remove N in runoff.

2. Materials and methods

2.1. Experimental site

The field experiments were conducted on a typical vegetable farm at Wuxi, in China's Jiangsu province (31°14′ N, 119°53′ E). The region has a subtropical monsoon climate with a mean air temperature of 15.6 °C. The annual precipitation over the study period was 824–1876 mm, with most of the rainfall occurring from July to September (Fig. 1). There was no rainfall input to the field in the plastic-covered greenhouses except from July to September, when the polyethylene cover was taken off. The pH was 5.58 (of water and soil mixed in a 1:2.5 ratio, w/w). At the beginning of the experiment, the nutrient status of the soil was as follows (values for every 1 kg of soil): organic matter,

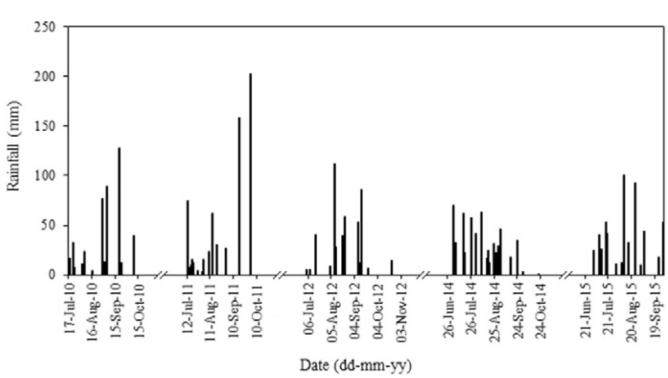

Fig. 1. Rainfall during the uncovered summer months at the experiment site.

24.9 g; total N, 1.04 g; NO_3-N, 0.04 g; Olsen-P, 0.06 g; and ammonium acetate extractable K, 0.06 g. The sequence of vegetable crops and the duration of greenhouse cover are shown in Fig. 2a.

2.2. Experimental design

2.2.1. Fate of fertilizer nitrogen

The experiment on the fate of fertilizer nitrogen comprised two treatments, namely N0, or no chemical fertilizer and N870, or the traditional dose of 870 kg N ha^{-1} as chemical fertilizer, the experiment was conducted in 2010.

2.2.2. Effects of optimizing nitrogen input

The experiment on the effect of optimizing N input on the extent of loss of N comprised five treatments (all the quantities are in kilograms of N per hectare, Table 1): (1) N0, or no fertilizer N (only 234 kg from manure), (2) N870, or the traditional dose of 870 kg plus 234 kg from manure, (3) N696, or 80% of 870 kg plus 234 kg from manure, (4) N522, or 60% of 870 kg plus 234 kg from manure, and (5) N348, or 40% of 870 kg plus 234 kg from manure. The dose from manure was split into three equal doses of 78 kg each, one dose applied in each season (Table 1). Each plot measured 7.0 m × 2.5 m. The experiment was conducted in 2011 and 2012.

2.2.3. The transport discharge factors of runoff N

The eco-ditch method was used for measuring the loss of N through runoff. The ditch was constructed by using an existing earthen ditch (0.45 m deep, and 1.1 m wide at the top and 0.5 m wide at the bottom) near the vegetable field, the length was 50 m. Ryegrass (*Lolium perenne* L.), a high-biomass grass, was planted along both the walls of the ditch. Runoff water from the vegetable field was discharged directly into the ditch. The 0 m, 25 m and 50 m were the water sampling points for the eco-ditch. The experiment was conducted in 2014 and 2015.

2.2.4. Effects of crop rotation on leaching of nitrogen

The study tested two rotational systems, namely the traditional rotation (Rt) comprising celery, tomato, fallow, and lettuce, and the modified rotation (Rm) comprising bur clover, tomato, fallow, and lettuce (Fig. 2a). The N application rates were 300 and 100 kg N ha^{-1} in celery and bur clover seasons, respectively. The application amounts of N used in tomato, fallow, and lettuce seasons were 300, 0 and 300 kg N ha^{-1}, respectively. Furthermore, each vegetable growth season received 170 kg N ha^{-1} from animal manure in addition to 150 kg K_2O ha^{-1} and 120 kg P_2O_5 ha^{-1} as basal fertilizer. The experiment was conducted in 2015.

2.2.5. Field-scale assessment of nitrogen lost through runoff

The experimental design is shown in Fig. 2b. It consists of 2 large intensive vegetable fields (2600 and 1510 m^2 for vegetable field 1 and 2, respectively), an eco-ditch (95 m), a paddy field (1350 m^2), and a concrete ditch. Common management practices used locally in terms of the crops, rotation, tillage, irrigation, and fertilizer application (including timing, rate, and source) were followed. The cultivation and fertilization for the intensive vegetable field are given in Table 1. The eco-ditch and the paddy fields were designed to remove the nutrients and sediments from the runoff from the vegetable fields, and the concrete ditch was used as a control. The eco-ditch was constructed as described in Section 2.2.3. Runoff water from the vegetable fields was discharged directly into the eco-ditch. At the end of the eco-ditch, a water tank (8 m × 10 m × 0.8 m) was constructed to collect the ditch water, and a pumping station was installed to pump the water accumulated in the tank to the paddy fields for further treatment. The paddy fields received only 50% of the conventional dose of N (135 kg ha^{-1} of N, Min et al., 2015) and were irrigated using the runoff. A, D were the greenhouse runoff sampling point, and B, C and E were the water sampling points for the eco-ditch, wetland paddy field and concrete ditch drainage, respectively.

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