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A Leaf Monitoring System for Continuous Measurement of Plant Water Status to Assist in Precision Irrigation in Grape and Almond crops

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Abstract: Measurement of plant water status (PWS) provides the key information necessary to implement efficient irrigation management schemes in almond orchards and vineyards. A continuous leaf monitoring system based on leaf temperature and relevant microclimatic variables is currently available to obtain PWS. These systems can be installed after careful analysis of how soil and plant characteristics are distributed throughout the field to implement site-specific irrigation. Crop water stress index (CWSI) or modified water stress index (MCWSI) values are usually computed with leaf monitor data, which requires a knowledge of well-watered and fully stressed conditions. Although these values can be estimated by assuming that trees reach saturation after each irrigation event, this is not the case when deficit irrigation is implemented. We proposed a new methodology to compute CWSI and MCWSI using the continuous leaf monitor data, where the well-watered and dry conditions were measured using a well-watered tree and a simulated dry leaf. The objectives of this work were: (1) to implement a plant water stress based site-specific irrigation management scheme in an almond orchard and (2) to assess PWS of grapes and almond trees by comparing MCWSI and CWSI with deficit stem water potential (DSWP). A wireless network was used in each study site to interface the leaf monitors, soil and pressure sensors, as well as latching solenoid valves. Two management zones were created using unsupervised fuzzy classification based on soil and plant characteristics in the almond orchard. In each management zone two treatments were implemented: grower and stress based. Leaf monitors were tested in grapes by measuring PWS in eight vines, where four of them corresponded to vines that were not being watered following full irrigation to experience increasing amount of stress and four other vines corresponded to vines that were watered daily after a long period of stress to recover from stress. In grapes, MCWSI and DSWP were found to be linearly related with a coefficient of determination value of 0.70. In almonds, CWSI and DSWP were found to be strongly correlated with a second order relationship and a coefficient of determination value of 0.78. Additionally, preliminary results indicated that the management zones #1 and #2 of the almond orchard required approximately 70% and 90%, respectively, of the water used in grower based irrigation.

Keywords: Leaf monitor, precision irrigation, stem water potential, crop water stress index, plant water status, management zones.

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1. INTRODUCTION

Current drought conditions in California and worldwide have led to intensified efforts to develop irrigation practices which increase water use efficiency of agricultural crops (Jones, 2004). Interest has arisen in the development of technologies that facilite the use of regulated deficit irrigation, which aims to find the right threshold to reduce irrigation requirements while maintaining most of the crop productivity (Fereres, E. and Soriano, M. A., 2007). Deficit irrigation has also demonstrated beneficial effects (in addition to water saving); for instance, it is well known that regulated deficit irrigation can increase the yield quality of grape crop if imposed for the correct period of time and if the stress is maintained within proper thresholds (Leeuwen et al., 2009). The success of implementing strategies based on deficit irrigation will most probably depend on how well researchers are able to assess the crop sensitivity to drought stress and on how accurately they can define thresholds to maintain the stress within bounds which do not significantly affect the production. In practice, its success will also depend on how easily growers can evaluate plant water status (PWS) in their fields, and if this information is available when needed. Currently, many irrigation scheduling practices are based on soil water balances, either by estimating the crop evapotranspiration (i.e. water removed from the soil by the plants) or by measuring soil water status. However, methods based on soil water balances do not directly relate to plant water stresses (McCutchan and Shackel, 1992) due to the ability of plants to develop strategies to avoid or tolerate stress (Levitt, 1980). Therefore, soil water balance techniques do not provide the information needed to implement deficit irrigation strategies. Plant based measurements, on the other hand, have demonstrated themselves to be an interesting alternative for irrigation scheduling, as they provide an integrated view of the plant-soil continuum (Dhillon et. al., 2014b) and as such are more suitable for developing deficit irrigation practices.

The PWS expressed as leaf or stem water potential (SWP) can be measured directly using a pressure chamber (Boyer, 1967) or obtained indirectly by measuring some plant response to the water stress, such as stomata closure (Jones, 2004, Dhillon et. al., 2014b). However, values of SWP have also been found to be sensitive to environmental conditions, and therefore baselines have been proposed to account for the effect of the vapour pressure deficit (VPD) (McCutchan and Shackel, 1992; Lampinen et al., 2001). Baselines can be used to compute deficit stem water potential (DSWP) which is the difference between SWP and its corresponding baseline value computed using the VPD of that particular day. Even though the pressure chamber is currently considered the standard method to measure PWS, it has not been widely adopted for scheduling purposes. This is mainly because measurements are very labour intensive and time consuming, making it impossible to obtain the large number of samples necessary to develop precision irrigation scheduling techniques.

Leaf temperature has been recognized to have the potential to assess the severity of plant water stress (Jackson et. al., 1982; Idse, 1982; Dhillon et. al., 2014b), as it is influenced by stomata closure, a well know physiological response to plant water stress. When plants are well hydrated, the stomata open and transpiration occurs; this has the effect of cooling the leaves. As water stress develops, the stomata close, transpiration stops and leaf temperatures tend to equilibrate with the air temperature (Jackson et. al., 1982). However, it has also been found that leaf temperature depends on VPD (McCutchan and Shackel, 1992) and light exposure, the latter having a strong effect on stomata closure (Assmann et. al., 1985). The contribution of these microclimatic variables have been investigated by Dhillon et. al. (2014a), who related leaf temperature to plant water stress, VPD, wind speed and photosynthetic active radiation levels. All these parameters were found to contribute significantly to multiple linear regression models developed for almond, walnut and grape crops. However, they observed a drift in the model calibration as the season progressed. To address this issue, a continuous leaf monitoring system was developed by Dhillon et al. (2014b), where plant water stress was obtained based on leaf temperature and relevant microclimatic variables (i.e. ambient temperature, relative humidity, photosynthetically active radiation (PAR) and wind speed) in real-time.

Temperature differences between air and leaf, and leaf temperature alone can be analyzed to determine a crop water stress index (CWSI) or a modified crop water stress index (MCWSI), respectively, that appear to be correlated to PWS in almond and walnut crops (Dhillon et al., 2014b). These indices require knowledge of temperature differences or of leaf temperature for a tree under fully stressed (i.e. stomata completely closed) and fully saturated (i.e. stomata completely open) conditions. Dhillon et al. (2014b) estimated the fully saturated condition assuming plants reach saturation one day after irrigation. However, this may be not true when deficit irrigation strategies are employed. Therefore, there is a need to improve these techniques to account for such conditions.

Current wireless network technologies allows proximal plant-based sensors, such as psychrometers, dendrometers or leaf monitors, to provide continuous real-time PWS information that can be transmitted though the internet or cellular networks. Growers can use this information to schedule their irrigation and remotly provide the amount of water needed without the need to perfom labour intensive data collection in the field. However, sensors that aim to measure PWS have shown differences in their perfomances and in their ability to maintain their accuracy for a prolonged period of time. Proximal-based sensors provide discrete information which requires extrapolation to represent a particular irrigation zone (Golhamer et. al., 1999). Representative values for a zone can be obtained by sampling methods, where the number of sensors needed in each zone can be computed by considering the variance of the PWS in that zone. An approach commonly used in precision agriculture is to separate the field into management zones (MZ), which are sections of the field that possess relatively homogeneous attributes (Schepers et. al., 2004). Different criteria have been used to determine an optimal delineation of the MZ; examples of variables used for these purposes include topography, aerial images, soil texture, electrical conductivities and yield (Kravchenko and Bullock, 2000; Mzuko et. al., 2005). Several of these studies