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Comparison of drip fertigation and negative pressure fertigation on soil water dynamics and water use efficiency of greenhouse tomato grown in the North China Plain

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ABSTRACT

Maintaining a stable soil water supply is the key for solar greenhouse vegetable production across the North China Plain. A three-season field experiment was conducted over 2 years to evaluate two methods of applying Yamazaki tomato nutrient solution (negative pressure and drip fertigation; NF and DF, respectively) for production of greenhouse tomato and water use efficiency (WUE). Soil moisture in the surface (0–20 cm) and entire soil profile (0–100 cm), as well as soil water storage (SWS) and crop evapotranspiration (ET) levels were measured during the growing season. Then, plant growth, fruit yield, and WUE were compared. The variations in soil moisture (0–20 cm) were small for the NF treatment, with ranges of 20.0–25.0% and 22.2–24.3% in the early spring and autumn winter seasons, respectively, which were less than the ranges of 19.7–28.5% and 21.4–26.7% for DF. The average SWS did not significantly differ between DF and NF treatments, while SWS in NF (318.6–339.3 mm) during the growing season showed small fluctuations compared with DF (315.7–342.9 mm). The ET over the whole growing season varied in the range of 224.0–319.9 mm, which was higher during fruit-set and flowering than other growth periods. With its higher irrigation amount, DF had a higher ET level than NF, but there was no significant difference in early spring. The consecutive and stable water supply of NF improved tomato plant height and stem diameter ($P < 0.05$) and improved fruit yield and WUE by 1.6–8.2% and 9.9–30.5% ($P < 0.05$), respectively, compared with DF. These results demonstrate that the NF system can save more water (11.3% and 32.0% in the ES and AW seasons, respectively) than DF. As a new mode of integrated water and fertilizer management, NF is appropriate for vegetable production in solar greenhouses.

1. Introduction

Tomato (*Solanum lycopersicum*) is one of the main commercial vegetables grown on the North China Plain, and is mainly cultivated in greenhouses during early spring (ES) and autumn–winter (AW) (Yuan et al., 2001; Ren et al., 2010; He et al., 2016). Water and fertilizer supply can significantly affect tomato growth in solar greenhouses and watering must be carried out with high efficiency, because vegetables have a high requirement for water whenever irrigation is the only source (Wang et al., 2009; Liu et al., 2009; Fan et al., 2014; Wang et al., 2015a). However, high rates of water and nitrogen (N) inputs are commonly used in tomato production in China (Chen et al., 2004; Liu et al., 2013). The total irrigation and N rate are about 1000 mm and 1049 kg N ha^{-1} per growing season, respectively, and have increased the production costs and resulted in large losses of water and N (Zhu et al., 2005; Ren et al., 2010). Many studies have shown that the increasing use of irrigation and chemical fertilizers has caused many environmental problems (Ren et al., 2010; Fan et al., 2014; Du et al., 2014; Cao et al., 2015), such as contaminating groundwater and nitrous oxide emissions. Previous research indicated a direct relationship between large nitrate losses and inefficient fertigation and irrigation management (Zotarelli et al., 2009; Shan et al., 2015). Therefore, water and fertilizer inputs should be carefully managed, especially in greenhouse vegetable production (Zhang et al., 2012; Chen et al., 2013; Wang et al., 2015a). Drip fertigation is one of the best techniques for applying water and fertilizer to vegetables (Simonne et al., 2006; Karlberg

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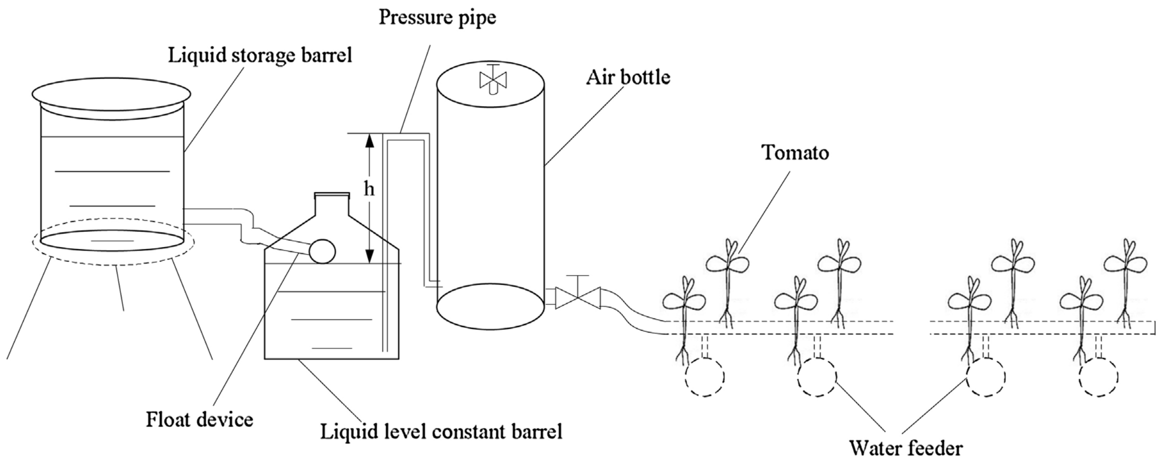

Fig. 1. Structure diagram of negative pressure fertigation system.

et al., 2007; Qiu et al., 2011). Many studies have reported that higher yield and higher water and fertilizer use efficiencies can be achieved with this technique compared with other irrigation and fertilization methods (Marino et al., 2014; Zhang et al., 2017). Because of the high water and fertilizer efficiency, application of drip fertigation has increased quickly inside solar greenhouses in China.

In recent years, the technique of negative pressure irrigation has been widely studied and used in solar greenhouses (Li et al., 2010a; Li et al., 2016). This new irrigation technology supplies water at a negative pressure, and soil water content can be controlled accurately and continuously by adjusting the suction of the negative pressure irrigation device (Zou et al., 2007; Li et al., 2008). This technique allows automatic irrigation according to crop requirements and changing environmental factors (Li et al., 2010b). Li et al. (2010a) showed a negative correlation between water supply tension and soil water content, with gravimetric soil water content maintained at 14.2–42.3% for water supply suction of 1–13 kPa. With the use of negative pressure irrigation, the soil water content can be maintained in an unsaturated state, which reduces water losses from soil evaporation and underground leakage (Li et al., 2008). Compared with conventional irrigation (flooding) methods, greenhouse tomato yield and water use efficiency (WUE) with negative pressure irrigation method increased by 8.6 and 11.0% ($P < 0.05$), respectively (Li et al., 2008). Studies of negative pressure irrigation have mainly focused on potted or soilless cultivation and on crop water management strategies (Li et al., 2010b; Xu et al., 2014). Integration of water and fertilizer can be achieved with negative pressure irrigation, and this technology has been patented (Li et al., 2015). However, research on integrating water and fertilizer for tomatoes in solar greenhouses with negative pressure irrigation systems is rare. Drip irrigation as the best water-saving technology has been widely used in greenhouses (Cetin and Uygan, 2008; Liu et al., 2013), but few studies have compared drip and negative pressure irrigation.

The objectives of this research were to (i) quantify the soil moisture, soil water storage (SWS) and crop evapotranspiration (ET) during the tomato growing season; and (ii) determine the effects of integrative water and fertilizer management practices on tomato growth, fruit yield and WUE.

2. Materials and methods

2.1. Site description

The present study was conducted during 2014–2015 at the National Experiment Station for Precision Agriculture (40°10′43″N, 116°26′39″E), Xiaotanshan Beijing, China. The site is warm temperate, with an annual mean air temperature of 11.8 °C, annual sunshine duration of 2684 h and precipitation of 550.3 mm.

The experimental greenhouse was 28 m long and 7.5 m wide, with a wall made of brick-concrete, and brackets constructed with welded metal wires. The soil used for this study was collected from the 0–20 cm surface layer of cultivated soil and was classified as silt loam. The main properties of the soil were pH 6.75 (1:5, soil/water), bulk density 1.39 g cm^{-3}, organic matter 23.3 g kg^{-1}, total N 1.57 g kg^{-1}, available phosphorus 96.4 mg kg^{-1}, available potassium 158.9 mg kg^{-1} and mass water content at field capacity of 26.3%.

2.2. Experimental design

Two different fertigation treatments were compared: negative pressure fertigation (NF) and drip fertigation (DF). The NF system was established based on a negative pressure device, which could apply integrative water and fertilizer management for tomatoes in the greenhouse (Li et al., 2015).

The structure diagram of NF system is shown in Fig. 1, and was used in each test plot. The system consisted of five parts connected by water pipes: liquid storage barrel, liquid constant-level barrel, pressure pipe, air bottle and water feeder. This system was sealed and connected with 14-disk water feeders at the terminal. Water feeders were ceramic and had 20 cm diameters. The feeders were pervious to water but not air, and were buried vertically, 25 cm deep in the soil, at equal intervals of 35 cm. The tomato seedlings were planted on both sides of the water feeder at a distance of 10 cm from the feeder.

Before the NF system was run, the water feeder was filled with water to eliminate air from the system. The system functions as follows. When soil dries, it absorbs water from the water feeder driven by soil water potential. Then, the water level in the air bottle begins to decline and its pressure reduces, which leads to a direct increase in vacuum of the pressure pipe. The water in the liquid constant-level barrel then enters the air bottle through the pressure pipe under the action of atmospheric pressure difference. In the liquid constant-level barrel, a float valve keeps water at the same level. When the water level declines, water in the liquid storage barrel automatically enters the liquid constant-level barrel and when the water level reaches its previous level, the filling ceases under control of the float valve. Finally, the irrigation amount was obtained by recording the water-level difference in the liquid storage barrel every day at 8:00 am.