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A novel dielectric tensiometer enabling precision PID-based irrigation control of polytunnel-grown strawberries in coir

Martin S. Goodchild [a,*], *Malcolm D. Jenkins* [a], *William R. Whalley* [b], *Chris W. Watts* [b]

[a] *Delta-T Devices Ltd., 130 Low Road, Burwell, Cambridge, CB25 0EJ, UK*
[b] *Rothamsted Research, West Common, Harpenden, St Albans, AL5 2JQ, UK*

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The benefits of closed-loop irrigation control have been demonstrated in grower trials which show the potential for improved crop yields and resource usage. Managing water use, by controlling irrigation in response to soil or substrate moisture changes, to meet crop water demands is a popular approach but requires substrate specific moisture sensor calibrations and knowledge of the moisture levels that result in water deficit or overwatering. The use of water tension sensors removes the need for substrate specific calibration and enables a more direct relationship with hydraulic conductivity. In this paper, we present a novel dielectric tensiometer that has been designed specifically for use in soil-free substrates such as coir, peat and Rockwool with a water tension measurement range of −0.7 kPa to −2.5 kPa. This new sensor design has also been integrated with a precision PID-based (drip) irrigation controller in a small-scale coir substrate strawberry growing trial: 32 strawberry plants in 4 coir growbags under a polytunnel. The data illustrates that excellent regulation of water tension in coir can be achieved which delivers robust and precise irrigation control - matching water delivery to the demands of the plants. During a 30-day growing period vapour pressure deficit (VPD) and daily water use data was collected and the irrigation controller set to maintain coir water tension at the following levels: −0.90 kPa, −0.95 kPa and −1 kPa for at least 7 consecutive days at each level. For each set-point the coir water tension was maintained by the irrigation controller to within ±0.05 kPa. Meanwhile the polytunnel VPD varied diurnally from 0 to a maximum of 5 kPa over the trial period. Furthermore, the combination of the dielectric tensiometer and the method of PID-based irrigation control resulted in a linear relationship between daily average VPD and daily water use over 10 days during the cropping period.

* *Corresponding author.*
E-mail address: martin.goodchild@delta-t.co.uk (M.S. Goodchild).

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1. Introduction

Sensors that use the dielectric properties of moist soil to measure soil water content are now widely available and, in many cases, have replaced the neutron probe as the instrument of first choice. This is largely due to safety considerations and the ease of logging offered by modern dielectric sensors. The most effective approaches to soil management, however, require measurement of the matric potential of soil water. Advances in technology to measure matric potential have been modest compared with those for soil water content.

Matric potential can be measured directly in a water reservoir that is connected hydraulically to the soil by a porous filter. In order to yield reliable results, both reservoir and porous filter must remain saturated throughout the period of measurement. To this end, devices that employ this technique (water-filled tensiometers) are typically fitted with ceramic filters with small air entry potentials in order to prevent desaturation when subjected to negative potentials. However, conventional water-filled tensiometers typically only work over the limited range of 0 to −85 kPa and require regular maintenance if long-term measurements are required (Whalley et al., 2009). Recent research into saturation techniques and tensiometer design has led to the development of a new class of high capacity tensiometer in which the magnitude of measurable suction is limited only to the air entry potential of the porous ceramic filter and the tensile strength of water (e.g. Take & Bolton, 2003). Although these devices can work successfully down to matric potentials as small as −2 MPa, their widespread use has been limited by the present lack of a commercially-available device and by the technical experience needed for the saturation and measurement processes.

The limited range of conventional water-filled tensiometers has led to the development of a second strategy for the measurement of matric potential, the porous-matrix sensor (e.g. Or & Wraith, 1999; Whalley et al., 2001). In contrast to the direct measurement of matric potential, the porous ceramic is chosen so that it will readily alter its degree of saturation to maintain equilibrium with the soil water. If the water retention characteristic of the porous matrix is known, measurement of the water content of the ceramic will allow the matric potential of the soil water to be estimated indirectly. Originally, these sensors used plaster of Paris as the porous matrix and electrical resistance measurements of matrix were calibrated against matric potential (Bourget, Elrick, & Tanner, 1958). Such sensors are now commercially-available and are best suited to dry soils (matric potential < −500 kPa), where they work well because hysteresis in the sensor is small at these matric potentials. Recently, they have been modified by increasing the pore size of the porous matrix, to obtain a sensor that will work at matric potentials between 0 and −200 kPa. However, there is a requirement, especially in horticulture to measure very high matric potentials (0 to −10 kPa), especially when controlling irrigation in horticultural substrates.

Closed-loop irrigation control employing soil moisture sensors has been demonstrated in grower trials which show the potential for improved crop yields and resource usage. Managing water use by controlling irrigation in response to changes in soil moisture conditions to meet crop water demands is a popular approach but requires knowledge of closed-loop control practice, substrate specific sensor calibrations and the water status limits that result in water-deficit or excessive run-off.

A key benefit of employing water tension (matric potential) measurements instead of soil moisture measurements is that a substrate specific sensor calibration is not required. However, whilst sensor based irrigation control has been performed in soil with soil moisture and tensiometer based measurements (Muñoz-Carpena, Bryan, Klassen, & Dukes, 2003; Whalley et al., 2009) the lack of suitable water tension sensors has made similar studies in soil-free substrates difficult. Furthermore, in the literature (Michel, 2010; Raviv, Lieth, Burger, & Wallach, 2001) such a sensor may have useful application in a wide range of soil-free substrates whilst also providing better management of hydraulic conductivity, a substrate property that can decrease sharply with water content (Raviv et al., 2001).

In this paper, we present a robust dielectric tensiometer designed for use in soil-free substrates where: the optimal substrate water tension that avoids plant water-deficit and over-watering conditions may be in the range of −0.7 kPa to −2.5 kPa and does not require the degassed water filling process of a water-filled tensiometer. In this respect, our paper describes a novel development because previous accounts of dielectric tensiometers have been concerned with dry soil at low matric potentials (e.g. Whalley et al., 2009). To calibrate sensors at very high matric potentials (e.g. −0.7 kPa to −2.5 kPa) we used a manometer based calibration. The application of the dielectric tensiometer described in this work is concerned with the control of irrigation in strawberry production. Matric potential data from the dielectric tensiometer was used in a PID irrigation controller (Goodchild, Kühn, Jenkins, Burek, & Dutton, 2015). This PID irrigation control system was evaluated in a small-scale growing trial using a coir substrate and has demonstrated that water tension can be maintained by precisely regulating the water flow under varying vapour pressure deficit (VPD) conditions. The context of this work is the need to reduce water use. Our paper describes a novel sensor optimised to control water status of coir, or similar growth substrates, in near-saturated conditions. The exemplar application in strawberry production illustrates that developments we describe may help industry reduce water consumption.

2. Materials and methods

2.1. *Description of the dielectric tensiometer*

The operation of a dielectric tensiometer takes advantage of the relatively high dielectric constant of water with respect to that of a porous substrate. The change in dielectric constant between a dry porous material and a water saturated porous material can be measured with appropriate electronics circuitry. This dielectric tensiometer is based on patented soil moisture measurement technology (Lock, 2011).

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