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# Identifying optimal water and nitrogen inputs for high efficiency and low environment impacts of a greenhouse summer cucumber with a model method

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## ABSTRACT

High-input of water and nitrogen (N) fertilizers in intensive greenhouse vegetable production regions in China has successfully increased crop productivity in the past decades, but at a significant environmental cost and resource consumption. It is essential to choose best management practice (BMP) to meet multiple goals, such as keeping greenhouse vegetable yield stable, improving nitrogen use efficiency (NUE), and reducing the nitrogen pollution issue. However, the bottleneck is the capacity of predicting the simultaneous effects of different management practice scenarios on multiple goals and choosing BMP among scenarios. The object of this study was to identify BMP of water and N fertilizer for greenhouse summer cucumber in North China Plain using calibrated and validated EU-Rotate_N model. The data used to calibrate and validate the model were collected from a typical greenhouse summer cucumber field with four different water and N fertilizer treatments within the target domain region. A total of 240 varied scenarios of water use and fertilizer application were set up and then simulated by the model. An osculating value method was used to evaluate combinations of irrigation and fertilizer practices. Agronomic indices (yield, WUE and NUE), environmental indices (nitrate leaching and gaseous N loss), and economic index (value to cost ratio) were selected as the evaluation indices to identify the BMP. The results showed that cucumber yield increased to maximum value as water input reached to about 277 mm, then kept constant or even decreased under lower N fertilizer rates. Nitrogen started to lose as nitrate leaching when irrigation increased to 300–400 mm, and then nitrate leaching increased with irrigation increasing. The effects of water input on gaseous nitrogen loss were not significant. Regardless of N fertilizer rates, irrigating about 300 mm water can obtain the maximum NUE. Cucumber yield increased to maximum values as N fertilizer input reached to about 313 and 310 kg N $ha^{-1}$ for furrow and drip irrigation, then was not affected by N fertilizer increase. The BMPs under furrow irrigation condition were to irrigate 300 mm with 300 kg N $ha^{-1}$ and 250 mm with 300 kg N $ha^{-1}$ under drip irrigation condition for greenhouse cucumber in the study area, respectively. Adopting the current BMPs, the applied nitrogen and irrigation water were at about 55 and 40% lower rates, respectively, than the current conventional use. Our study indicated that the EU-Rotate_N model combined with Osculating value method can be helpful to assess multi-goal effects of management alternatives and identify BMP.

## 1. Introduction

At present, the China's economy has developed rapidly and scientific innovations have been increasing continuously. However, the shortage of resources and environmental restrictions are the biggest challenges to China's economic growth. Hence, maintaining its rapid economic growth, China needs to transform the traditional high-consumption and high-pollution production pattern to the green development mode as rapidly as possible. To produce food in a highly efficient manner with the lowest possible environmental hazards, China's modern agriculture is shifting from a single-goal to a multi-goal strategy. A multi-goal management of the green agriculture is expected to simultaneously aim for the following four goals: (a) sustaining/enhancing productivity (crop yields); (b) reducing reactive nitrogenous

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gases emissions to protect the air quality and the climate; (c) mitigating hydrological nitrogen losses (mainly nitrate leaching) to secure water quality; and (d) enhancing resource efficiency to reduce the cost and create higher values. However, single-goal management is obviously not environmentally friendly and thus unsustainable because of high water and nitrogen consumption and low use efficiencies. Therefore, best management practice (BMP) is highly essential, which includes the assessment of biogeochemical effects of various management practices, i.e., fertilization and irrigation. There are two challenges of identifying a BMP. One is how to quantify the biogeochemical effects of various management alternatives on the multiple goals stated above, and the other is how to identify the BMP from these management alternatives (Cui et al., 2014). Field experiments have played a key role in determining management practice effects. For example, various water and N fertilizer practices have been employed in field plot experiments to study their effects on nitrogen use efficiency and obtain an optimal water and nitrogen practice (Smith et al., 1998; Hu et al., 2010; Min et al., 2012; He et al., 2009; Pang et al., 2009). Surface drip or subsurface drip irrigation could not only reduce nitrate leaching by decreasing water drainage but also increase vegetable yield (Yohannes and Tadesse, 1998; Sharmasarkar et al., 2001). In addition, optimizing N fertilizer rates, application times and methods could further reduce nitrate leaching, gaseous nitrogen release and soil residue nitrogen content (Waddel et al., 2000; Halvorson et al., 2002; Muñoz et al., 2008; Zotarelli et al., 2009). Some studies also recommended the best nitrogen fertilizer application rates (e.g., Ren et al., 2010; Min et al., 2012). However, these experimental methods are costly and time-consuming, and some processes are difficult to measure due to the limited experimental treatments (Liu et al., 2016).

Alternatively, simulation models are a potentially useful approach for the development of management strategies to identify the BMP. Once calibrated and validated for a given agricultural system, they can be used to examine multiple management scenarios. They are also very effective tools for demonstrating the effects of improved management practices to growers, technical advisors and policy makers. Recently, many mechanistic models have shown good performance in simulating the soil water content, nitrogen loss and crop uptake nitrogen (Sabit and Rüstü Karaman, 2001; Gallardo et al., 2009; Zhang et al., 2009). For example, the EU-Rotate_N model based on the N_ABLE model has been proposed as a powerful tool for simulating water and nitrogen dynamics in soil-plant systems and crop growth (Nendel, 2009; Rahn et al., 2010). The EU-Rotate_N model has been validated and has been used to simulate water, nitrogen dynamics and vegetable growth in some studies conducted in various climatic regions (Guo et al., 2010; Sun et al., 2012, 2013; Soto et al., 2014). Sun et al. (2013) also used the EU-Rotate_N model to identify the BMP for a greenhouse tomato planting system in China in conjunction with the osculating value method.

The North China Plain is one of the major vegetable cultivation bases in China. For example, the vegetable cultivation area has increased to 65,000 ha in Beijing city (Beijing Municipal Bureau of Statistics, 2016). The severe environmental impact induced by the intensive vegetable production has increased over the last several years (Shi et al., 2009; Chen et al., 2004; Ju et al., 2006). Because of the notably different characteristics of vegetable production in greenhouse, such as more water and nitrogen input, higher water and N applied frequency, higher humidity, lower evaporative demand, and negligible wind speed, it is necessary to develop a model method that is expected to be applicable for such complicate cases. EU-Rotate_N is likely a valuable tool for the evaluation of changes in management on yields, environmental impacts, resource efficiency with, for example, a much larger number of scenarios and more complex responses of the goal variable. However, to date, the studies for the use of the EU-Rotate N model for greenhouse vegetables are still rare. Especially, very few studies on identifying the BMPs delimitate the contribution rate of economic cost.

To identify BMP for the greenhouse vegetables system in the North China Plain, we conducted a modeling case study at a greenhouse summer cucumber field in Beijing suburb, where simultaneous observations of cucumber yield, soil water content and soil nitrate concentration were available. Our objectives were to (a) validate and apply the EU-Rotate_N model using simultaneous observations, (b) use model simulation to analyze the biogeochemical effects of alternative irrigation (furrow and drip) and fertilization conditions, and (c) identify the best water and fertilizer N management practices aiming at our four goals stated above.

## 2. Materials and methods

### 2.1. Study area

The experiment was conducted at the Luxi Vegetable Research Institute demonstration site, Fangshan district (39.38°, 116.01 E), which is located in the southwest of Beijing Municipality in the Northern China. The annual average air temperature and total precipitation are 11.9 °C and 528.5 mm, respectively. The soil of the experimental field is classified as a Cambisol (FAO/Unesco, 1988). The annual average temperature in the greenhouse is 21.0 °C. The irrigation amounts and fertilizer application rates of greenhouse cucumber in farm practice are approximately 600–700 mm and 1000–1200 kg N $ha^{-1}$ per growth season, respectively.

### 2.2. Experiment design

This field was used for greenhouse cucumber cultivation starting in 2012. Four irrigation and fertilizer treatments were designed: furrow irrigation + conventional fertilizer (farmer's practicF + C), drip irrigation + conventional fertilizer (D + C), furrow irrigation + optimal fertilizer (F + OPT), and drip irrigation + optimal fertilizer (D + OPT).The area of the experimental field was 155 m × 6 m. Each plot size was 6 m × 8 m. All of the treatments were set up in a randomized block designed with three replicates. The field data used to calibrate and validate the model in this study were collected from March 2014 to July 2014 over one growing season. During this time, the monthly average temperature was 19.9, 19.5, 23.0, 27.5, and 32.7 °C, respectively. The cucumber cultivar was Zhongnong26. Cucumber seedlings with two leaves were transplanted on 22 February 2014 and were harvested on 6 July 2014. The row spacing was 0.35 m, and the seedlings were spaced at 0.25 m within each row in all of the experimental treatments.

The details of the irrigation and fertilizer applications are shown in Table 1. Cattle manure was applied for all of the treatments at a rate of 500 kg N $ha^{-1}$ as the basal fertilizer on 19 February 2014. The F + C and D + C treatments received 210 kg N $ha^{-1}$ of urea as the basal fertilizer and 490 kg N $ha^{-1}$ as the dressing fertilizer. The F + OPT and D + OPT treatments received 126 kg N $ha^{-1}$ of urea as the basal fertilizer and 294 kg N $ha^{-1}$ as the dressing fertilizer. In all of the treatments, 120 kg $P_2O_5$ $ha^{-1}$ of calcium monophosphate and 200 kg $K_2O$ $ha^{-1}$ of potassium sulfate were applied as the basal fertilizer. For all of the treatments, the irrigation time and fertilizer application were based on the local farmers' practices, and the fertilizer was dissolved in irrigation water and then applied. For the drip irrigation treatments (D + C

**Table 1**
Water and fertilizer management for greenhouse cucumber cultivation in 2014.

| Year | Treatments | Irrigation mm | Manure kg N $ha^{-1}$ | Fertilizer kg N $ha^{-1}$ |
|---|---|---|---|---|
| 2014 | F + C | 513 | 500 | 700 |
| | D + C | 513 | 500 | 700 |
| | F + OPT | 313 | 500 | 420 |
| | D + OPT | 313 | 500 | 420 |