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Optimal drip fertigation management improves yield, quality, water and nitrogen use efficiency of greenhouse cucumber

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ABSTRACT

Establishing reasonable water and fertilizer inputs is of great importance to improve crop yield and water and fertilizer use efficiency in greenhouses. This experiment was conducted in 2013 to investigate the effects of different levels of irrigation and nitrogen (N) fertilizer on the yield, fruit quality, and water and nitrogen use efficiency of cucumbers under fertigation systems in a greenhouse in China. The least square method and multiple regression analysis were used to select the largest single target and multi-objective optimum in this study. The treatments comprised three drip irrigation levels (with ET_0 as the reference crop evapotranspiration, W_1: 60% ET_0; W_2: 80% ET_0 and W_3: 100% ET_0) and four N fertilizer levels (N_0: 0 kg/ha; N_1: 180 kg/ha; N_2: 360 kg/ha and N_3: 540 kg/ha). The results revealed that the single factors of irrigation and N had an extremely significant effect on the yield. The fruit yield increased with the amount of irrigation water and reached 55.9 t/ha and 51.6 t/ha with the use of N 540 kg/ha and 360 kg/ha, respectively. The yield of 49.6 t/ha, the highest water use efficiency (WUE) of 55.8 kg/m^3 and vitamin C of 128.4 mg/kg were obtained from conditions involving medium irrigation levels (80% ET_0) with the application of 360 kg/ha N. The highest soluble sugar content at 2.8% was achieved when the irrigation level was 60% ET_0 and the application of N was 360 kg/ha. The nitrogen production efficiency (NPE) and partial factor productivity of nitrogen (PFPN) decreased with the increase in the nitrogen application rate. The highest NPE and PFPN of 263.4 kg/kg and 265.9 kg/kg were obtained from irrigation levels of 80% ET_0 and 100% ET_0, respectively. The yield response factor k_y of the cucumbers was 0.94. Taking into account the yield, quality, and water and nitrogen use efficiency, the irrigation level of 80% ET_0 with the nitrogen level of 360 kg/ha were the best fertigation strategy. Within a 90% confidence interval, it was concluded that when the irrigation interval was 124–151 mm and the nitrogen interval was 318–504 kg/ha, the yield, WUE, and Vitamin C reached ≥90% of their maximum values at the same time. The determination of this region is of great significance to the management of water and fertilizer in greenhouse cucumis sativus.

1. Introduction

Greenhouses are one of the most important facilities for the production of winter-spring vegetables all over the world. The solar radiation resources can be efficiently used by them (Hassanien et al., 2016; Fan et al., 2018a, b). Their high efficiency has made cucumbers become the main vegetable in protected cultivation, with a production area increasing rapidly in China (He et al., 2003). Cucumber is one of the vegetables with high requirements for water and fertilizers. Excessive irrigation and fertilization are used in the planting process to induce rapid growth and high-yield crops, which results in low efficiency of water and fertilizer use (Li et al., 2014). Therefore, scientific water and fertilizer management systems are needed to ensure the yield while improving the quality of cucumbers and their water andfertilizer use efficiency.

The volume of irrigation water has a strong influence on fresh fruit yields of cucumbers at every growth stage (Mao et al., 2003). In recent years, many researchers have studied the irrigation systems of

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cucumber. Şimşek et al. (2005) revealed that 100% irrigation water was optimal for cucumber growth and that the highest yield and water use efficiency could be obtained at this irrigation level. Ertek et al. (2006) proposed that under field conditions, full irrigation with 8 day irrigation intervals was good for the growth of cucumbers. Ayas and Demirtas (2009) also found that irrigation had a significant effect on the weight and length of the cucumbers and that 100% E_{pan} was the optimum irrigation schedule in greenhouses. However, Wang et al. (2009) noted that drip irrigation at 80% E_{pan} with 8-day irrigation intervals was the best irrigation strategy for the cucumbers grown in the northeast of China. Rahil and Qanadillo (2015) found that a 70% ETc water level surpassed all other treatments in yield and water use efficiency, and the highest crop yield of 59.52 t/ha and WUE of 33 kg /m^3 were obtained. Additionally, Wan et al. (2010) used saline water for supplemental irrigation of cucumbers in fields with insufficient fresh water for irrigation and found that saline water up to 4.9 dS/m can be used for irrigation.

Fertilizer is another important factor that affects the growth of cucumbers. Ruiz and Romero (1998) studied the effects of different nitrogen fertilization amounts on commercial yield and the quality of cucumbers and found that nitrogen applications of 10 and 20 g/m^2 were the best fertilization strategy. Mahmoud et al. (2009) noted that the combination of organic and inorganic fertilizers could improve cucumber plant growth, yield, quality, and soil fertility. Yan et al. (2009) observed that the yield and quality of cucumber increased with the increase in fertilization levels but decreased under excessive water and fertilizer. At the same time, other researchers have also performed numerous studies on the yield and quality of greenhouse vegetables and soil NO_3^- N accumulation in response to different nitrogen rates (Sharmasarkar et al., 2001; Singandhupe et al., 2003; Sun et al., 2012).

In addition, some researchers also studied how cucumber yield and water use efficiency respond to the coupling of planting periods and nitrogen, water methods and nitrogen, or plastic mulch and drip irrigation. Guo et al. (2008) revealed that seasonal temperatures have more influence than nitrogen fertilizer rates on cucumber yield and nitrogen uptake. Zhang et al. (2011, 2012) found that alternate furrow irrigation with optimized fertilizer was beneficial to plant root development and fruit growth. Sun et al. (2013) noted that compared with border irrigation and traditional fertilization, drip irrigation and optimal fertilization can improve nitrogen use efficiency and reduce nitrogen leaching. Yaghi et al. (2013) found that drip irrigation with transparent plastic mulch obtained the highest fruit yield of 63.9 t/ha and a WUE of 0.262 t ha^{-1} mm^{-1}.

However, these previous studies mainly focused on the effects of single factors such as irrigation and fertilization or the coupling of irrigation methods and nitrogen on cucumber growth. Furthermore, some of these experiments were conducted under furrow irrigation or border irrigation conditions. The organic unity of water and nitrogen and simultaneous use under drip fertigation were absent from these scenarios. In a single treatment, it is often difficult to balance multiple objectives of high yield, high efficiency, and high quality. Multi-objective optimization of water and nitrogen management based on yield, water use efficiency, and quality is still scarce. High yield is pursued by farmers, high water use efficiency is the key to the sustainable development of agriculture, and high quality is pursued by customers. The purpose of this paper is to determine an optimal water and fertilizer management strategy that can make comprehensive improvements to the yield, quality, and water and nitrogen use efficiency by establishing the quantitative relationship between the inputs of water and nitrogen and the yield, quality, and water and fertilizer use efficiency to provide a scientific basis for the effective implementation of water and fertilizer integration for greenhouse cucumbers.

Table 1
Climatic situation of cucumbers during entire growth period.

Time	Temperature (°C)			Relative humidity (%)
	T_{max}	T_{min}	T_{mean}	
August	35.6	17.2	25.0	72.5
September	39.0	14.4	23.1	75.5
October	35.4	8.1	18.1	77.3
November	32.1	10.3	15.1	87.6
Mean of whole growth period	35.5	12.5	20.3	78.2

2. Material and methods

2.1. Experimental site description

The experiment was conducted in 2013 in a solar-heated greenhouse at the key laboratory of agricultural soil and water engineering in arid and semiarid areas of the Ministry of Education, Northwest A&F University, Yangling, Shaanxi, China (34°18′N, 108°40′E). The site is 521 m above sea level. The annual average temperature is 13 °C. Annual precipitation is mainly concentrated in July to September at 645 mm. The type of cultivated soil in the experimental area is heavy soil, with a bulk density of 1.43 g/cm^3. The field water holding rate is 23.67% (mass moisture content), and the pH is 7.87. Total N content is 0.87 g/kg, total alkali-hydrolyzable nitrogen is 63 mg/kg, the available phosphorus is 58.5 mg/kg, and the available potassium is 146.8 mg/kg.

There is a small weather station (HOBO event logger, Onset Computer Corporation, USA) in the greenhouse. Every 10 min, the weather station automatically records atmospheric pressure, temperature, relative humidity, solar radiation, and other meteorological factors. The climatic situation of the cucumbers during their whole growth period is shown in Table 1.

2.2. Experimental treatments and design

The experiment consisted of three drip irrigation water levels and four fertilizer levels. Three drip irrigation levels were designated as low irrigation (W_1: 60% ET_0, where ET_0 is the reference crop evapotranspiration), medium irrigation (W_2: 80%ET_0) and full irrigation (W_3: 100% ET_0). Four nitrogen fertilizer levels (0, 180, 360 and 540 kg/ha) were designated as N_0, N_1, N_2 and N_3, respectively. The twelve treatments were replicated three times in a randomized complete factorial block design. The size of each plot was 1.25 m in width and 6 m in length. To prevent mutual leakage between the plots, each plot was separated by plastic film.

Urea (N 46.4%), superphosphate (P_2O_5 44%), and potassium chloride (K_2O 60%) were used for fertilization. The amounts of P_2O_5 and K_2O were 200 kg/ha and 450 kg/ha, respectively. Before planting, all the phosphate fertilizer, 22% of the nitrogen fertilizer, and 33% of the potash fertilizer were applied to the field as a base fertilizer. Then, 17% of the nitrogen fertilizer was applied on September 5th at the seedling stage. The remaining nitrogen and potash fertilizers were divided into seven parts to be applied to the field at seven-day intervals by the fertilizer proportion pump. Fertilization dates were on September 23rd, October 1st, October 9th, October 17th, October 25th, November 2nd, and November 10th.

Cucumber seeds were sown on July 15th, transplanted on August 21st and finished on November 22nd. The variety for this experiment was "Bonai 9-1". It is a hybrid variety and hermaphrodite. The growth period is about 130 days. The variety is suitable for planting in autumn and winter in greenhouses. And it is resistant to low temperature and disease. The growth of Bonai 9-1 is medium level, the setting rate of fruit is high, the melons are straight, the weight of single melon is about 200 g and it is about 35 cm long with a good commodity.

The cultivation mode was ridging covered with film, and two rows