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Comparative effects of two water-saving irrigation techniques on soil water status, yield, and water use efficiency in potato

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ABSTRACT

This study was conducted to compare two water-saving techniques: deficit irrigation (DI) and partial root-zone drying (PRD) with full irrigation (FI) on potato (*Solanum tuberosum* L.). These techniques were studied using drip irrigation in an arid region of Saudi Arabia in 2014 and 2015. Five irrigation treatments, i.e., FI (control treatment where the full amount of irrigation water was applied to both sides of the plant), DI70, DI50 (70% and 50% of the FI treatment, respectively, supplied to both sides of the plant), PRD70, and PRD50 (70% and 50% of the FI treatment, respectively, supplied to a single side of each plant in an alternating manner), were applied. The dry and wet sides of the plant in the PRD treatments were switched weekly. The soil water content was the highest in the FI treatment followed by DI70 and PRD70 and DI50 and PRD50 thereafter in 2014 and 2015. The fresh weight of the vegetative parts for both the FI and PRD70 treatments (average of 14.7 Mg ha^{-1} and 11.9 Mg ha^{-1}, respectively) was significantly ($p < 0.05$) higher than that of the other irrigation treatments. The FI and PRD70 treatments increased ($p < 0.05$) the dry weight of the vegetative parts by approximately 48.3%–57.7% relative to the other treatments in 2014. The highest number of branches per plant occurred in the PRD treatments, and the lowest number was in the DI70 treatment. The DI and PRD treatments decreased ($p < 0.01$) the fresh and dry tuber yield compared to FI. The FI produced the highest number of tubers per plant. The DI treatments did not have a significantly lower irrigation water use efficiency (IWUE) compared to FI in 2014, whereas PRD had significantly ($p < 0.01$) lower IWUE than FI in both years.

1. Introduction

Potato (*Solanum tuberosum* L.) is one of the most important crops in the world in terms of its use as a food for people and in the starch industry (Fabeiro et al., 2001). Potato production ranks fourth in the world after rice, wheat and maize and is expected to continue to increase, providing an important source of food, nutrition and income (Bowen, 2003). Due to its sparse and shallow root system, potato is highly sensitive to drought stress (Jefferies, 1993), and tuber yield may be considerably reduced by soil moisture deficits (Porter et al., 1999).

In areas with water scarcity, such as Saudi Arabia, irrigation is necessary for successful agricultural production. The increasing shortage of water resources requires the optimization of irrigation management in order to increase crop productivity and improve the irrigation water use efficiency (IWUE). Innovations are needed to increase IWUE.

Many crop irrigation investigations have been conducted to maximize performance, efficiency and profitability. Deficit irrigation (DI) and partial root-zone drying irrigation (PRD) are water-saving irrigation methods that decrease the amount of water that is used compared to the full irrigation (FI).

DI is a strategy where crops are irrigated with lower amounts of water and the minor stress that develops has minimal effects on the yield (English and Raja, 1996). In this mode of irrigation, the entire root-zone is irrigated at less than the maximum rate of crop evapotranspiration. Knowing when to apply water is necessary for the successful implementation of DI because the sensitivity of the crop to water stress is different at different growth stages (Andersen et al., 2002; Kirda, 2002; Liu et al., 2004). DI was developed to improve the control of vegetative vigor in order to optimize fruit size, fruitfulness and fruit quality. DI is usually applied during the period of slow fruit growth when shoot growth is rapid. DI can generate considerable water savings. Thus, DI can be useful for reducing excessive vegetative vigor, and for minimizing irrigation and nutrient loss through leaching (Chaves et al., 2007, 2010; Santos et al., 2007). Shock and Feibert (2002) found

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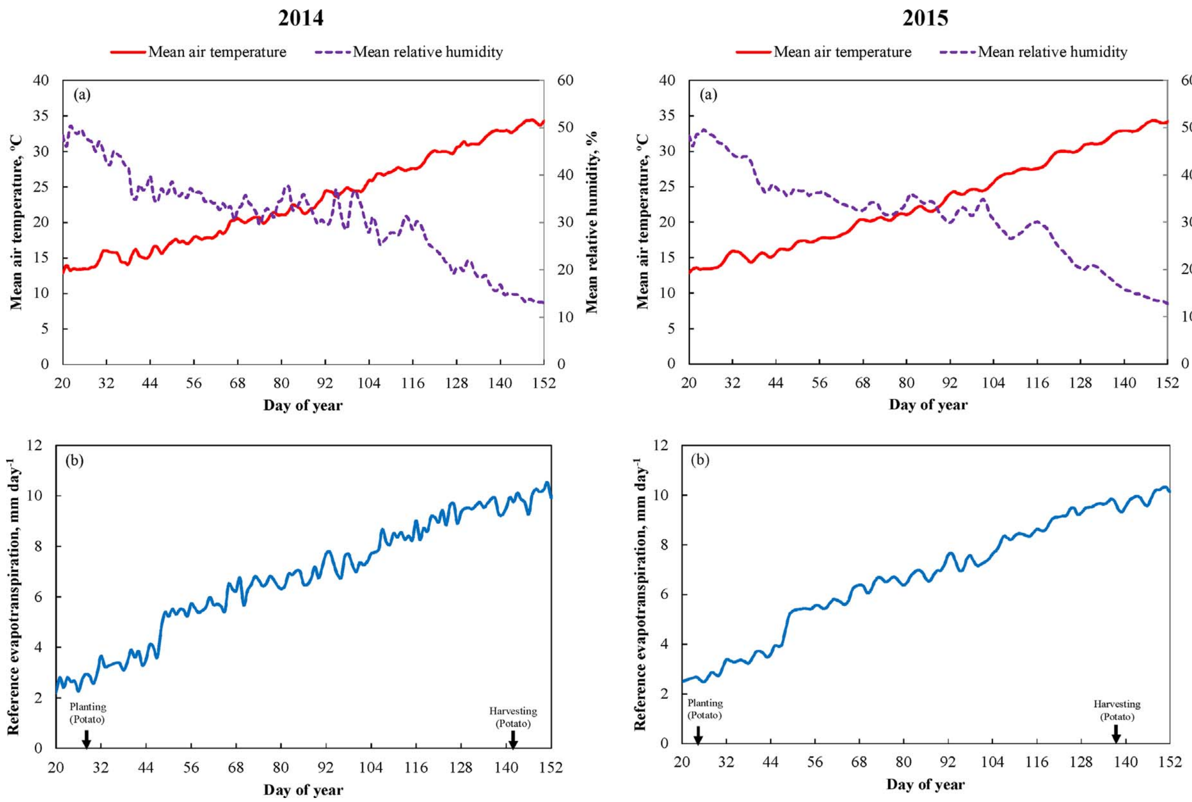

Fig. 1. Meteorological variables of (a) mean air temperature and mean relative humidity, and (b) reference evapotranspiration during the 2014 and 2015 experimental periods.

that DI was not useful for sprinkler-irrigated potato in a semi-arid environment.

PRD is a new innovation in DI and is commonly applied as part of a DI strategy because it does not require the application of more than 50%–70% of the water used in a fully irrigated strategy. PRD is a system of alternating irrigation in space and time to generate wet/dry cycles in different sections of the root system. This system seeks to promote chemical signals from roots in dry soil, thereby reducing stomatal conductance and transpiration and shoot growth while maintaining the water supply from the roots in the wet soil fraction, thereby avoiding a severe water deficit (Davies et al., 2002; Morison et al., 2008). The wetting and drying of each side of the roots is dependent on the crop, growth stage, evaporative demands, soil texture and the soil water balance (Saeed et al., 2008).

DI and PRD irrigation have been tested in several field crops and fruit trees across the globe, such as bean (Samadi and Sepaskhah, 1984); sugar beet (Sepaskhah and Kamgar-Haghighi, 1997); grapes (Kriedmann and Goodwin, 2003); maize (Kang and Zhang, 2004); green bean (Gencoglan et al., 2006); apple (Leib et al., 2006); peach (Gong et al., 2005); potato (Shayannejad, 2009; Ahmadi et al., 2010a,b); and tomato (Wang et al., 2013).

PRD has improved yield per unit of applied water with respect to conventional irrigation using FI (Kirda et al., 2007; Morison et al., 2008). PRD has been shown to be successful in grapevines (Stoll et al., 2000) and in fruit trees (Kang et al., 2002) and is also said to be promising for field crops (Kang et al., 1998, 2000a,b; Kirda et al., 2005) and vegetables (Dorji et al., 2005; Zegbe-Domínguez et al., 2006). However, Wakrim et al. (2005) reported no significant difference between IWUE of bean in PRD and DI, but these irrigation strategies did result in a substantial increase in IWUE compared to FI. There is evidence that PRD is able to save water with little or no effect on yield when compared with FI plants (Davies et al., 2002; Kang and Zhang, 2004). PRD irrigation has since been found to increase IWUE in a variety of crops (e.g., sunflower, maize) by reducing evaporative losses during periods of limited soil moisture availability or high evaporative potential (Kang et al., 2000a,b; Loveys et al., 1997, 1998).

Shahnazari et al. (2007) showed that DI and PRD produced potato yields in Denmark that were similar to FI and increased IWUE by 60%, as approximately applied 30% of the irrigation water was saved. Liu et al. (2006b) found that PRD did not improve the yield and IWUE in potatoes compared to DI in Denmark. Saeed et al. (2005) showed that PRD could also modify shoot growth and increase IWUE in potatoes grown in United Kingdom. Ahmadi et al. (2010a) showed that DI and PRD did not have significant effects on the fresh yield and IWUE of potatoes grown in Iran compared to FI. Yactayo et al. (2013) in Peru found that early use of PRD in potatoes, initiated 6 weeks after planting with a watering level equivalent to 50% of full irrigation, increased IWUE with no yield reduction relative to full irrigation. The objective of our experiment was to compare the responses of potato to DI and PRD irrigation and FI under a surface drip irrigation system by assessing the effect of DI and PRD irrigation on the soil water status, yield, and IWUE of potato in arid climatic conditions.

2. Materials and methods

2.1. Experiment location and climate conditions

The field experiment was conducted over two consecutive years (2014–2015) from January to May in the northwestern section of Riyadh, Saudi Arabia. The site is located at 24°44′11.10″ N and 46°37′06.61″ E at an elevation of approximately 665 m above sea level. A Rain Bird® WS-PROLT meteorological station collected and stored weather data from experimental field according to the specifications of the World Meteorological Organization. This station measured air temperature, solar radiation, relative humidity, wind speed, wind direction and rainfall. Daily climatic data was used to calculate daily reference evapotranspiration (ET_o) using the Penman-Monteith equation (Allen et al., 1998).

The daily crop evapotranspiration (ET_c) was estimated using crop coefficients (K_c) with values of 0.5, 1.15 and 0.75 during initial, mid-