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Performance of partial root-zone drip irrigation for sugar beet production in a semi-arid area

Ramazan Topak[a,*], Bilal Acar[a], Refik Uyanöz[b], Ercan Ceyhan[c]

[a] Department of Irrigation, Faculty of Agriculture, Selcuk University, Konya, Turkey
[b] Department of Soil Science and Nutrition, Faculty of Agriculture, Selcuk University, Konya, Turkey
[c] Department of Field Crops, Faculty of Agriculture, Selcuk University, Konya, Turkey

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ABSTRACT

Partial root-zone drying (PRD), a water-saving irrigation strategy, is being tested in many field crops species. In this study, the effects of PRD on root yield, sugar yield, water use efficiency (WUE), and fertilizer-nitrogen use efficiency (FNUE) of field-grown sugar beet were compared with those of conventional deficit irrigation (CDI) and full irrigation (FI). The experiments were conducted at Konya-Çumra, a Central Anatolian region of Turkey, in 2012 and 2013. Five irrigation techniques were designed and three nitrogen levels were chosen for the current study. These five irrigation techniques were applied to the study crops with the help of a drip irrigation system. In FI (control), the irrigation water was applied to both sides of the root system such that 35–40% of the available soil moisture was consumed in the 0.90-m root zone. In CDI_{50} and CDI_{75}, 50% and 75% irrigation water of FI, respectively, was supplied to both sides of the root system. In alternative PRD_{50} ($APRD_{50}$), the half of the root system was exposed to soil drying and the other half was kept well-watered with 50% irrigation water of FI. In fixed PRD_{50} ($FPRD_{50}$), 50% irrigation water of FI was supplied only to half of the fixed side of the root system. Furthermore, the three chosen nitrogen levels included N_{100}, where the plant's nitrogen requirement is met completely; N_{75}, where 25% reduction was made in the plant's nitrogen requirement; and N_{50}, where 50% reduction was made in the plant's nitrogen requirement. Although the effect of nitrogen levels on sugar beet root and sugar yields was not significant, irrigation treatments had a significant effect (5% of the level). Compared to the FI treatment, the CDI_{75}, CDI_{50}, $APRD_{50}$, and $FPRD_{50}$ treatments decreased the standardized root and sugar yields by 6.36%, 26.97%, 19.12%, and 23.50%, respectively. $APRD_{50}$ and $FPRD_{50}$ increased the standardized yield by 10.74% and 4.75% compared to CDI_{50}, respectively. In addition, when same amount of irrigation water was used, PRD ($APRD_{50}$ and $FPRD_{50}$) treatments outperformed CDI_{50} in WUE and FNUE of sugar beets. Compared to FI and CDI_{50}, $APRD_{50}$ increased WUE_{root} by 19.8% and 8.5% and $FNUE_{root}$ by 26.2% and 68.2%, respectively. The varying nitrogen levels had a significant effect on $FNUE_{root}$ and $FNUE_{sugar}$. The highest $FNUE_{root}$ and $FNUE_{sugar}$ values were obtained with N_{50}. Further, combinations of different irrigation treatments and nitrogen levels had a significant effect on $FNUE_{root}$.

1. Introduction

In dry lands, water shortage is a major factor that restricts agricultural production; therefore, efficient use of water resources is a prerequisite in such areas. To achieve this, viable alternatives such as development of deficit irrigation (DI) techniques with drip systems can help manage and use water more efficiently. Of them, partial root-zone drying (PRD) technique is an innovative and environmentally friendly irrigation technique that can be employed more easily using drip irrigation systems (Du et al., 2008). Some studies have demonstrated that, given the same amount of irrigation water, PRD is superior to conventional DI (CDI) in terms of yield maintenance and increase in water use efficiency (WUE) (Dodd, 2007; Liu et al., 2009; Sadras, 2009; Wang et al., 2010). In cases where the optimum water requirement of a crop cannot be met, the PRD technique can be preferred instead of the CDI technique.

The most important characteristic of PRD technique is that half of the root system is subject to drying soil and the other half is growing in irrigated soil in each irrigation event. In this technique, the wetted and dried sides of the root system are alternated in a frequency according to crops, growing stages and soil water balance (Kang et al., 1997; Kang and Zhang, 2004). If the root system of the

* Corresponding author.
E-mail address: rtopak@selcuk.edu.tr (R. Topak).

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plant is compatible with PRD technique, it can result in significantly water saving, and WUE can be substantially improved in comparison to conventional full irrigation (FI) techniques without causing a significant reduction in yield and quality (Kang et al., 2000a; Tang et al., 2005; Sepaskhah and Parand, 2006; Shahnazari et al., 2007; Du et al., 2008; Ahmadi et al., 2010).

However, PRD-imposed drying and wetting cycles in the soil may cause uneven availability of nutrients in soil, leading to uneven nutrient absorption by the roots in different root zones (Hu et al., 2006; Li et al., 2007; Wang et al., 2009). Water and nitrogen are essential resources for crop production, and their availability predominantly effects crop yield and quality. Crop nitrogen nutrition under the PRD irrigation technique has been tested in some crops such as maize (Kirda et al., 2005; Hu et al., 2006, 2009; Li et al., 2007; Wang et al., 2012), potato (Shahnazari et al., 2008; Wang et al., 2009; Jovanovic et al., 2010; Li et al., 2010), tomato (Wang et al., 2013), and winter wheat (Sepaskhah and Hosseini, 2008). According to Wang et al. (2009), PRD irrigation may increase not only WUE but also nitrogen use efficiency (NUE). To the best of our knowledge, no study till date has reported the effects of PRD on nitrogen use of sugar beet crop.

Some researchers studying the CDI technique with drip systems in sugar beet have reported that maximum 20% water savings can be made using this technique without causing a substantial reduction in sugar beet yield (Faberio et al., 2003; Tognetti et al., 2003; Pocan, 2008; Topak et al., 2010; Esmaeili and Yasari, 2011). A few studies testing the PRD technique in sugar beet using the furrow method (Sepaskhah and Kheradnam, 1977; Sepaskhah and Kamgar-Haghighi, 1997) and drip irrigation method (Şahin et al., 2014) concluded that application of this technique can save 34–42% water, incurring 18–22% loss in crop yield. Further, studies focusing on the effects of CDI and PRD techniques on sugar beet have indicated that the PRD technique may save more irrigation water in sugar beet production compared to the CDI technique.

Globally, Turkey is the sixth leading producer of sugar beet and ranks the fourth in root yield (FAOSTAT, 2015). In Turkey, approximately 40% of the sugar beet is produced in the Konya closed basin (TSI, 2014; TSFGD, 2014). Although this basin has approximately 3 million hectares of cultivated land, it faces a lot of water scarcity due to limited water resources (3% potential available water of Turkey) and low precipitation (320 mm/year). Therefore, sugar beet is produced by irrigation in this region. The cultivation rate of sugar beet is approximately 15%, based on the current crop patterns in the basin. Sugar beet is a high water-consuming crop (Allen et al., 1998; Faberio et al., 2003); and the seasonal crop water use varies between 900 and 1200 mm (Hills et al., 1990; Dunham, 1993; Allen et al., 1998). In studies performed by Topak et al. (2010) and Süheri et al. (2011) in the Konya closed basin, the crop water use of sugar beet at FI conditions is 1000 mm and irrigation water use is approximately 850–900 mm. Therefore, studies focusing on reducing irrigation water consumption in sugar beet production without causing a significant reduction the crop yield and quality are warranted. Thus, the aim of this study was to investigate the effects of PRD on root yield, sugar yield, WUE, and fertilizer-nitrogen use efficiency (FNUE) of sugar beet compared to those of CDI and FI.

2. Materials and methods

The field experiments were conducted at Konya-Çumra, a Central Anatolian region of Turkey (latitude 37° 35′ N, longitude 32° 47′ E, altitude 1013 m), during the 2012 and 2013 growing season. The soil of the research field can be classified as Fluvisol, according to the classification system of FAO/UNESCO, and has a clay texture with flat topography (de Meester, 1970). Some properties of the experimental site soils are given in Table 1.

The research area has a continental climate, with hot and dry summers and very cold winters. According to long-term data (1971–2014), the average temperature is 11.29 °C, average relative humidity is 62.3%, average wind speed is 1.0 m s^{-1}, and annual total precipitation is 317.4 mm. The total precipitation during the sugar beet production period (April 1–September 30) was recorded to be 38.6 and 91.6 mm in 2012 and 2013, respectively. However, this was lower than the long year's average (114 mm).

Fig. 1 shows the seasonal variations of air temperature and relative humidity during both growing seasons. The mean temperature varied between 12.2 °C and 29.3 °C in 2012 and 12.9 °C and 26.1 °C in 2013 during the growing season. On most days, the maximum temperature was above 25 °C (Fig. 1A and B). The relative humidity varied between 19% and 75.3% and 25.9% and 75.2% in 2012 and 2013, respectively.

The study was conducted in split plots in randomized blocks with three replicates. The main treatments were different nitrogen levels; and the subplots were different irrigation techniques. The irrigation techniques consisted of one FI (control), two CDI (CDI_{75} and CDI_{50}), and two PRD [alternative PRD_{50} ($APRD_{50}$) and fixed PRD_{50} ($FPRD_{50}$)]. The irrigation treatments were designed to replenish the soil water depletion. The FI treatment was designated to receive 100% replenishment of soil water depletion. Depletion was defined as the difference between the depth of water held in the root zone at field capacity and the depth of water actually held in the root zone at the time of an irrigation decision. Irrigation was applied when 35–40% of the available soil moisture was consumed in the 0.90-m root zone in the FI treatment during the irrigation periods. In addition, the four DI techniques were applied. In CDI_{50} and CDI_{75}, 50% and 75% irrigation water of FI, respectively, was supplied to both sides of the root system. In $APRD_{50}$, half of the root system was exposed to soil drying and the other half was kept well-watered with 50% irrigation water of FI. In $FPRD_{50}$, 50% irrigation water of FI was supplied only to half of the fixed side of the root system, while the other side was left drying. Furthermore, the three nitrogen level treatments included N_{100}, where the plant's nitrogen requirement is met completely; N_{75}, where 25% reduction was made in the plant's nitrogen requirement; and N_{50}, where 50% reduction was made in the plant's nitrogen requirement. In addition, a treatment of no nitrogen fertilizer application was included in the study.

In the drip irrigation system designed for the experiment, 16-mm diameter drip laterals carrying 2 L h^{-1} water with in-line emitters and 30-cm spacing were used. The drip irrigation system consisted of three fertilizer tanks, three venturi systems, screen filters, pressure gauges, water meters, valves, manifolds, drip lines, and mini valves. In the FI, CDI_{75}, and CDI_{50} plots, a drip line was arranged for each plant row. For the $APRD_{50}$ plots, the drip lines were arranged in the middle of two plant rows such that they were parallel to the plant rows (Fig. 2). In the $FPRD_{50}$ plots, a drip line was arranged for two plant rows (90-cm drip line spacing), and the drip lines were placed in the middle of the two plant rows (Fig. 2).

Fertilizers were applied on the basis of soil analysis. Soil at depths of 0–30, 30–60, and 60–90 cm was sampled before seed sowing and subjected to physicochemical analyses. Total nitrogen analysis of the soil samples was performed according to the micro-Kjeldahl method ($NH_4 + NO_3$) (Bremner, 1960; Jackson, 1962), and the available phosphorus was evaluated using the Olsen's $NaHCO_3$ method (Olsen et al., 1954). The available potassium in the soil samples was determined using the ammonium acetate method (Jackson, 1962; Kacar, 1994). For sugar beet, 90 kg P_2O_5 ha^{-1}, 270 kg K_2O ha^{-1}, and 220 kg N ha^{-1} were recommended by Şiray (1990) and Arıoğlu (1997). Diammonium phosphate fertilizer (18% N, 46% P_2O_5) was applied to the soil at a rate of 200 kg ha^{-1} prior to seeding. The remaining nitrogen level requirements for the treatments were applied in the form of a urea fertilizer (46% N) in