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RESEARCH ARTICLE

Response of yield, quality, water and nitrogen use efficiency of tomato to different levels of water and nitrogen under drip irrigation in Northwestern China

DU Ya-dan*, CAO Hong-xia*, LIU Shi-quan, GU Xiao-bo, CAO Yu-xin

Key Laboratory of Agricultural Soil and Water Engineering in Arid and Semiarid Area, Ministry of Education/Northwest A&F University, Yangling 712100, P.R.China

Abstract

The objective of this study was to investigate the effects of applying different amounts of water and nitrogen on yield, fruit quality, water use efficiency (WUE), irrigation water use efficiency (IWUE) and nitrogen use efficiency (NUE) of drip-irrigated greenhouse tomatoes in northwestern China. The plants were irrigated every seven days at various proportions of 20-cm pan evaporation (E_p). The experiment consisted of three irrigation levels (I1, 50% E_p; I2, 75% E_p; and I3, 100% E_p) and three N application levels (N1, 150 kg N ha^{-1}; N2, 250 kg N ha^{-1}; and N3, 350 kg N ha^{-1}). Tomato yield increased with the amount of applied irrigation water in I2 and then decreased in I3. WUE and IWUE were the highest in I1. WUE was 16.5% lower in I2 than that in I1, but yield was 26.6% higher in I2 than that in I1. Tomato yield, WUE, and IWUE were significantly higher in N2 than that in N1 and N3. NUE decreased with increasing N levels but NUE increased with increase the amount of water applied. Increasing both water and N levels increased the foliar net photosynthetic rate. I1 and I2 treatments significantly increased the contents of total soluble solids (TSS), vitamin C (VC), lycopene, soluble sugars (SS), and organic acids (OA) and the sugar:acid ratio in the fruit and decreased the nitrate content. TSS, VC, lycopene, and SS contents were the highest in N2. The harvest index (HI) was the highest in I2N2. I2N2 provided the optimal combination of tomato yield, fruit quality, and WUE. The irrigation and fertilisation regime of 75% E_p and 250 kg N ha^{-1} was the best strategy of water and N management for the production of drip-irrigated greenhouse tomato.

Keywords: tomato, drip irrigation, yield, fruit quality, water use efficiency (WUE)

1. Introduction

The competition for limited water resources among agricultural, industrial, and urban consumers has become increasingly serious, which necessitates the continuous improvement of irrigation practices in vegetable production in China. Tomato is one of the most water-demanding crops (Sharmasarkar *et al.* 2001; Kiymaz and Ertek 2015), and water deficit is the main factor affecting crop production throughout most of the growing season in arid and semiarid regions. Further-

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DU Ya-dan, Mobile: +86-18220558473, E-mail: dyd123027@163.com; Correspondence CAO Hong-xia, E-mail: chx662002@163.com
* These authors contributed equally to this study.

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more, border and furrow irrigation are the domain irrigation methods in northwestern China, which usually causes large percolation losses. Farmers tend to manage water use for maximising tomato yield based on their experience but use more than the vegetable requires, which lowers the efficiency of water use. The over-exploitation of groundwater has serious consequences, e.g., gradual lowering of the groundwater table, reduction of vegetated areas, soil salinisation, and desertification (Kang *et al.* 2004). Water supply is an important factor affecting crop yield and fruit quality, so increasing the efficient use of the limited water resources is an important issue.

Drip irrigation is the most efficient method of irrigation for vegetable cultivation. The delivery of low amounts of water at a high frequency usually limits water evaporation and drainage, thus represents a high water use efficiency (WUE) (Sharmasarkar *et al.* 2001), which has been confirmed experimentally (Sun *et al.* 2013). Jiang *et al.* (2012) reported that tomato yield increased by 10% under drip irrigation even though the water and nitrogen (N) supply were 50 and 55% lower, respectively, than the common farmer practices. Drip irrigation not only reduces water and N supplies, but also increases WUE and N use efficiency (NUE) compared to furrow irrigation (Aujla *et al.* 2007). Drip irrigation has been widely used for many crops, such as broccoli (Erdem *et al.* 2010), sugar beet (Kiymaz and Ertek 2015), cucumber (Zhang *et al.* 2011), eggplant (Aujla *et al.* 2007), potato (Wang *et al.* 2011) and tomato (Kuscu *et al.* 2014).

N is the most limiting nutrient for plant growth and potential yield. However, Min *et al.* (2011) reported that NUE was only 18% for conventional methods of N application. Karaman *et al.* (2005) similarly found that NUE was generally below 50%. Excessive N application may result in high nitrate leaching and contamination of groundwater (Song *et al.* 2009; Min *et al.* 2011; Sun *et al.* 2013). Kuscu *et al.* (2014) found that the high application of N in tomato increased fruit nitrate content, which is harmful to human health. Tomato production requires large inputs of water and N, so tomato cultivation represents a high risk of nitrate pollution. Many studies have concluded that drip irrigation is also adaptable for the injection of fertiliser into the irrigation system, which enables farmers to improve the synchronisation between fertilisation and nutrient uptake.

Tomato is one of the most popular vegetables around the world, and it is a rich food source of vitamins, lycopene, orgnic acids and essential minerals (Toor *et al.* 2006). Recent annual China production of tomato has been approximately 5.06 million tons according to the Food and Agriculture Organization of the United Nations (FAO 2016). Tomato is the major vegetable crop grown in solar greenhouses in northwestern China due to its high potential yield and profitability. Cultivation in greenhouses has developed rapidly in recent years to protect the limited water resources. Growth conditions are much easier to manage in greenhouses compared to the field. Much less water and N are required for tomato grown in greenhouses compared to traditional management under field conditions (Sun *et al.* 2013). Optimising inputs for tomato cultivation, however, is difficult for local farmers, who rely on traditional practices for supplying water and N, which prevents the effective use of water and fertiliser. So it is impreative to optimise the supply of water and N under drip irrigation for tomato growing in greenhouse.

The objectives of this study were to (1) investigate the effects of various levels of water and N on yield and quality parameters of drip-irrigated tomato, (2) determine WUE and NUE, and (3) recommend a suitable strategy of water and N management for drip-irrigated tomato grown in greenhouses in northwestern China.

2. Materials and methods

2.1. Experimental site

The experiment was conducted in a greenhouse at the Yangling Research Station of the Agricultural Facility and Entrepreneurship Training Center (34°17´N, 108°04´E and 521 m a.s.l.) in Yangling, Shaanxi Province, China. The region has a typical semiarid climate. The annual mean temperature and precipitation are 13.2°C and 632 mm. And the annual mean evaporation is 1510 mm. The field capacities and dry bulk densities were 0.24 and 1.27 g cm^{-3}, 0.23 and 1.45 g cm^{-3}, and 0.23 and 1.42 g cm^{-3} in 0–20, 20–40, and 40–60 cm layers, respectively. The organic-matter, total N, phosphorus (P), and potassium (K) contents in the 0–20 cm soil layer before transplantation were 15.94, 1.66, 0.39, and 1.82 g kg^{-1}, respectively.

2.2. Experimental design

The experimental area in the greenhouse was 75 m×7.5 m. Experiment plots (6.5 m× 2.4 m) were arranged in a split-plot design, with the irrigation amount as the main plot factor and N application as the sub-plot factor. An impermeable plastic film was embedded vertically in the soil to a depth of 100 cm between each plot to prevent lateral infiltration of water. Three irrigation levels of 50% (I1), 75% (I2), and 100% (I3) of the pan evaporation (E_p) were applied every seven days *via* a 20-cm diameter pan located near the plots (Zhang *et al.* 2011; Liu *et al.* 2013; Xing *et al.* 2015). The three levels of N application included