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Application of partial rootzone drying to improve irrigation water use efficiency in grapefruit trees

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ABSTRACT

Partial rootzone drying (PRD) has been reported to potentially improve crop water use efficiency (WUE_{crop}) compared to full irrigation in different fruit trees; however, field studies on the effect of PRD in citrus are scarce. In this field study, three irrigation strategies were tested in an orchard of mature grapefruit trees during two consecutive seasons (2013/2014 and 2014/2015): drip PRD (two drip lines, alternating irrigation between lines every month), microsprinkler irrigation, and double-line drip irrigation (control). Irrigation was applied during the fruit enlargement stage (April–August). The aims of this field study were: 1) to provide a quantitative comparison of irrigation water productivity among irrigation treatments; and 2) to study their effects on fruit quality, yield, tree growth, and flowering. Drip PRD saved 43 to 47% of irrigation water compared to control irrigation, and microsprinkler irrigation saved 12 to 18% of water compared to control irrigation PRD-irrigated trees maintained or increased yield compared to microsprinkler-irrigated and control trees, depending on the experimental season. Therefore, WUE_{crop} in PRD-irrigated trees was significantly higher than in control and microsprinkler-irrigated trees at the end of both seasons. Fruit and juice quality parameters were statistically similar among all treatments. PRD irrigation did not reduce the flowering potential of the trees although it delayed the onset of flowering in trees relative to the other treatments in 2013/2014. There was a similar timing of flowering among treatments in 2014/2015 and there were no differences in vegetative growth among the irrigation treatments by the end of March (86 Julian data) in both experimental seasons. Our results suggest that PRD can be economically beneficial for citrus growers who use double-line drip irrigation systems, and a strategy to sustain tree growth, tree health and yield during seasons of extreme drought or when high water restrictions are placed in citrus-producing areas.

1. Introduction

Irrigation is essential for citrus production in arid and semiarid areas where annual rainfall is lower than the evapotranspirative needs or where there is an erratic distribution of rainfall that does not fulfill seasonal demands. Water restrictions can adversely affect shoot and fruit growth in citrus because vegetative and fruit growth occur simultaneously and are not independent (Hutton et al., 2007).

Under water scarcity conditions, appropriate water management comprises any strategy that achieves adequate yield with significant water savings (García-Tejero et al., 2011). Thus, the implementation of water-saving irrigation management strategies that improve tree growth and/or yield per unit of water used, i.e. crop water use efficiency (WUE_{crop}), is a key factor for the sustainability of agro-ecosystems.

Partial rootzone drying (PRD) is an irrigation strategy that exposes approximately half of the root system on either side of tree canopy to drying soil while the remaining half is irrigated as in full irrigation (Kang and Zhang, 2004). As a result, there is a spatial separation of roots under dry and wet soil conditions. PRD irrigation can be applied either as alternate PRD, which allows alternate wet and dry zones (Loveys et al., 2000), or as fixed PRD where the wet and dry rootzones are consistently maintained while this strategy is applied (Talluto et al., 2007). In an optimized PRD-irrigated system,

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stomatal behavior, tree water status and leaf growth can be regulated such that water use efficiency can be significantly increased (Davies et al., 2002). In this situation, partial stomatal closure can maintain CO_2 assimilation, and fruit yield and canopy development can be sustained.

The effects of PRD irrigation have been investigated on different fruit tree species such as apple, grapevine, peach, pear, mango, and olive trees (Caspari et al., 2004; Dry et al., 1996; Goldhamer et al., 2002; Kang et al., 2002; Spreer et al., 2007; Wahbi et al., 2005). Great potential for the enhancement of irrigation WUE and the maintenance of yield has been observed under PRD irrigation (Davies and Hartung, 2004). Furthermore, the improvement of fruit quality at harvest (Dry et al., 2000; Leib et al., 2006; Spreer et al., 2007; Zegbe et al., 2006) and even at postharvest (Zegbe et al., 2008) have also been demonstrated.

However, limited research has been conducted in citrus with PRD, and very few of them have been performed at the on-farm level (Faber and Lovatt, 2014; García-Tejero et al., 2013; Pérez-Pérez et al., 2012). Furthermore, these studies focused only on physiological responses related to root-to-shoot signaling, on yield, and fruit quality, and there is no information on the effects of PRD on flowering phenology and vegetative growth of field-grown mature citrus trees. It is well-known that the presence of fruits (sinks) may cause a decrease in spring sprouting of vegetative and flowering buds, which causes alternate bearing (Iglesias et al., 2007). Thus, understanding the influence of PRD management during phase II (rapid cell expansion), and its effect on vegetative growth and canopy development are key factors for the development of flowering sites the following year.

Irrigation management during phase II in citrus has been extensively studied in deficit irrigation (DI) experiments, and most of these research studies provide evidence of the benefits of reducing water applications during phase II. For instance, Ballester et al. (2008, 2011) reported that the application of DI with moderate water restrictions during phase II of fruit growth allowed for about 20% water savings without significant reductions in yield and fruit size in sweet orange and mandarin. Similarly, García-Tejero et al. (2010) reported increased in water productivity (i.e. yield per unit of water applied) and small yield reduction (10%) in orange trees under DI, which is of remarkable importance in climates with seasonal water availability. However, fruit of grapefruit trees under DI seems to be more sensitive to water stress during phase II than other citrus, probably because of a different pattern of vegetative-reproductive resource distribution in response to water stress (Pérez-Pérez et al., 2014), and reduced yield, delayed fruit maturation, and reduced fruit and juice quality have been reported in grapefruit trees under DI during phase II (Navarro et al., 2015), even if it is followed by a recovery period during phase III (ripening phase; Pérez-Pérez et al., 2014). In this sense, the agronomic responses of grapefruit trees under PRD applied during the phase II of fruit growth have not previously been assessed.

The goal of this study was to provide citrus growers from semiarid regions with a water-saving irrigation strategy that does not impair yield, fruit quality, and tree growth. A comparison among drip PRD, microsprinkler, and double-line drip irrigation during the same growing season may provide a better understanding of the agronomic basis behind those irrigation systems, and of the potential benefits of PRD in semiarid citrus production. It was hypothesized that water savings can be achieved without causing any negative impact on yield, fruit quality, and tree growth in drip PRD compared to microsprinkler and double-line drip irrigation. Thus, this paper aims to provide a quantitative comparison of irrigation water productivity (WUE_{crop}, yield per unit applied irrigation water) in a mature citrus orchard managed with drip PRD, microsprinkler, and double-line drip irrigation, and to study their effects on fruit quality traits, tree growth, and flowering.

2. Materials and methods

2.1. Tree growth conditions

The experiment was conducted during two consecutive seasons (2013/2014 and 2014/2015) in a 0.6 ha experimental citrus orchard at the Texas A&M University-Kingsville Citrus Center South Farm, Weslaco, TX, USA (location 26°18′N latitude, 97°97′W longitude). The soil at the site was a hyperthermic Vertic Calciustoll (FAO soil classification; IUSS Working Group WRB, 2015), with 33% sand, 20% silt and 47% clay. This region has a subhumid to semiarid subtropical climate that consist of high atmospheric moisture content but that is uniformly moisture deficient because of limited annual rainfall combined with high evapotranspiration rates (Norwine et al., 2007). The mean annual rainfall is of 635 mm, of which over 70%

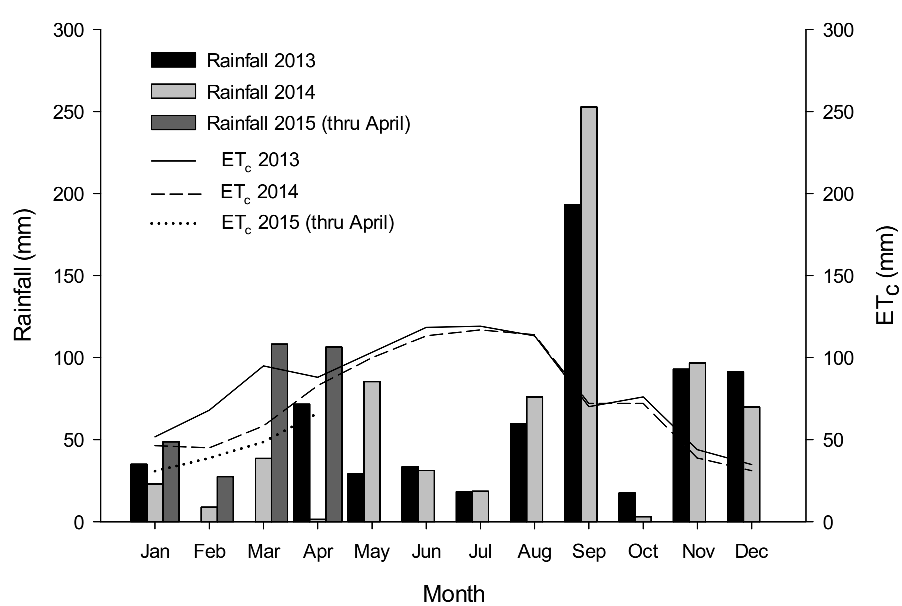

Fig. 1. Monthly mean precipitation (mm) and ET_c (mm) for Year 2013, 2014, and 2015 (during January to April) at Weslaco, Texas.