ARTICLE IN PRESS

Applied Soil Ecology xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Applied Soil Ecology

journal homepage: www.elsevier.com/locate/apsoil

Subsurface drip irrigation enhances soil nitrogen and phosphorus metabolism in tomato root zones and promotes tomato growth

Jingwei Wang[a,c], Wenquan Niu[a,b,*], Yuan Li[a], Wang Lv[d]

[a] Institute of Soil and Water Conservation, Northwest A&F University, Yangling, Shaanxi 712100, China
[b] Institute of Soil and Water Conservation, CAS & MWR, Yangling, Shaanxi 712100, China
[c] The Center of Ecological Environment Construction of Soil and Water Conservation in Shanxi Province, TaiYuan, Shanxi 030002, China
[d] College of Water Resources and Architectural Engineering, Northwest A&F University, Yangling, Shaanxi 712100, China

ARTICLE INFO

Keywords:
Subsurface drip irrigation
Tape depth
Root-zone soil
Interaction
Nitrogen and phosphorus metabolism
Tomato

ABSTRACT

To understand the effects of subsurface drip irrigation (SDI) on soil microorganisms and the soil microbial mechanism underlying yield improvement, we performed field experiments to investigate the microbial community composition and function and the "soil-plant-microorganism" interactions in root zones. The results showed that the compositions of soil bacteria under surface drip irrigation with plastic film mulching (DI-PFM) and SDI were significantly different; the relative abundance of bacteria that metabolize organic matter was lower under SDI than under DI-PFM, but the relative abundance of nitrogen- and phosphorus-metabolizing bacteria was significantly higher under SDI than under DI-PFM. The depth of the drip irrigation tape was an important factor affecting soil microbes. With a drip irrigation tape depth of 20 cm, soil porosity and root growth were greatly improved, thus strengthening the "soil-plant-microorganism" interactions, as were the soil urease and phosphatase activities at the peak fruiting stage and the soil available nitrogen and phosphorus contents. Furthermore, the absorption and utilization of nitrogen and phosphorus by tomato were promoted; the total nitrogen and phosphorus contents in the tomato root were 1.18 and 1.47 times higher, respectively, than those under DI-PFM. Similarly, the total nitrogen and phosphorus contents in the tomato stem were 1.11 and 1.66 times higher, respectively. The tomato yield per plant was 22.47% higher than that under DI-PFM, while the contents of soluble protein, vitamin C and lycopene of the tomato fruit were also significantly increased, resulting in improved fruit quality. With a drip irrigation tape depth of 30 cm, tomato root length and forks were also remarkably improved, and nitrogen absorption by the tomato root was significantly enhanced. Although the tomato yield per plant was not significantly different from that with a drip irrigation tape depth of 20 cm, the soluble protein, vitamin C and lycopene contents of the tomato fruit were significantly decreased. Taken together, a drip irrigation tape depth of 20 cm is the most appropriate irrigation arrangement for tomato cultivation and production.

1. Introduction

Subsurface drip irrigation (SDI) reduces soil moisture evaporation and deep percolation (Irmak et al., 2016), enables the more even distribution of soil moisture (Enciso-Medina et al., 2011), uses less water, improves water-use efficiency (Kumar et al., 2007) and is easy to manage and control (Bekele and Tilahun, 2007; Niu et al., 2012). Furthermore, it improves soil nutrient-use efficiency, promotes crop growth, improves crop health (Lamm and Camp, 2007) and increases yield (Bidondo et al., 2012). Therefore, SDI is increasingly used in agricultural production.

Soil is an ecosystem with complex components; in the growth cycle of crop plants, soil supports, as well as interacts with, crop growth. In particular, the interaction of soil-plant-microorganisms in the root zone forms a close-knit and dynamic system, interacting continuously (Nihorimbere et al., 2011) and affecting soil material flow and energy exchange, ultimately determining the status of crop growth. Because the drip irrigation tape in SDI is buried in the soil, its depth under certain soil matrix conditions affects the transportation and distribution of soil moisture, which further influences soil fine structure, the transportation and distribution of soil nutrients, the growth and distribution of soil microbes (Deng, 2012), the growth of plant roots and the absorption of nutrients by crop plants (Mmolawa and Or, 2000). In turn, these factors affect the internal "soil-plant-microorganism"

* Corresponding author at: Institute of Soil and Water Conservation, Northwest A&F University, Yangling 712100, Shaanxi, China.
E-mail address: nwq@nwafu.edu.cn (W. Niu).

https://doi.org/10.1016/j.apsoil.2017.11.014
Received 19 June 2017; Received in revised form 15 November 2017; Accepted 17 November 2017

Please cite this article as: Wang, J., Applied Soil Ecology (2017), https://doi.org/10.1016/j.apsoil.2017.11.014

interactions in the root zone. The mutual promotion or antagonism of soil-plant, soil-microorganism and plant-microorganism interactions (Chaparro et al., 2012) will eventually be reflected in aspects such as crop growth, yield and quality (Lambers et al., 2009). Subsurface drip irrigation indirectly affects the "soil-plant-microorganism" dynamics by regulating the root-zone environment, which is likely the internal mechanism by which SDI improves crop growth, yield and quality while saving water. However, in recent years, studies have focused more on the deep placement of drip irrigation tape (Santos et al., 2016), soil salt and water transportation, water/nutrient utilization (Zhang et al., 2011), and the growth, yield and quality of different crops in response to SDI (Sharma et al., 2014). Meanwhile, investigations of changes in the root-zone environment and the association between these changes and crop growth under SDI have rarely been reported. Studies of the internal "soil-plant-microorganism" mechanism of SDI in water savings and yield improvements have been inadequate.

In the "soil-plant-microorganism" system, soil is the carrier and basis; plants are the main receivers of matter and energy; and microbes are important driving forces of soil nutrient decomposition and transformation, soil matter circulation and energy flow (Zhong et al., 2010). The microbial composition, growth and community changes are affected by the soil environment (Girvan et al., 2003; Frey et al., 2004; Faoro et al., 2010; Rousk et al., 2010) but are also shaped by the growth of crop roots (Iii and Frank, 2001). Thus, dynamic changes in the composition and function of soil microbial communities promptly reflect the state of soil moisture, pH, temperature and nutrients and are effective indicators of soil quality and health (Lauber et al., 2008; Zhalnina et al., 2015) while indirectly manifesting the growth of crop root systems, highlighting the role of "soil-plant-microorganisms" in the root zone. Soil bacteria compose the largest group of soil microbes. In this study, changes in the community composition and function of the soil bacterial communities of tomato root zones under SDI were investigated to examine the "soil-plant-microorganism" interaction, to provide a reference for understanding the internal mechanism of SDI in improving the water/nutrient utilization efficiency of crop plants and promoting crop growth and to further improve irrigation systems and water/nutrient utilization efficiency.

2. Materials and methods

2.1. Experiment site

The experiment was conducted in the sunlight greenhouse of Dazhai Village, Dazhai Township, Yangling District, Shaanxi Province (east longitude: 108°08′; north latitude: 34°16′; altitude: 521 m) from October 2014 to May 2015. The experiment site was in the warm temperate, semi-humid monsoon zone, with an average annual temperature of 16.3 °C, an annual average rainfall of 535.6 mm, an average annual sunlight time of 2163 h and an average annual frost-free period of 210 d. The soil type was stratified, old, manured loessial soil (or lou soil), and the soil compositions at the experimental site were as follows: gravel (2–0.02 mm), 25.4%; silt (0.02–0.002 mm), 44.1%; and clay (< 0.002 mm), 30.5%. The physical properties of the soil were as follows: unit weight, 1.34 g cm^{-3}; field moisture capacity, 28.17% (mass fraction of water in the soil); and soil porosity, 49.38%.

2.2. Experimental design

The greenhouse was 108 m in length (in the east-west direction) and 8 m in width (in the south-north direction). The test crop was tomato, and the cultivar was "Haiti." Plots were built from west to east in the greenhouse, in two ridges per plot; the ridge was 6.0 m in length, 0.6 m in width and 0.2 m in height, divided by a ditch 0.3 m in width. The area of each plot was 3.4 m^2. Thirty-four plants were planted in two rows, with a spacing of 0.35 m in each plot and protection rows at each end of the plot.

The experiment had four treatments: surface drip irrigation with plastic film mulching (DI-PFM) (control, CK), in which the drip irrigation tape was installed in the middle of the tomato rows with a lower irrigation limit of 70% of the field capacity and an upper irrigation limit of 75% of the field capacity, and three SDI treatments with plastic film mulching, in which the drip irrigation tape was installed in the middle of the tomato rows at a depth of 10 cm (S10), 20 cm (S20) or 30 cm (S30). Given that SDI is more water efficient than DI-PFM, the lower irrigation limit in these treatments was set at 60% of the field capacity, and the upper irrigation limit was set at 65% of the field capacity. Each treatment had three replicates, giving rise to a total of 12 experimental plots. Plastic film mulch was used, which was a white translucent high-pressure and low-density polyethylene plastic film (0.014 mm in thickness) manufactured by Xinfeng Plastic Factory, Jingjiang City, Jiangsu Province. The drip irrigation tape was flat-type pipelines (16 mm in diameter) with inlaid dripping holes and was manufactured by Gansu Dayu Water-saving Group Co., Ltd., with a wall thickness of 0.3 mm, an emitter spacing of 30 cm, a working pressure of 0.1 MPa and an emitter flow rate of 1.2 l/h.

Soil moisture was determined and controlled using a Field TDR 200 (Spectrum, US). In the center of each plot, one probe tube was installed to reach 100 cm in depth, through which soil moisture was determined in 10-cm intervals to the depth of 60 cm, and further calibrated using the coring and drying method. When the soil moisture content reached the lower limit of soil moisture, the soil was rehydrated based on the calculation of the 40 cm wetting layer. Irrigation amounts were calculated using the following formula:

$$M = s\rho_b ph\theta_f (q_1 - q_2)/\eta$$

wherein M is the irrigation amount (m^3), s is the planned wetting area and valued at 4.6 m^2, ρ_b is the soil unit weight and valued at 1.35 g m^{-3}, p is the wetting ratio and valued at 0.8, h is the depth of the wetting layer and valued at 0.4 m, η is the maximum field water capacity and valued at 31.54%, $q1$ and $q2$ are, respectively, the irrigation upper limit and measured soil moisture content (% F) and η is the water use coefficient and valued at 0.95.

2.3. Determination of indicators

2.3.1. Sample collection

After tomato fruits were ripe, three tomato plants were selected at each plot and labeled. Various samples were collected:

(1) Fruit sampling: From March 18 to May 3, 2015, fruits were collected from the labeled plants, labeled accordingly and weighed on an electronic balance with a precision of 0.01 g.
(2) Plant sampling: After the fruit sampling, plant samples were collected on May 5, 2015. The aboveground portion of the labeled plants were collected and labeled accordingly to be used for the analysis of dry biomass and plant nutrition ingredients.
(3) Soil and root sampling: After collecting the aboveground portion of the labeled plants, root samples were collected using the whole root system collecting method. Briefly, the roots were excavated in a 40 cm × 30 cm rectangular area that was formed by centerlines between adjacent plants at a depth of approximately 50 cm, which was also the actual root depth. Roots were recovered intact and rid of large chunks of soil, and the soil clinging to the root was then vigorously shaken off onto a clean and sterile filter paper. Rhizosphere soil samples were made into two parts in two sterile plastic tubes, of which one tube (approximately 50 g) was stored at −80 °C, and the other tube (approximately 10 g) was used in the analysis of soil bacterial diversity. The root samples were placed in a mesh bag with 0.5-mm diameter mesh and taken to the laboratory for subsequent tests.