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Using plant water status to define threshold values for irrigation management of vegetable crops using soil moisture sensors

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ABSTRACT

Thresholds of soil matric potential (SMP) and available soil water content (AWC) required to prevent water limitations between irrigations were determined for bell pepper, melon, and spring and winter tomato grown in Mediterranean-type greenhouses on the south-eastern coast of Spain. Thresholds were identified by measuring the divergence of leaf water potential of un-watered plants from that of well-watered plants. Soil matric potential thresholds were −58 kPa for pepper, −35 kPa for melon, and −38 to −58 kPa for tomato. In general, SMP thresholds were more negative under lower evaporative demand conditions such as during autumn and winter months. Available soil water content thresholds, for a given crop and drying cycle, differed appreciably depending on soil depth and the method used to calculate the values. For the four crops studied, AWC thresholds calculated at 0–40 cm were 13–15% higher than those calculated at 0–20 cm. Each AWC threshold for 0–20 cm depth was 21–29% lower when AWC was based on laboratory rather than field determinations of field capacity and permanent wilting point. For a given method of calculating AWC, AWC threshold values were similar for different crops and drying cycles, suggesting limited sensitivity of the AWC approach. Using the manufacturer's calibration, the capacitance sensor used for SWC measurements overestimated SWC by an average of 36%. An in situ calibration provided generally good agreement with the actual SWC between 0.15 and 0.22 $cm^3 cm^{-3}$; however, for higher SWC values, the in situ calibration underestimated SWC. The results of this study demonstrated the uncertainty of using recommended fixed AWC threshold values for irrigation management, using SWC sensors, because of issues related to the definition of rooting depth, measurement of FC and PWP, sensor calibration, and sensor accuracy across the relevant range of water contents. These data suggest that SMP thresholds are much more reliable than AWC thresholds for scheduling irrigations in greenhouse-grown vegetable crops. Technical issues regarding on-farm measurement of SMP and SWC are discussed.

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1. Introduction

Intensive vegetable production systems are commonly located in warm climatic regions, such as the Mediterranean coast, because growing conditions are favourable for numerous vegetable species. Irrigation is required to ensure a continuously adequate water supply. These regions commonly have limited fresh water resources, and experience increasing competition for limited water resources from tourism and housing development. Many fresh water resources have been degraded by agricultural activity, through over-exploitation, contamination with nutrients and salinisation (Gardner, 1993; Fereres et al., 2003). Consequently, there is considerable pressure on vegetable growers, in these regions, to optimise their use of irrigation water because of limited availability and to minimise adverse effects on local fresh water resources.

The greenhouse-based vegetable production system located along the south-eastern Spanish Mediterranean coast, consisting of more than 37,000 ha of greenhouses (Castilla and Hernández, 2005), with 27,000 ha in the province of Almería alone (Castilla and Hernández, 2005), provides an example of the previously-mentioned issues. Currently, 80% of cropping is conducted in soil, and drip irrigation is used on all farms (Pérez-Parra and Céspedes, 2001). Most irrigation water is obtained from over-exploited local aquifers (ITGME, 1991). Other impacts on the local aquifer system include contamination with nitrate and pesticides, a rapidly rising water level in a superficial aquifer, salinisation and saltwater intrusion (Pulido-Bosch et al., 1997, 2000; Pulido-Bosch, 2005). Three of the major crops in this horticultural system are fresh market tomato, bell pepper and melon. Tomato and pepper are transplanted in summer/early autumn and grown through autumn and winter, with tomato sometimes continuing until early summer. Tomato and melon are grown as spring/summer crops.

Irrigation scheduling is generally based on experience (Fereres, 1996; Fereres et al., 2003), and it is generally accepted that farmers and vegetable growers over-irrigate to ensure that water is not limiting production. The scientifically based irrigation scheduling methods most suitable for vegetable production are the FAO method of estimating crop water requirements (Allen et al., 1998) and soil moisture sensors. Given the variable nature of vegetable production through differences in farm management, crop varieties and soil type, the FAO method can be considered as providing general guidelines. Soil moisture sensors potentially provide the means to irrigate in accordance with the unique characteristics of a given crop in a given field. These sensors can be used as a ‘‘stand-alone’’ method, or their use can be combined with the FAO method, or they can be used to complement irrigation management based on experience.

Soil moisture sensors measure either soil water matric potential (SMP) or volumetric soil water content (SWC). While tensiometers are probably the most commonly used SMP sensor on commercial farms, granular matrix sensors are widely available and have a number of favourable technical characteristics for on-farm use (Thompson et al., 2006). A variety of dielectric sensors, using time domain reflectometry (TDR) (Ferré and Topp, 2002) or capacitance (also referred to as frequency domain reflectometry or FDR) technologies (Starr and Paltineanu, 2002; Fares and Polyakov, 2006), are available for on-farm measurement of SWC (SOWACS, 2002); with multiple depth capacitance sensors (Paltineanu and Starr, 1997; Fares and Polyakov, 2006) probably being the most widely used for on-farm applications. Tensiometers, granular matrix sensors and capacitance sensors can be read manually or logged continuously, and can be used to automatically control irrigation systems. Critical to the use of both SMP and SWC soil moisture sensors is the threshold or lower limit value, which indicates the degree to which soil can dry before irrigation is required. Generally, threshold values are selected that ensure that crops do not experience water stress or a loss in production.

In practice, threshold SMP values are commonly recommended by Extension services, consultants or suppliers. Recommended SMP values appear to be based on experience and on a limited number of published scientific studies. Most published SMP threshold values for vegetable species are from agronomic studies comparing yields from treatments with different threshold SMP values (e.g. Bower et al., 1975; Smajstrla and Locascio, 1996). Most of these studies have been conducted with open field crops, and, for a given species, show a wide range of threshold SMP values, suggesting that site-specific factors were influential. For fresh tomato, reported SMP threshold values are −10 kPa in a fine sandy soil (Smajstrla and Locascio, 1996), −20 kPa in a clay loam soil (Bower et al., 1975), −30 kPa for loamy soils (Wang et al., 2005), and −60 to −150 kPa (Taylor, 1965; Hanson et al., 2000a). For pepper, reported SMP threshold values are −25 kPa (Smittle et al., 1994; Beese et al., 1982), −45 to −65 kPa (Hedge, 1988) and −100 kPa (Tedeschi and Zerbi, 1984). For melon, reported SMP threshold values are −35 to −40 kPa (Taylor, 1965; Hanson et al., 2000a) and −50 to −75 kPa (Pew and Gardner, 1983).

For SWC sensors, the concept of available soil water content (AWC) provides a practical framework for using SWC data for irrigation management. Threshold values of AWC (AWC_t) have been estimated for many species and are listed in the relevant FAO manuals as allowable depletion factors ($100 - AWC_t$) (Doorenbos and Kassam, 1979; Allen et al., 1998). Recommended FAO threshold values for AWC are: 70% for bell pepper and 60% for tomato and melon under conditions of medium evaporative demand (Allen et al., 1998), with a reduction of 20% of AWC for conditions of low evaporative demand.

Published AWC threshold values, from agronomic studies, for tomato, pepper and melon are generally higher than the FAO recommendations; Hartz (1993) reported values >80% for tomato, Jaimez et al. (1999) values of 68–80% for pepper, and Pellitero et al. (1993) values of 85–90% for processing pepper. Several authors (Sadras and Milroy, 1996; Sinclair et al., 1998; Girona et al., 2002) have commented upon the uncertainty of using fixed threshold values of AWC for irrigation scheduling or modelling studies; because for a given species, many factors such as soil characteristics, evaporative demand, or root distribution can affect AWC threshold values.

Identification of threshold values of soil moisture for irrigation management, either as SMP or AWC, using plant water status ensures the maintenance of soil moisture conditions that avoid physiological stress. This approach is likely to be more sensitive than assessing differences in production. To achieve statistically significant effects on yield in field studies, it is likely that the stresses would need to be