Agriculture, Ecosystems and Environment 241 (2017) 133–141

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Reducing nitrogen leaching in a subtropical vegetable system

Baige Zhang[a,b], Qiang Li[c], Jian Cao[a], Changyuan Zhang[a], Zhao Song[a], Fusuo Zhang[b], Xinping Chen[b,*]

[a] Vegetable Research Institute, Guangdong Academy of Agricultural Sciences, Guangzhou, 510640, PR China
[b] College of Resources and Environmental Sciences, Center for Resources, Environment and Food Security, China Agricultural University, Beijing, 100193, PR China
[c] Foshan Research Institute of Agricultural Science, Guangzhou, 528145, PR China

ARTICLE INFO

Article history:
Received 19 October 2016
Received in revised form 3 March 2017
Accepted 6 March 2017
Available online xxx

Keywords:
N leaching
Tropic/subtropics
Intensive vegetable field
Systematic approach
Nitrification inhibitor
N form

ABSTRACT

Nitrogen (N) leaching is considered a substantial problem in South China vegetable production because of the heavy rainfall and the excessive application of N fertilizer, but quantitative data and effective countermeasures are lacking. A systematic approach to reducing N leaching while maintaining or increasing vegetable yields is urgently needed. A 2-year field study was conducted to quantify N leaching in a subtropical vegetable system (bitter gourd, *Momordica charantia* L.) in South China and to evaluate how leaching is affected by the following three N management strategies: zero N application (Nno, 0 kg N ha^{-1}), conventional N management (Ncon, 377 kg N ha^{-1}, with NH_4^+), and optimized N management (Nopt, 300 kg N ha^{-1}, with a combination of NH_4^+ and NO_3^- at a reduced rate plus nitrapyrin, a nitrification inhibitor). Lysimeter data indicated that 139 kg N ha^{-1} per growing season was lost by leaching with Ncon, this represented 36% of the N applied. With Nopt, leaching was reduced by 27.1%, and yield was increased by 25.1%. A combination of NH_4^+ and NO_3^- plus nitrapyrin at a reduced rate increased plant N uptake, maintained a high NH_4^+/NO_3^- ratio in the soil, and thereby reduced leaching. The alternative N management strategy exemplifies a new way to achieve high yields with low environmental costs in intensive vegetable production systems.

1. Introduction

Vegetables are important to the human diet because they are rich sources of fiber, trace minerals, antioxidants, vitamins, folic acid, carbohydrates, and protein (Johanna, 1999; Sahu, 2004). Commercial vegetable production often depends on N fertilizer, but application of N fertilizer can result in environmental contamination, particularly in the tropics/subtropics (Cameron et al., 2013).

In the tropical and subtropical regions of Asia, where intensive vegetable production is common (Johnson et al., 2008; George, 2010; FAO, 2013), farmers often attempt to maximize production by applying excessive amounts of N fertilizer (Chen et al., 2010; Min et al., 2011; Zhang et al., 2015a). In vegetable production areas of subtropical China, for example, the N use efficiency averages only 18%, mainly because of the large input of N fertilizer (Min et al., 2012; Guan et al., 2015). Much of the N is assumed to be lost to leaching, because the rainfall is high, the soils have high permeability and low cation exchange capacity, and the vegetables have shallow root systems (Wetselaar, 1962; Pleysier and Juo, 1981; Qafoku, 2014). The mounting public concern about the negative effects of excessive N fertilization has made it imperative to estimate N leaching from agriculture (Xu et al., 2013) and to develop practical N-management strategies to reduce N leaching without reducing yield (Min et al., 2012). For vegetable production in the tropics/subtropics, however, little quantitative information is available about the extent of N losses and about ways to reduce those losses.

Although the traditional approach to reduce N leaching is to decrease the N application rate, this seldom results in significant reductions in N leaching but often results in significant reductions in yield in tropical/subtropical vegetable production, because low crop biomass and heavy rainfall result in low N absorption (Kleinhenz, 1999; Sabine et al., 2013). N leaching could be reduced by using a nitrification inhibitor (NI) (Xu et al., 2013; Chen et al., 2010; Guo et al., 2013). For example, nitrapyrin is a well-studied NI

---

* Corresponding author.
E-mail address: chenxp@cau.edu.cn (X. Chen).

http://dx.doi.org/10.1016/j.agee.2017.03.006
0167-8809/

in corn in the Midwest of the USA (Trenkel, 2010). Nitrapyrin has low solubility in water (Subbarao et al., 2006), provides substantial inhibition (Frye, 2005) at relatively low concentrations (Zacherl and Amberger, 1990), and has reduced N loss in acid soils (Islam et al., 2007). However, nitrapyrin has seldom been studied in vegetable production (Zhang et al., 2015a).

Because NO$_3^-$ is the predominant N source for vegetables, an NI could potentially reduce vegetable yield (Feil et al., 1993; Batal et al., 1994; Marschner, 1995; Ali and Ceyhan, 2001; Chen et al., 2004). On the other hand, NO$_3^-$ is infrequently applied in tropics/subtropics because of its high vertical mobility in the soil profile (Lucia et al., 2013). The simultaneous application of NH$_4^+$ and NO$_3^-$ can reduce N leaching (Coelho and Roy, 1999) and support high yields (Marschner, 1995; Xu et al., 2001). But the form of the applied N were often demonstrated to affects plant production under some but not all production setups (Marschner, 2002; Elman et al., 2016; Rioba et al., 2015; Bernstein et al., 2005).

NH$_4^+$, NO$_3^-$, and NIs are often studied separately but should be studied together to develop effective ways to reduce N leaching while maintaining high yields in vegetable production in the tropics/subtropics. Such a holistic, systematic approach for reducing N contamination and increasing yields has been applied to cereals (Chen et al., 2010, 2014) and has been recommended for global sustainability (Liu et al., 2015).

In this study, N management practices in tropical/subtropical vegetable production were investigated. The effects of three N strategies (zero N application as a control; conventional N management; and optimized N management) on N dynamics in the crop, soil, and leachates were assessed. The study (i) evaluated N leaching under conventional farming practices and (ii) determined whether an optimized N strategy could reduce leaching and increase or maintain yield. The research was conducted in a high risk production system (bitter gourd, *Momordica charantia* L.) in subtropical South China.

2. Materials and methods

2.1. Study sites and plants

An experiment was conducted in one field in Guangzhou (23°08′N,113°16′E), Guangdong Province, from August to December in 2013 and was repeated in an adjacent field in 2014. Both fields had a typical vegetable system. The previous crop was sweet corn for the field used in 2013 and was a 1-yr fallow for the field used in 2014. Both fields had a latosolic red soil. The soils had the following properties at 0–30 cm depth before the experiment began in 2013 and 2014: total N (0.79 and 0.56 g kg^{-1}); Olsen-P (192 and 46.9 mg kg^{-1}); NH$_4$OAc-K (103 and 111 mg kg^{-1}); pH in water (6.2 and 6.6); initial soil mineral N, i.e., Nmin (37.8 and 13.2 mg kg^{-1}); and organic matter content (19.1 and 11.1 g kg^{-1}). Bitter gourd, which is a popular local vegetable, is typically cultivated in open fields (Zhang et al., 2015b). Plants were grown from seed (FengLv; Seed Co., Ltd., Kenong, China) in a greenhouse, and when the plants had two to three true leaves, they were transplanted in the field, with 1.2 m between rows and 1.0 m between plants within the row.

The climate of South China ranges from subtropical to tropical. The average air temperature at the experimental site is 23°C, and the average annual precipitation is 1700 mm. During the experimental periods, 781 mm of rain fell in 2013 and 601 mm in 2014 (Fig. 1). In 2013, temperatures below 16 °C (the Tmin for bitter gourd) were first recorded on October 25, the temperature then increased slightly before steadily declining until the end of the experiment (Fig. 1). In 2014, the temperature dropped in mid-October but fluctuated between the Tmin and 20 °C for the remainder of the experiment (Fig. 1).

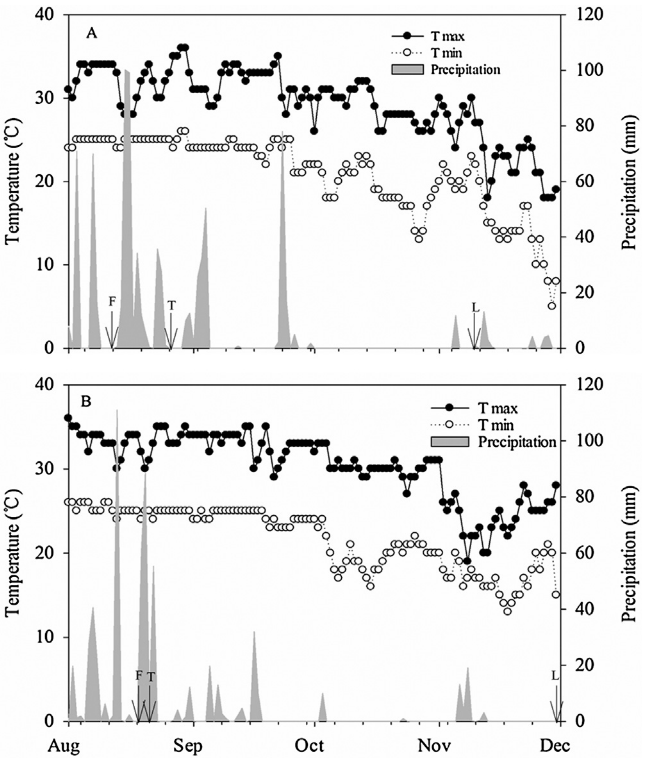

Fig. 1. Daily precipitation and temperature during the bitter gourd growing season near the field sites in (A) 2013 and (B) 2014.
F: application date for basal fertilizer.
T: transplanting date.
L: last sampling date.
Total precipitation during the experiment was 781 mm in 2013 and 602 mm in 2014.

2.2. Field management and experimental set-up

Three N fertilization strategies or treatments were compared, and these are referred to as Nno, Ncon, and Nopt. For Nno, no chemical N was applied before or after the bitter gourd was transplanted in the field; Ncon corresponded to conventional farming practices; and Nopt was considered to be a holistic, optimized N-management strategy. Nopt was based on comprehensive information from soil testing, the literature (Zhang et al., 2006; Li et al., 2011), and expert recommendations. Nopt was optimized in terms of N form (with the help of NI addition) and N rate. Detailed information for each treatment is provided in Table 1. The basal fertilizer in Ncon and Nopt treatments were applied 1 week before transplanting in 2013 but only 1 day before transplanting in 2014 because of rain in 2013. The other N fertilizers were band applied at a depth of 10 cm at 15 days (4%), 35 days (15%), 50 days (15%), 58 days (9%), 66 days (9%), 75 days (9%), and 90 days (9%) after transplanting in both Ncon and Nopt treatments. In addition to N, the same amount of K$_2$O (377 kg ha^{-1}) was applied in all three treatments. P$_2$O$_5$ was applied at 377 kg ha^{-1} for Nno and Ncon (this rate is consistent with local farming practice) but at 150 kg ha^{-1} for Nopt (Zhang et al., 2006).

All other aspects of crop management were consistent with local farming practices. The fields were drip irrigated, and irrigation was managed empirically and uniformly, the total volume of water applied was approximately 1500 m^3 ha^{-1} in each year. A randomized block design was used with four replicates. Each plot was 36 m^2 (5 m long × 7.2 m wide) and included six rows. The middle four rows in each plot were used for plant sampling, soil sampling, and harvesting.