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Effects of different irrigation and fertilization practices on nitrogen leaching in facility vegetable production in northeastern China

Yi-min Chen[a,b,1], Jin-yuan Zhang[a,b,1], Xin Xu[c], Hong-yun Qu[d], Meng Hou[a,b], Ke Zhou[c], Xiao-guang Jiao[c,**], Yue-yu Sui[a,b,*]

[a] Key Laboratory of Mollisols Agroecology, Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, 150081, Harbin, China
[b] University of Chinese Academy of Sciences, 100049, Beijing, China
[c] College of Agricultural Resources and Environment, Heilongjiang University, 150080, Harbin, China
[d] Institute of Horticulture, Heilongjiang Academy of Agricultural Sciences, 150040, Harbin, China

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ABSTRACT

Excessive nitrogen fertilizer and irrigation in facility vegetable production cause N leaching, which leads to a series of environmental problems. It is urgent to develop practical management strategies to reduce N leaching while maintaining or increasing yield and water use efficiency (WUE). In the present study, a greenhouse experiment was conducted in the mollisols of northeastern China, where eggplant was planted as the main vegetable. We aimed to evaluate the effects of different fertilization and irrigation practices on N leaching, eggplant yield and WUE. Four treatments were set: applying regular amounts of fertilizer and irrigation (WF), reducing chemical fertilizer application rates by 20% (W80%F), reducing irrigation by 20% (80%WF) and adding biochar into the WF treatment (WF + B). The results showed that the WF + B treatment significantly decreased N leaching while increasing eggplant yield and WUE by 5.5% and 11%, respectively, in comparison with the results of the WF treatment. The amount of N leaching, eggplant yield and WUE in the W80%F treatment were quite similar with those in the WF treatment. Compared with the WF treatment, the 80%WF treatment significantly decreased N leaching and increased WUE; however, it casued a sharp decrease in yield. Our results demonstrated that adding biochar may be a good practice for minimizing N leaching and increasing yield and WUE in facility vegetable production systems.

1. Introduction

Excessive application of nitrogen (N) fertilizers to arable lands leads to a large amount of N losses via leaching, which not only causes water pollution (Du et al., 2011; Shi et al., 2009; Zhu et al., 2005) but also increases the cost of agricultural production (Galloway et al., 2008). To meet the demand for vegetables, large amounts of water have been used for irrigation (Liang et al., 2018), which aggravates N leaching (Min et al., 2011; Song et al., 2009). Compared to the level of fertilizer and irrigation for traditional vegetable land, more fertilizers and irrigation are applied in facility vegetable production, which makes N leaching more serious. In the past decades, facility vegetable cultivation has expanded worldwide, particularly in China, where it accounts for more than 90% of all the global area (Chang et al., 2013). In the rapid expansion of facility agriculture, excessive N fertilization and irrigation have caused more nitrogen transferring downward with water, which has increased N losses via leaching. Therefore, it is imperative to abate N leaching on facility vegetable lands from the viewpoints of both sustainable production and the environment.

Various fertilizer and water management practices for preventing N leaching have been suggested, including reducing the N application rate, decreasing the irrigation amount, or combining them together. However, most of the studies on these topics have focused on field or pot experiments, and the effects of these practices are in debate. Decreasing the irrigation amount has been proven to be an efficient way to prevent N leaching (Fan et al., 2014; Jamali et al., 2015, Oppong Danso2015) but may cause yield losses in some cases (Woli et al., 2016). The effects of reducing the N application rate may have little effect on N leaching and caused significant yield loss in some studies (Heumann et al., 2013; Zhang et al., 2017), but some studies also

* Corresponding author at: Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, China.
** Corresponding author.
E-mail addresses: 2004086@hlju.edu.cn (X.-g. Jiao), suiyy@iga.ac.cn (Y.-y. Sui).
[1] Yi-min Chen and Jin-yuan Zhang make equal contribution to the article.

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revealed that reducing N-application rates decreased N leaching significantly without yield losses (Li et al., 2015; Min et al., 2012). Thus, a systematic analysis on whether reducing fertilizer or decreasing irrigation could minimize N-leaching losses while maintaining yields on facility vegetable lands should be conducted.

In recent years, biochar incorporation and application to agricultural soils have been reported to improve soil physicochemical properties and enhance crop yield (Barrow, 2012; Lin et al., 2015; Thomazini et al., 2015). This process has also been used for reducing N leaching in agricultural soils (Singh et al., 2010; Xu et al., 2016; Yoo et al., 2014; Zheng et al., 2013). Due to its adsorption properties, biochar can adsorb NH_4^+-N or NO_3^- -N and increase water holding capacity, which would contribute to the reduction of N leaching directly (Wang et al., 2015; Xu et al., 2013; Zheng et al., 2013). On the other hand, biochar additions also enhanced microbial biomass and changed bacterial community structures of the soil (Song et al., 2014; Xu et al., 2016), which would indirectly mitigate N leaching. However, the benefits of biochar applications varied with land management practices (Schomberg et al., 2012); thus, we need a better understanding of how biochar influences N leaching in facility vegetable production systems with intensive cultivation, fertilization and irrigation.

In northeastern China, facility agriculture is expanding rapidly due to the climate characteristics, and it is expected to reach 267,000 ha in this area in 2020 (Chinese Ministry of Agriculture, 2015), which will increase the risk for N leaching. Furthermore, the typical soil in this region is mollisol, which is quite different from other soils. The unique soil type in this region may mean that the previous practice of minimizing N leaching does not work in this region. The effect of different fertilization and irrigation management practices on N leaching remains unclear in the mollisol region.

In this study, we hypothesized that reducing all N application rates, decreasing irrigation and adding biochar could reduce N leaching, but reducing N-application rates and decreasing irrigation would cause yield losses while adding biochar would enhance vegetable yields. Therefore, the objectives of this study were to determine what is a better practice for minimizing N leaching among reducing N application rates, decreasing irrigation and adding biochar, and to investigate the effect of different practices on water use efficiency (WUE) and vegetable yield. We believe that this work can improve knowledge about the impact of reducing N application rates, decreasing irrigation and adding biochar in facility vegetable production systems in mollisols of northeastern China and provide information to guide sustainable development of facility vegetable production in northeastern China.

2. Materials and methods

2.1. Site description

The experiment was conducted at the Institute of Horticulture, Heilongjiang Academy of Agricultural Sciences, Harbin, China (45°37.836′N, 126°39.050′E). The climate is temperate continental monsoon climate with cold winters and hot summers. The mean annual temperature is 4.25 °C, with the lowest temperature at -42.6 °C and the highest temperature at -39.2 °C. The mean annual precipitation is 569.1 mm, with 60% ~ 70% occurring in summer.

The greenhouses were built in 2002 and were oriented south–north with an area of 324 m^2 (12 m in width and 27 m in length). Eggplant has been planted in the greenhouses since 2002. The eggplant variety was *Longqie 8* in 2017. On 10th March 2017, eggplant seeds were sowed in float tray for nursery. The young plants were transplanted on 3rd May 2017. When the eggplant matured, it was picked by hand. The first picking was on 29th, June 2017 and the last picking was on 5th October 2017. In total, 14 picking were done during the period and the frequency was about once per week.

According to the soil texture classification system of the USDA, the present tested soil is mollisol. The initial physical and chemical properties of the soil profile are listed in Table 1. The soil was tilled, and seedbeds (1 m in width, 50 cm between two seedbeds) were prepared before eggplant transplantation. A drip tape was placed in the middle of seedbed, and then, the bed was covered with black polyethylene mulch (1.2 m in width). Two rows of eggplant plants were transplanted with 50 cm spacing in rows and 50 cm line spacing.

Table 1
Initial soil properties before eggplant transplant in 2017.

Depth (cm)	SOC ($g\,kg^{-1}$)	TN ($g\,kg^{-1}$)	pH (H_2O)	Bulk Density ($g\,cm^{-3}$)
0-20	26.9	2.5	6.93	1.07
20-40	18.3	1.7	6.45	1.28
40-60	14.8	1.3	6.80	1.25
60-80	9.8	0.9	6.85	1.33
80-100	9.6	0.8	6.75	1.41

SOC: soil organic carbon; TN: total nitrogen.

2.2. Experimental design

The experiment was designed as follows:

(1) Regular fertilization and irrigation (WF)

In this treatment, 5 t ha^{-1}organic fertilizer and 72, 72 and 110 kg ha^{-1} of N, P_2O_5 and K_2O, respectively, were applied as basal fertilizer and were fully mixed into the 0-20-cm layer when the soil was tilled. Fertilizer of 70 kg N ha^{-1} was used as the dressing in the early fruiting stage, and 23 kg N ha^{-1} together with 113 kg K_2O ha^{-1} was top dressed in the full bearing period. The top dressing fertilizer was applied in a hole near each plant.

After transplanting, approximately 27 m^3 ha^{-1} water was used for irrigation. When the plant recovered, 45 m^3 ha^{-1} water was used for irrigation every 7–10 days. The irrigation was ceased at the last picking stage of the eggplants.

(2) Reducing 20% chemical fertilizer and regular irrigation amount (W80%F)

In this treatment, 5 t ha^{-1} organic fertilizer and 57.6, 57.6 and 88 kg ha^{-1} for N, P_2O_5 and K_2O, respectively, were applied as basal fertilizer and were fully mixed into the 0-20-cm layer when tilling the soil. A fertilizer of 56 kg N ha^{-1} was used as the dressing in the early fruiting stage, and 18.4 kg N ha^{-1} together with 90.4 kg K_2O ha^{-1} was top dressed in the full bearing period. The top dressing fertilizer was applied in a hole near each plant. Irrigation amount and frequency were the same as the WF treatment.

(3) Regular fertilizer and reducing 20% irrigation amount (80%WF)

In this treatment, the fertilization amount and frequency were the same as the WF treatment.

After transplanting, approximately 21.6 m^3 ha^{-1} water was used for irrigation. When the plant recovered, 36 m^3/ha water was used for irrigation every 7–10 days.

(4) Biochar addition with regular fertilizer and irrigation (WF + B)

In this treatment, 30 t ha^{-1} biochar was added into soil together with basal fertilizers, and the other fertilization amounts and frequencies were the same as the CK treatment. Irrigation amount and frequency were the same with WF.

Commercial organic fertilizer (with N-P_2O_5-K_2O 5-3-3%), urea (with 46% N), superphosphate (with 12% P_2O_5) and potassium sulfate (with 50% K_2O) were used as the basal and topdressing fertilizers, and drip irrigation systems were applied in this experiment. A completely randomized design with three replications was used. Biochar was made from fruit wood under 600 °C. The total carbon, total nitrogen and pH of biochar are 715 g kg^{-1}, 6.9 g kg^{-1} and 8.87, respectively. The plot area was 18 m^2 (6 m in length *3 m in width). In each plot, a leachate collecting device was installed in 2016. Briefly, a pit (length 1.5 m * width 0.8 m * depth 0.9 m) was dug in the middle of each plot, and soils from the pit were separated by 0–20 cm, 20–40 cm, 40–60 cm and