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Matric potential-based irrigation management of field-grown strawberry: Effects on yield and water use efficiency

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ABSTRACT

Effective and adapted criteria for irrigation scheduling are required to improve yield and water use efficiency (WUE) and reduce the environmental impacts associated with water and nutrients losses by runoff and leaching. In this study, field-scale experiments were conducted at four commercial strawberry production sites with contrasting soil and climatic conditions. Within each site, the influence of different soil matric potential-based irrigation thresholds (IT) on yield and WUE was evaluated. Matric potential-based irrigation management was also compared with common irrigation practices used by producers in each site's respective areas. At Site 1 (silty clay loam; humid continental (Dfb) climate), an IT of −15 kPa improved yields by 6.2% without any additional use of water relative to common irrigation practices. At Site 2, with similar soil and climatic conditions, the irrigation treatments did not affect yield and the matric potential-based management decreased WUE relative to common practices. However, the results suggested that maintaining the soil matric potential lower than −9 kPa could induce stressing conditions for the plants. At Site 3 (sandy loam; Mediterranean (Cs) climate), the best yield and WUE were obtained with an IT of −8 kPa and suggested that WUE could be further improved by implementing high-frequency irrigation. At Site 4 (clay loam; Mediterranean (Cs) climate), results suggested that an IT between −10 and −15 kPa could optimize yield and WUE, and matric potential-based irrigation considerably reduced leaching under the root zone relative to common practices. Considering the results from all sites, an IT of −10 kPa appears to be adequate as a starting point for further optimizing irrigation under most field conditions.

1. Introduction

Irrigation management is of primary importance for the profitability and sustainability of field strawberry production because it affects yield, water use efficiency and diffuse pollution of ground and surface water. These issues are of great importance in some areas, such as coastal California, Spain and Australia, where water availability is a growing concern. In recent decades, the increased implementation of more efficient water management practices, mainly subsurface drip irrigation (SDI) and the use of plastic mulch, has greatly improved WUE in commercial strawberry production. However, questions remain regarding irrigation management criteria that could improve WUE and reduce the environmental risks of SDI. Currently, the most common criteria are based on climatic water balance (evapotranspiration), plant physiological properties, soil water status measurements or a combination of these factors.

Many studies have shown that evapotranspiration (ET)-based irrigation management could be efficient for strawberry production (Hanson and Bendixon, 2004; Krüger et al., 1999; Yuan, 2004). However, this method is also criticized for its inability to account for rapid changes in climatic conditions and because it generally does not account for differences in the water requirements of different strawberry cultivars (Giné Bordonaba and Terry, 2010; Klamkowski and Treder, 2008; Krüger et al., 1999). The availability of locally determined crop coefficients that account for the wetting patterns resulting from the combined effects of SDI system configuration and soil type can also be problematic. Additionally, management based only on ET cannot be used to assess whether the applied irrigation water is lost beneath the root zone due to percolation (Simonne et al., 2012).

Numerous studies have proven that physiological measurements on plants could be used to measure water stress and its effect on plant performance. However, plant-based irrigation scheduling is still limited by many theoretical and practical difficulties, most of which are discussed in a comprehensive review by Jones (2004). In strawberry production, leaf temperature measurements with infra-red thermometers were identified as a potential tool

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for irrigation management because they allow for the detection of severe stresses that affect yield and biomass production (Peñuelas et al., 1992). Photosynthesis, stomatal conductance, and leaf water potential measurements have also been successfully used to detect hydric stress and to understand and differentiate stress adaptation mechanisms among strawberry cultivars. Such measurements have shown great potential to be used for breeding drought-resistant cultivars (Blanke and Cooke, 2004; Klamkowski and Treder, 2006, 2008; Savé et al., 1993). Canopy spectral reflectance or transmittance measurements also present potential for irrigation management because they are correlated with strawberry fruit yield. However, a clear interpretation of their effects still requires topography, soil water content and climatic information (Hoppula and Salo, 2007). Despite the relevance of understanding the physiological parameters tackled in the studies cited above, they do not currently allow for the definition of a criterion for irrigation scheduling or for assessing the appropriate volume of water that should be applied (Jones, 2004).

Soil water status measurement methods, whether based on water content or soil matric potential, have been well documented (Topp and Ferré, 2002; Young and Sisson, 2002) and have frequently been used for irrigation scheduling. In this study, soil matric potential (ψ) measurements were favored over soil water content measurements because of their ease of use in various field conditions (no calibration required for soil types or salinity levels). The soil matric potential is also directly related to the soil's hydraulic conductivity, which is linked to the soil's capacity to supply water at the rate required by plants (Rekika et al., 2014). Because potential gradients are the leading force responsible for water movement in soils, ψ measurements can also be used to infer the direction and magnitude of soil water fluxes. This information can be used to prevent leaching under the root zone (Krüger et al., 1999). ψ-based irrigation management has been successfully used to improve the yields of many agricultural crops and to evaluate the impacts of irrigation practices on water and fertilizer leaching (Pelletier et al., 2013; Périard et al., 2012; Shock and Wang, 2011).

Many studies have evaluated the impacts of ψ-based irrigation management on strawberry yield and WUE. However, their results differ with regard to which ψ value should be used as an irrigation threshold (IT). Similarly, little information is generally provided regarding the optimal duration of each irrigation event. From a field experiment in a sandy loam presenting a significant proportion of coarse particles ($\varnothing$ > 2 mm), Bergeron (2010) noted an increase in WUE that did not affect yield when the IT was −18 kPa. For strawberry grown in a sandy loam under a high tunnel, greater yields were obtained when an IT of −10 kPa was used than when a drier regime of −70 kPa was used (Guimerà et al., 1995; Peñuelas et al., 1992). Under similar soil and production conditions, significant yield and fruit quality decreases were observed for ITs of −30, −50 and −70 kPa relative to an IT of −10 kPa, and the highest WUE was obtained when using an IT of −50 kPa. In the same study, the yields from all of the treatments were 150–250% greater than the average yields from growers in the area (Serrano et al., 1992). Based on field experiments, a similar trend was observed in sand with an optimal yield at an IT of −15 kPa and a better WUE at −30 kPa (Hoppula and Salo, 2007). In addition, irrigation regimes were shown to affect fruit quality during greenhouse production. Deficit irrigation was shown to increase the sugar/acid ratios, antioxidant capacity and total phenolic contents of strawberries (Giné Bordonaba and Terry, 2010; Terry et al., 2007).

Nonetheless, not all studies support the previously mentioned benefits of ψ-based irrigation management. After conducting field experiments during three production seasons, Krüger et al. (1999) concluded that ET-based management showed a greater potential for improving yield and WUE, mainly due to economical and practical reasons. However, only one ψ-based irrigation treatment was tested, and irrigation scheduling was based on bi-weekly measurements. Problems with regards to probes locations in the field were also reported. In a bell pepper production experiment, it was shown that the soil matric potential presented large spatial and temporal variability and that several tensiometers were necessary for obtaining representative values for a given field. (Hendrickx and Wierenga, 1990; Hendrickx et al., 1994).

Some of the previously mentioned studies were conducted in greenhouses or tunnels and others in fields. Additionally, the tensiometers installation depths, matric potential measurement frequencies and treatment application procedures varied between studies. Considering this, the optimal IT for given soil and climatic conditions is not obvious. The aim of this study is to determine optimal matric potential based IT for field strawberry production with regards to yield and WUE for a variety of soil type and climatic conditions.

2. Material and methods

2.1. Site descriptions

From 2010 to 2013, field-scale strawberry production experiments were conducted at four commercial sites that were chosen to cover a wide range of soil properties and climatic conditions. The site locations, soil types, climatic conditions and cultural practices are provided in Table 1. Generally, the experimental sites can be classified into two main groups. Group A includes Sites 1 and 2, which are located near Quebec City (Qc, Can) in an area with a humid continental (Dfb) climate where the growing season is short and generally rainy. The historical mean water budget (Precipitation – ETc) of the area is positive during the growing season, but the use of polyethylene mulches make supplemental irrigation necessary, especially in July and August. At these sites, irrigation water is provided by private reservoirs that are filled by snowmelt and rainwater. Thus, the irrigation water is free and usually available in sufficient volumes throughout the growing season. The day neutral "Seascape" cultivar was planted in mid-May and harvested from mid-July to early October, with a production peak in September. Group A sites were located near each other and their soils were very similar. However, Site 1 was a former pasture where strawberries were grown for the first time, and Site 2 had been cultivated in rotation with strawberries, sweet potatoes and oats for many years. Thus, the soil from Site 1 was expected to have hydraulic properties and nutrient element contents that were more favorable for plant growth than Site 2.

Group B includes Sites 3 and 4, which are located near Oxnard and Watsonville in the southern and northern parts of California (USA), respectively. Both areas have Mediterranean or dry subtropical (Cs) climates. At Site 3, a commercial short-day cultivar was planted in October and produced from February to June. At Site 4, locally developed commercial day neutral cultivars were planted in November, were slowly established during the winter, and produced berries from April to mid-October. Both of these sites were near the Pacific Ocean and were characterized by foggy mornings and clear afternoons. Furthermore, most of the precipitation in this region occurred between December and mid-March. Consequently, most of the production period was rain free.

2.2. Experimental setup

At each site, a typical management zone (i.e. a zone that was irrigated independently from the rest of the farm) was selected as the experimental area. That zone was divided in 3–7 blocs where two