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Spatial distribution of soil water, soil temperature, and plant roots in a drip-irrigated intercropping field with plastic mulch

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ABSTRACT

Intercropping and drip irrigation with plastic mulch are two agricultural practices used worldwide. Coupling of these two practices may further increase crop yields and land and water use efficiencies when an optimal spatial distribution of soil water contents (SWC), soil temperatures, and plant roots is achieved. However, this coupling causes the distribution of SWCs, soil temperatures, and plant roots to be more complex than when only one of these agricultural practices are used. The objective of this study thus was to investigate the effects of different irrigation treatments on spatial distributions of SWCs, soil temperatures, and root growth in a drip-irrigated intercropping field with plastic mulch. Three field experiments with different irrigation treatments (high T1, moderate T2, and low T3) were conducted to evaluate the spatial distribution of SWCs, soil temperatures, and plant roots with respect to dripper lines and plant locations. There were significant differences ($p < 0.05$) in SWCs in the 0–40 cm soil layer for different irrigation treatments and between different locations. The maximum SWC was measured under the plant/mulch for the T1 treatment, while the minimum SWC was measured under the bare soil surface for the T3 treatment. This was mainly due to the location of drippers and mulch. However, no differences in SWCs were measured in the 60 100 cm soil layer. Significant differences in soil temperatures were measured in the 0 5 cm soil layer between different irrigation treatments and different locations. The soil temperature in the subsoil (15 25 cm) under mulch was higher than under the bare surface. The overlaps of two plant root systems in an intercropping field gradually increased and then decreased during the growing season. The roots in the 0 30 cm soil layer accounted for about 60% 70% of all roots. Higher irrigation rates produced higher root length and weight densities in the 0 30 cm soil layer and lower densities in the 30 100 cm soil layers. Spatial distributions of SWCs, soil temperatures, and plant roots in the intercropping field under drip irrigation were significantly influenced by irrigation treatments and plastic mulch. Collected experimental data may contribute to designing an optimal irrigation program for a drip-irrigated intercropping field with plastic mulch.

1. Introduction

Intercropping is a very popular agricultural practice used around the world, such as in China (Zhang and Li, 2003), Germany (Munz et al., 2014), Brazil (Crusciol et al., 2014), India (Tanwar et al., 2014), Pakistan (Asghar Shah et al., 2016). It not only improves the land use efficiency (e.g., Dhima et al., 2007; Tanwar et al., 2014; Wang et al., 2015) and the light and radiation use efficiency (Awal et al., 2006), but also enhances crop yields and farmers' income(Gou et al., 2016). However, there are often different water requirements needed by two different crop species during the growing period, which the traditional flood irrigation, incapable of providing different irrigation amounts in one field at the same time, cannot satisfy. This results in a low water use efficiency (WUE) in intercropping fields (Sampathkumar et al., 2012). On the other hand, drip irrigation with plastic mulch can be an effective practice to increase soil temperatures, the WUE, and crop yields (e.g., Hou et al., 2010; Liu et al., 2012; Yahgi et al., 2013; Wang et al., 2014). Combining drip irrigation with intercropping can increase not only crop yields, but also the land and water use efficiencies. Such a system may provide independent drip irrigation lines for different crop species, and thus optimize irrigation for every crop species and their different root systems (Sampathkumar et al., 2012). However, such a multi-practice system produces more complex spatial distributions

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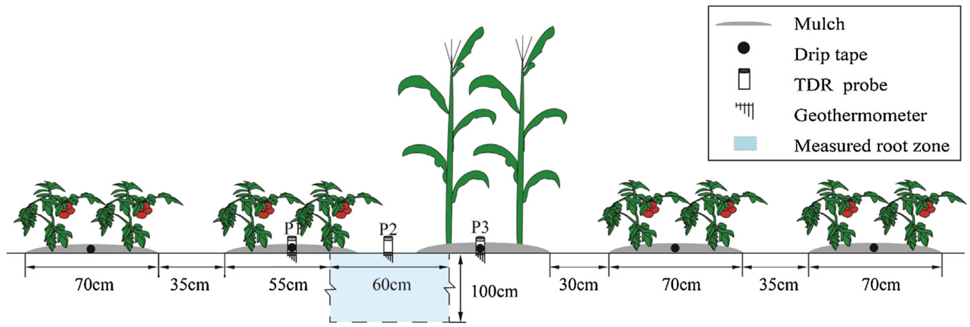

Fig. 1. Schematic showing the cropping pattern (with two double rows of tomatoes and one double row of corn), the arrangement of drip tapes, and locations of TDR probes, geothermometers, surface mulch, and measured root zone.

of soil water contents, soil temperatures, and root growth, when compared to a single-practice system. It is thus important to investigate variations in soil water contents (SWC), soil temperatures, and root distribution, and to study the competitive mechanisms in such multi-species systems in order to design optimal irrigation programs for drip-irrigated intercropping fields with plastic mulch.

Soil water movement under drip irrigation with different crops has been studied during the last few decades, both through experimentation (e.g., Yahgi et al., 2013; Badr and Abuarab, 2013) and the use of simulation models (e.g., Skaggs et al., 2004; Kandelous et al., 2011; Arbat et al., 2013). For example, the effects of different drip irrigation frequencies (Abou Lila et al., 2013), different drip patterns (Skaggs et al., 2010), and different irrigation amounts (van Donk et al., 2013) on soil water movement and crop growth were all researched in many countries. Results in general show that drip irrigation produces a higher WUE and lower leaching compared to surface irrigation (Patel and Rajput, 2008). Additionally, the effect of the drip irrigation on root growth is very complicated. Sharma et al. (2014) found that while deficit irrigation (50% of ET_c) increased the root length density of one variety of melon (cv. Mission), it did not have any impact on another variety (cv. Super Nectar), and it even decreased the root length density in the third variety (cv. Da Vinci).

The spatial distribution of roots in an intercropping field is different from the distribution in a single crop system. The overlapping root systems of two crop species lead to the competition for water and nutrients. For example, an uneven distribution of roots was measured in a maize/cabbage intercropping system (Zhang and Huang, 2003), with the roots of maize extending horizontally to greater distances than those of cabbage. The roots of the two crops extended into the rhizospheres of each other in the maize/cowpea intercropping field (Adiku et al., 2001), with the roots of maize being much larger.

Plastic mulch not only increases crop yields, soil temperatures, and the WUE, but it also stabilizes the daily range of soil temperatures (Xing et al., 2012), which can benefit crop growth. Although the thermal effects of SWC on soil temperature in a soil system with plastic mulch have been studied by many scientists (Mahrer et al., 1984; Hunt et al., 2010), much less similar work has been done for drip-irrigated intercropping systems with plastic mulch. Such systems are much more complicated because the spatial distribution of SWCs is affected by the different water consumptions of two crop species and their overlapping or not overlapping root systems, depending on crop species and their particular growing periods (Gao et al., 2010). The SWCs and root distribution in a drip-irrigated intercropping field are thus influenced not only by drip wetting patterns, but also by the root water uptake competition between two crops (Gao et al., 2010; Sampathkumar et al., 2012).

The spatial distribution of soil temperature is influenced not only by plastic mulch and water contents, but also by the different heights of two crops and their shading of the soil surface. All these factors, i.e., water contents, soil temperatures, and the presence or absence of surface mulch, affect root growth (Ceccon et al., 2011). Understandably, the spatial distributions of SWCs, soil temperatures, and root systems in a drip-irrigated intercropping field with plastic mulch are very complex and difficult to predict.

The main objectives of this study therefore are (i) to analyze the effects of drip irrigation on SWCs under different drip irrigation practices in an intercropping field, (ii) to evaluate the distribution of soil temperature in a drip-irrigated intercropping field with plastic mulch, and (iii) to compare root system distributions under different irrigation treatments.

2. Materials and methods

2.1. Experimental site

The field experiment was conducted at the Dunkou Agroecosystem Experimental Station (40°20′15′′N, 107°1′45′′E, altitude 2004 m), located at the western Hetao Irrigation District, in the Yellow River basin of Northwest China, during the 2012 and 2013 seasons. The main soil texture on the site is sandy clay loam, and the groundwater table is between 70 and 250 cm deep. The site is representative of inland arid climate with a long-term average annual rainfall of 198 mm and an average annual potential evapotranspiration of 2460 mm. Note that average annual potential evapotranspiration is 12.4 times higher than average annual precipitation, which makes irrigation necessary for crop growth.

2.2. Experimental treatments and procedures

The planting pattern in the intercropping field consisted of 4 rows of tomatoes and 2 rows of corn. One drip line was used for both two crop rows and one mulch strip in order to reduce irrigation costs (Fig. 1). Two rows of crops were irrigated with one drip line and covered with one white plastic mulch sheet with 80 cm width. Three irrigation treatments, with high T1 (Conventional drip irrigation), moderate T2 (about 75% of T1), and low T3 (about 50% of T1) irrigation amounts (which were the same in each irrigation event in a particular year, but different between treatments) (Table 1), were delivered in three replicates in a completely randomized block design of 9 plots, and the more detail agronomic management can be found in paper of Li et al. (2015). Different irrigation amounts were adopted for tomato and corn in one irrigation treatment (Table 1). Two water meters (with a precision of 0.001 m^3) were used to control irrigation amounts in each treatment. Corn was direct-seeded in the field (with a 40 cm row spacing), while tomatoes were transplanted to an intercropping field (with a 40 cm row spacing). After transplanting, all treatments received a large flood irrigation (about 55 mm) on day of year (DOY)