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Soil Temperature and Maize Nitrogen Uptake Improvement Under Partial Root-Zone Drying Irrigation

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ABSTRACT

Soil temperature is a major effective factor on the soil and plant biological properties. Irrigation can affect soil temperature and thereby induces a temperature effect on plant growth, which may result in an economic increase due to higher yield and plant nutrition. A field experiment was carried out to investigate the effects of three irrigation strategies including full irrigation (FI), partial root-zone drying (PRD) and deficit irrigation (DI) on soil temperature and the consequent results on the grain yield and N uptake of maize (*Zea May* L.). Soil temperature was measured by time domain reflectometry (TDR) sensors during the 2010 growing season. Irrigation treatments were applied from 55 to 107 d after planting. The PRD treatment caused soil temperature to be in a favorable domain for a longer period (for over 60% of the measuring dates) as a consequent result of water movement to deeper soil layers compared with the other treatments; the PRD treatment also reduced soil temperature at deeper soil depths to below the maximum favorable soil temperature for maize root growth, which resulted in deeper root penetration due to both water availability and favorable soil temperature. Compared to the FI treatment, the PRD treatment increased root water uptake by 50% and caused no significant reduction in total N uptake, while this was not observed in the DI treatment partially due to the negative temperature effect of DI on plant growth, which consequently affected the water and nutrient uptake. A longer vegetation period in the PRD treatment was observed due to higher leaf N concentrations and no significant reduction in maize grain yield occurred in the PRD treatment, compared with those in the FI treatment. Based on the results, having 15.2% water saving during the whole growing season, the PRD irrigation would positively affect soil temperature and the water and nutrient uptake as a consequent, which thereby would prevent significant reduction in maize grain yield.

Key Words: full irrigation, deficit irrigation, grain yield, irrigation strategy, leaf N concentration, root growth, water saving, water uptake

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INTRODUCTION

Soil temperature affects lots of soil physical, chemical and biological properties, which consequently can affect plant growth in different ways. Root growth has been reported to be a sensitive parameter to soil temperature (Psarras *et al.*, 2000; Lahti *et al.*, 2005; Callejas *et al.*, 2009). There is a species-specific soil temperature threshold, below or over which root growth would decrease (Callejas *et al.*, 2009). A favorable soil temperature relative to an unfavorable soil temperature would favor root growth (Callejas *et al.*, 2009). Soil temperature could significantly affect the amount of water and nutrient uptake due to its major effect on root growth (Pregitzer *et al.*, 2000; Dong *et al.*, 2001; Puhe, 2003). Lower nutrient and water uptake under unfavorable soil temperature conditions would consequently lead to a significant reduction in yield (Schwarz *et al.*, 1997; Aphalo *et al.*, 2006).

Despite the major role of soil temperature on plant growth, there are yet only a few investigations, in which the soil temperature variation has directly or indirectly been assessed (Kasubuchi, 1982; Tanaka and Ishii, 2000; Duna *et al.*, 2010). Kasubuchi (1982) has illustrated a two-dimensional distribution of soil temperature in the soil surface layer using the relation between soil temperature and heat conductivity. Duna *et al.* (2010) have investigated the effect of the plant growth stage on the domain of soil temperature fluctuation and concluded that the difference between the minimum and maximum values of soil temperature was higher at the early season stage compared with the other growth stages. Some researchers also considered the extraction of soil temperature variations using nu-

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merical models (Tanaka and Ishii, 2000).

Soil water content has been reported to be a driving factor in controlling soil temperature (Hlavinka *et al.*, 2009; Nainanayake *et al.*, 2009; Roxy *et al.*, 2010). Therefore, introducing a suitable irrigation strategy may help with both maintaining the soil temperature in a favorable domain for root growth and subsequently increasing nutrient and water uptake. As fresh water resources become scarce, it is difficult to irrigate crops to meet their full demand. To reduce the irrigation volume, some irrigation strategies such as deficit irrigation (DI) have been developed to aim at meeting the minimum crop water requirement. In the DI strategy, crops are exposed to water stress during the whole growing season or at some growth stages. Despite water saving, DI usually causes a significant reduction in crop yield and quality (Shahnazari *et al.*, 2007).

During the last years, a novel irrigation strategy, partial root-zone drying (PRD), has been developed (Kang and Zhang, 2004). The PRD approach is to use irrigation to alternately wet and dry two spatially distinct parts of the plant root system. In fact, in PRD one half of the root zone is irrigated, while the other half kept dried. Irrigated and dry sides are periodically switched (Dry and Loveys, 1998). Regularly alternating the wet and dry root compartments causes some plant physiological responses, which makes the PRD hypothesis to be different from the other water saving strategies (Stoll *et al.*, 2000). The PRD irrigation has been tested for field crops and fruit trees (Kang and Zhang, 2004). Most recently, it has also been tested in vegetables (Shahnazari *et al.*, 2007). In most cases, PRD has shown a great potential to increase irrigation water use efficiency and to maintain yield (Davies *et al.*, 2002).

Partial root-zone drying has shown a great potential to improve nutrient and root water uptake (Shahnazari *et al.*, 2008; Hu *et al.*, 2009; Wang *et al.*, 2012). Since the soil water dynamics under PRD differ from those under other water saving strategies, soil temperature may be consequently different under PRD due to the major driving role of soil water content on soil temperature (Nainanayake *et al.*, 2009; Roxy *et al.*, 2010). Nevertheless, in spite of numerous researches on the physiological response of plants under PRD (Shahnazari *et al.*, 2007, 2008; Hu *et al.*, 2009; Wang *et al.*, 2012), there is still a lack of information on the soil temperature condition under this novel irrigation strategy. Thus, the major objective of this study was to investigate the soil temperature variations under full irrigation (FI), DI and PRD and to determine subsequently their effects on the water and nutrient uptake of maize.

MATERIALS AND METHODS

Site and climatic conditions

The field experiment was carried out in 2010 at the research farm of Sari Agricultural Sciences and Natural Resources University (SANRU) (36.3° N, 53.04° E) in Sari, Iran. The mean elevation of the site is 15 m above sea level. Based on the DeMarten method (Oliver, 2005), the climate of the area is humid. The mean annual rainfall at the site is 616 mm and the class "A" pan evaporation is 2 500 mm. About 70% of annual rainfall occurs over the October–March period. The long-term annual average, minimal, and maximal air temperatures are 17.3, −6 and 38.9 °C, respectively (Darzi-Naftchali *et al.*, 2013). Weather data were collected at the SANRU weather station, less than 1 km distance from the site of the experiment.

The climate condition during the 2010 growing season (May 26–September 9) is shown in Fig. 1. Daily minimal temperature ranged from 15.5 to 28.6 °C during the growing season with a mean of 23.3 °C. The lowest (26.4 °C) and highest (38.1 °C) values of daily maximal temperature occurred on the 95th and 78th d after planting, respectively. The lowest (51%) and highest (83.5%) values of relative humidity occurred on the 13th and 95th d after planting, respectively. Daily reference evapotranspiration (ET_o) varied between 2.2 to 9.2 mm with a mean of 6.7 mm totaling 543.4 mm in the 2010 growing season. Totally, 8 mm precipitation was recorded for the whole growing season of 2010, which occurred from 1 to 54 d after planting. No rainfall occurred during the stress period (55–107 d after planting). The average wind speed during the whole growing period was 4.37 m s^{-1}.

The surface soil (0–20 cm) of the study site is classified as Typic Haplxereptd based on Soil Survey Staff (2014). Chemical properties of the surface soil are as follows: electrical conductivity (EC), 1.64 dS m^{-1}; organic matter, 12.2 g kg^{-1}; organic carbon, 7.1 g kg^{-1}; nitrogen (N), 0.6 g kg^{-1}; phosphorus (P), 3.6 mg L^{-1} and potassium (K), 75 mg L^{-1}. The soil physical properties in 0–100 cm profile are summarized in Table I. Prior to planting, field capacity (FC) and permanent wilting point (PWP) of different soil samples were determined at suction of about 30 and 1500 kPa, respectively, using a pressure plate apparatus. The average water table in the experimental field was about 122 cm below the soil surface at the beginning of the growing season, and then it continued to fall to 211 cm below the soil surface at the end of the experiment.