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Irrigation Scheduling of Drip-Irrigated Vegetable Crops Grown in Greenhouses Using Continuous Soil Moisture Monitoring

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Abstract

Continuous monitoring of volumetric soil water content (VSWC) has considerable potential for irrigation management (IM). Dynamic protocols were developed for IM of drip-irrigated vegetable crops grown in soil, in greenhouses using the EnviroSCAN system (ES). Melon, tomato and pepper were grown sequentially. The manufacturer's recommended protocols ("Sentek protocols") were applied to melon, using a single ES probe located close to the plant and dripper (position 1), with four sensors at different depths. The upper limit was defined by vertical drainage at depth, and the lower limit by reduced/slowed crop water uptake when irrigation was withheld. The imposition of water stress on the extremely fast-growing melon crop (crop height increased from 0.7 to 3.7 m, in 6 weeks) was considered potentially deleterious. Additionally, because of rapid plant and root growth, a series of potentially deleterious water stresses would be required to re-define the lower limit. In tomato, the Sentek protocol for the upper limit was unsuitable. Compared to IM with manual tensiometers, soil matric potentials (10 cm depth, 8 a.m measurement before possible irrigation) were consistently appreciably higher, –7 to –12 kPa compared to –14 to –20 kPa. In 3.5 months after transplanting, cumulative irrigation was 179 and 123 mm, respectively, for the ES and tensiometer-managed treatments. The high bulk density of 1.8 g cm^{-3} at 10–20 cm soil depth, arising from constant foot traffic on moist soil, presumably impeded vertical drainage and promoted horizontal movement. In pepper, an additional ES probe was installed in an "edge of bulb" (EOB) position. The upper limit was defined by vertical drainage at depth (position 1) or horizontal movement (accumulation at EOB), and the lower limit by uptake at depth or reductions at the EOB position. Compared to a tensiometer-managed treatment, total irrigation applied, fruit production and soil matric potential (10 cm depth) were very similar. These protocols are suggested for this and similar horticultural systems. A large reduction in soil salinity affected the calibration of the ES.

INTRODUCTION

Continuous soil moisture monitoring (CSSM) has considerable potential for irrigation management (IM), because it enables irrigation to be "tailored" to the requirements of individual crops and the characteristics of individual cropping locations, and it can be used to automatically control irrigation.

The use of soil moisture sensors for IM is based on maintaining soil moisture within defined upper and lower limits. For soil matric potential sensors (SMP; most commonly, tensiometers), a “static” approach is used, in which previously defined numerical values of upper and lower limits are generally applied. However, for volumetric soil water content (VSWC), the conventional “static” approach of using pre-defined general limits is unsuitable. Due to differences in soil texture and organic matter content, VSWC can differ appreciably between locations despite having equal SMP values. The use of absolute values requires accurate calibration of indirect measurement of VSWC content (e.g. capacitance or TDR sensors). “Dynamic” approaches, where limits are defined *in-situ* for individual crops and locations, and where accurate calibrations are not critical, are well suited for the definition of limits of VSWC.

A fundamental consideration with the use of soil moisture sensors for IM is that the configuration and location of the sensors must provide sufficient information to define the limits, and to effectively manage irrigation. Given the substantial heterogeneity of soil moisture with drip irrigation, sensor configuration and location are fundamental issues with respect to the application of CSMM to IM. The protocols used for applying CSMM to IM can be considered as a package that includes the configuration and location of the sensors, in addition to the protocols for defining upper and lower limits.

The context of this work was the greenhouse-based, intensive vegetable production system located along the Spanish Mediterranean coast. Eighty percent of cropping is in soil, the rest in hydroponics. Drip irrigation (above-ground tape) is used. Commonly, two crops are grown per cropping year, an autumn-winter crop (e.g. tomato, pepper) followed by a spring-summer crop (e.g. melon).

This work developed “dynamic” protocols for the use of continuous monitoring of VSWC for IM in this horticultural system. The EnviroSCAN system (Sentek Sensor Technologies Ltd., Australia) was used. The manufacturer of the EnviroSCAN has developed “dynamic” protocols (see “EnviroSCAN Training Manual”, Sentek Sensor Technologies Ltd., Australia) for applying the EnviroSCAN to IM. These protocols essentially consist of defining (a) the upper limit by preventing or reducing drainage, and (b) the lower limit by selecting a value above which crop water uptake is reduced. These limits are applied to the volumetric soil water content (measured in mm) in a given depth of soil. In this work, these protocols were adapted for application to the greenhouse-based, intensive vegetable production system of the Spanish Mediterranean coast. The issues raised in this work and the protocols developed will have relevance to other drip-irrigated, vegetable production systems.

MATERIALS AND METHODS

Three successive crops (melon, tomato and pepper; Table) were grown in a (28 by 23 m) plastic greenhouse at the “Las Palmerillas" research station in El Ejido, Almeria province, Spain. The crops were transplanted as 8 week old seedlings. The soil was 20 cm of imported silty-loam soil over the natural soil (loam texture, moderate stone content), with 10 cm of coarse sand mulch placed over the imported soil. This artificial soil system is widely used in the region. It was formed in this greenhouse in 1985. All soil depths are expressed relative to the surface of the imported silty-loam soil.

For comparing irrigation treatments, there were three separate irrigation sectors, each formed from four randomly selected plots (10 by 4.5 m). Adjoining plots were separated by plastic sheeting to 30 cm depth. The aboveground drip irrigation system had 50 cm linear spacing between drippers and 1.5 m between laterals (3 laterals per plot).

The melon and tomato crops were grown with one plant per dripper (6–8 cm separation). The pepper was grown with one plant either side of the dripper (20 cm separation).

The EnviroSCAN (ES) capacitance sensor system (Sentek Sensor Technologies Ltd., Australia; Paltineanu and Starr, 1997) was used to continuously monitor volumetric soil moisture. Each probe, consisted of sensors centrally located at depths of 5, 15, 25, and 35 cm, and was placed vertically within a 5.7 cm outside dia. PVC access tube. On account of the stone content of the natural soil, the ES access tubes were installed using the soil slurry technique. In the melon and tomato crops, one ES probe was installed in each plot; in the pepper, there were two probes in each plot. The probes in melon and tomato, and one of the two probes in each plot in pepper were installed relatively close to the dripper and the plant where maximum root activity was considered to occur (Position 1), this was 8 cm to the side of the dripper and plant, the distance from the drip-line was 6–8 cm in melon and tomato, and 14 cm in pepper. In pepper, an additional ES probe was installed, in each plot, in an "edge of bulb" position (Position 2), 24 cm from the drip-line, and 8 cm to the side of the plant and dripper.

Given the 10 cm axial depth measured by each EnviroSCAN sensor (Paltineanu and Starr, 1997), the soil depths measured were 0-10, 10-20, 20-30, and 30-40 cm. In this work, the upper and lower limits, for irrigation management were developed for the 20 cm layer of imported silty-loam soil (0–20 cm soil depth), using the 5 and 15 cm deep sensors, for the melon and tomato. For the pepper crop, IM was based on limits established for the 0–30 cm soil depth.

In all crops, one irrigation treatment was managed with the ES, using the subsequently described protocols, and another with manual tensiometers (10–30 kPa), which being an established method was used as a reference. In all plots, soil matric potential (SMP) was measured daily with manual tensiometers (Irrometer Co., USA), and soil solution electrical conductivity in samples obtained using soil solution suction samplers once every 2 weeks. In melon and tomato, the manual tensiometers were read at 8 a.m., immediately prior to any irrigation. In the pepper crop, electro-tensiometers with pressure transducers for continuous monitoring (Skye Instruments, UK) were installed at 10 cm depth. Manual tensiometers, soil solution suction samplers and electro-tensiometers were installed at 10 cm depth, in Position 1, as described for the ES. Crop height was measured every 1–2 weeks. Total biomass, fruit production and volume of irrigation were measured. All data are means of 4 replicates. During the trials, protocols for irrigation management using the EnviroSCAN were progressively developed.

RESULTS AND DISCUSSION

Melon

The Sentek protocol for defining the lower limit requires the imposition of water stress to identify a limit. Correspondingly, irrigation was withheld from the melon from 19 to 22 April 2000, corresponding to 46–49 DDT (days after transplanting). A feature of melon crops in greenhouses in southern Spain, growing under spring-summer conditions, is extremely rapid vegetative growth. Crop height increased from 0.7 to 3.7 m between 32 and 74 DDT; in the 3 weeks after imposing the stress, crop height increased by 1.6m. Imposing a detectable stress on a very rapidly growing crop may result in reduced growth and production. Data did not demonstrate a deleterious effect. Commercial fruit production and total biomass production were, respectively, 12 and 9% less than in the tensiometer treatment; however, these differences were not statistically significant ($P<0.05$; ANOVA). There were no clearly discernible trends or differences to demonstrate that crop height was affected by the imposed stress.

Although no data demonstrated a negative effect on crop growth and production, imposing an appreciable stress during very rapid growth carries a risk of doing so. Additionally, during rapid crop growth, it is likely that lower limits of soil moisture will change due to larger transpiration capacity, higher root density, deeper roots etc. To define and then re-define lower limits for rapidly growing crops would require imposing two or more successive stresses, which would increase the risk of deleterious affects on overall crop growth and production. For very fast-growing crops grown in the spring-summer period in greenhouses in southern Spain, imposing water stress is an unsatisfactory method for identifying lower limits. To develop generic methods for this agricultural system, an alternative method is required. Data collected during the final period of the melon crop suggested that crop water uptake at depth occurred when soil water began to be limiting (data not presented). Uptake at depth was subsequently regarded as an indicator that soil moisture was limiting.

Tomato

For IM of the tomato crop using CSMM, a simplified system for identifying limits based on tendencies in volumetric soil water content at the lowest soil depth (30-40 cm) was adopted. The objective was to develop protocols that avoided stressing crops and that were relatively simple in order to assist in future adoption by commercial farmers. Increases in soil moisture at 30–40 cm depth were regarded as indicating vertical drainage, and were used to define the upper limit. Reductions in soil moisture at 30–40 cm depth were regarded as indicating that insufficient moisture was available in the upper part of the profile, and were used to define the lower limit. Essentially, IM was based on maintaining the moisture content at 30–40 cm depth as a horizontal line. The limits were applied to the volumetric soil water content (in mm) in the 0–20 cm soil depth.

During the period 16 October 2000 to 22 December 2000, the volumetric soil water content of the CSMM managed treatment at a soil depth of 30–40 cm remained relatively constant (Fig. 1). However, the 8 a.m. soil matric potential (SMP) at 10 cm depth (recorded before possible irrigations) was consistently high, generally being within the range of –7 to –12 kPa (Fig. 2). The equivalent SMP values from the tensiometer managed treatment were clearly drier, being mostly within the range –14 to –20 kPa (Fig.2). Considerably much more irrigation was applied to the CSMM managed treatment, the accumulated volumes of water applied from transplanting on 7 September until 22 December 2000 were, respectively, 179 and 123 mm for the CSMM and tensiometer managed treatments.

The SMP and irrigation volume data indicate that irrigation in the CSMM managed treatment was considerably in excess of crop requirements. The volumetric soil water data for 30–40 cm suggest that the upper limit used may have been slightly too high (Fig. 1). Compared to the tensiometer-managed treatment, the smaller reduction during the period to 10 November, as the soil slurry between the access tube and surrounding soil dried, and the slight increase from 22 November to 3 December were indications of minor vertical drainage. Nevertheless, volumetric soil water content at the 30–40 cm soil depth, from the CSMM treatment, was constant during the periods 8–21 November and

10–22 December, demonstrating that no vertical occurred during these periods despite the high SMP values observed at 10 cm depth.

The explanation for the lack of vertical drainage despite high SMP at 10 cm, and the excessive irrigation volume, appeared to be that the high bulk density of the soil, 1.6 g cm^{-3} for 0–10 cm and 1.8 g cm^{-3} for 10–20 cm, impeded the downward movement of irrigation water and that appreciable horizontal movement was also occurring. The high bulk densities are a consequence of the (i) the moderately high clay content of the silty loam soil, (ii) the constantly high soil moisture content – high-frequency drip irrigation maintains the soil at close to Field Capacity for much of the year, and (iii) the constant foot traffic associated with regular manual pruning, sequential manual harvesting, manual applications of various treatments. These three factors are general characteristics of this agricultural system.

Consequently, the protocols being developed for the use of CSMM for IM, in this agricultural system, were subsequently modified to consider horizontal movement of soil water on account of soil compaction.

Pepper

The upper limit for the pepper crop was based on minimising both vertical drainage at 30–40 cm depth and horizontal soil water movement as detected at 0–20 cm depth at the edge of bulb position. The lower limit was based on minimising crop water uptake from the 30–40 cm depth and on preventing prolonged reductions at 0–20 cm depth at the edge of bulb position. The limits, as applied to the 0–30 cm depth at Position 1, for the period 4 Sep. to 11 Nov. 2001 are indicated on Fig 3a.

Soil matric potential (SMP) as measured with electro-tensiometers indicated that adequate soil moisture conditions for optimal crop growth were generally maintained in the zone of maximum root concentration during the period 4 Sep. to 8 Nov. 2001 (Fig. 4). Until 8 Nov., daily mean SMP was generally within –12 to –22 kPa, daily maximum SMP values were generally –7 to -12 kP, and daily minimum SMP values were generally –17 to -40 kPa. The SMP data suggest that irrigation was excessive after 8 Nov. and also during the periods 11–18 Oct. Total commercial fruit production and water use were similar from the CSMM and tensiometer managed irrigation treatments. For the CSMM and tensiometer managed irrigation treatments, fruit production was, respectively, 6.3 and 6.7 kg m^{-2} (difference not statistically significant; $P<0.05$, ANOVA), and the total volumes of irrigation water applied were, respectively, 293 and 294 mm.

Downward or upward trends in VSWC at 0–20 cm at the edge of bulb position (Fig. 3b) and at 30–40 cm at the ES probe closer to the dripper (Fig. 3c), were indicative of insufficient or excessive irrigations, subsequent corrective measures or of technical problems. The reduction at 0–20 cm at position 2 during 7–12 Sep and during 22–26 Sep were, respectively due to a blocked filter and under irrigation. The increases observed at both 30–40 cm at position 1, and 0–20 cm at position 2, on 3 Oct. and 9–13 Oct. were, respectively due to a programming error (double irrigation) and over-irrigation. Irrigation was maintained within the defined limits, for 0–30 cm at position 1, during the period 17 Oct. to 8 Nov. (Fig. 3a), as reflected in the stable VSWC's measured at 0–20 cm at position 2 (Fig. 3b) and 30–40 cm at position 1 (Fig. 3c). The large apparent reduction in VSWC at 0–30 cm at Position 1 after 8 Nov. (Fig. 3a) occurred despite an increase in SMP at 10 cm (Fig. 4) and vertical drainage at Position 1 (Fig. 3c). This reduction is clearly an artefact, which was apparently due to the ES calibration being influenced by the large reduction in soil electrical conductivity that occurred at this time (Fig. 5).

General

The dynamic protocols developed for the use of continuous monitoring of volumetric soil moisture content for irrigation management were effective in the pepper crop. The use of these protocols enabled the identification and correction of over-irrigation, under-irrigation, technical problems and programming errors. These protocols were able to deal with two issues that were considered to limit the generic use of the Sentek protocols in this agricultural system: the very rapid growth of melon crops in the spring-summer period, and the restrictive effect of soil compaction on vertical drainage. Although these protocols were developed using the EnviroSCAN sensor system, they are applicable to any sensor system that measures volumetric soil water content and provides continuous data on various depths of soil.

Whilst developed for an individual cropping system, these protocols have sufficient versatility to be widely applicable to most high frequency drip-irrigated vegetable cropping systems. They can be considered as providing a detailed and dynamic two-dimensional image of soil water dynamics as opposed to a single point measurement (both spatially and temporally) with a conventional manual tensiometer. These protocols require the use of two probes in one location. For use in commercial systems, we recommend a minimum of three replicate pairs of probes, although we recognise in commercial practice that two replications could be considered as an absolute minimum.

The protocols developed in this work do not require the precise calibration of the sensors; what is important is that the calibration used remains constant. A calibration, performed in the greenhouse used for the three crops reported here, indicated that EnviroSCAN data were approximately 50% larger than the actual (M.D. Fernandez, unpublished data). Because these protocols are based on tendencies, the precise accuracy with which absolute values are measured does not influence their application. However, changes in sensor calibration as occurred at the end of the pepper crop, when there was a large reduction in soil electrical conductivity (EC), do influence the application of these protocols. Similar apparent effects on EnviroSCAN calibration (but causing an increase in measured values) were seen when soil EC was increased during fruit maturity in a tomato crop (R. Thompson, unpublished data). These protocols are only applicable when soil EC remains relatively constant; considerable care should be used when there are large changes in soil EC during a crop. Where changes in soil EC are commonly used to increase fruit quality as in fresh tomato and melon, consideration should be given to the supplementary use of tensiometers.

In the pepper crop, CSMM management performed similarly to manual tensiometer management. The higher costs of the CSMM system need to be evaluated against the considerable advantages of automatic data collection, detailed data sets of soil moisture dynamics, low maintenance requirements, and possible automation of irrigation.

Acknowledgements

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Literature Cited

Paltineanu, I.C. and Starr, J.L. 1997. Real-time soil water dynamics using multisensor capacitance probes: Laboratory calibration. Soil Sci. Soc. Am. J. 61:1576-1585

Table. For each of the three crops grown: the entire crop growth period, the irrigation treatment period, and the protocols used to define the Upper and Lower Limits for irrigation management using continuous soil moisture monitoring

Crop	Crop Growth Period	Treatment Period	Protocol for Upper Limit	Protocol for Lower Limit
Melon	4 Mar – 27 Jun 2000	30 Mar – 27 Jun 2000	vertical drainage at 30-40 cm	reduced uptake in 0–20 cm depth
Tomato	7 Sep – 22 Dec 2000	6 Oct – 22 Dec 2000	vertical drainage at 30-40 cm	uptake at 30-40 cm depth
Pepper	4 Jul – 27 Nov 2001	23 Aug – 27 Nov. 2001	vertical drainage at 30-40 cm; increase at “edge of bulb”	uptake at 30-40 cm depth &/or “edge of bulb”

Figures

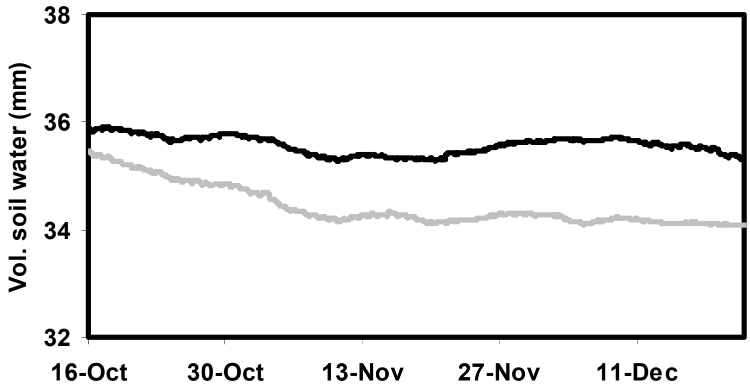


Figure 1. Tomato. Volumetric soil water content at 30-40 cm. The black and grey lines are, respectively, the CSMM and tensiometer managed irrigation treatments.

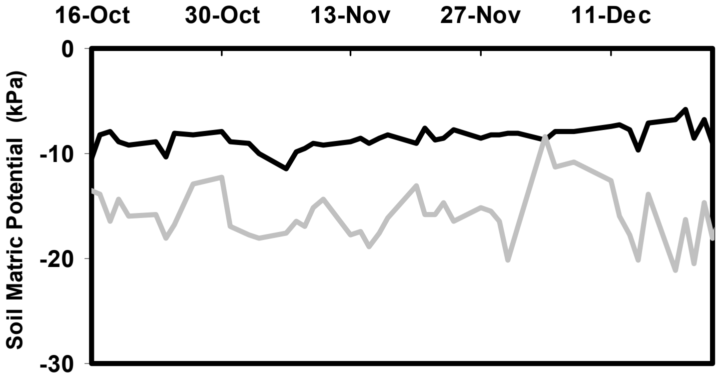
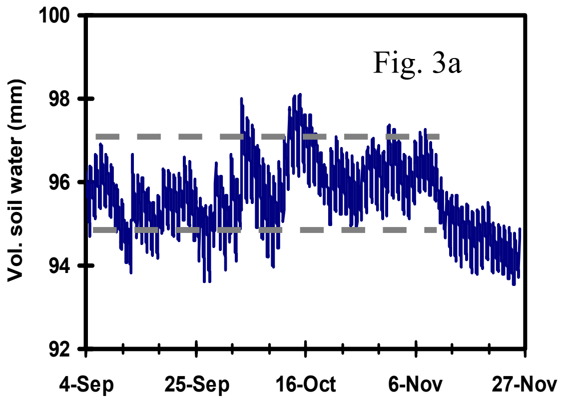
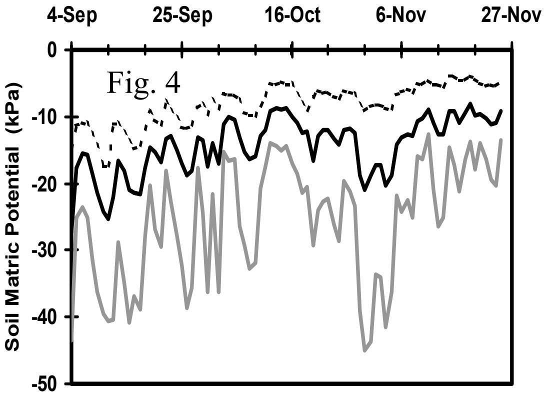
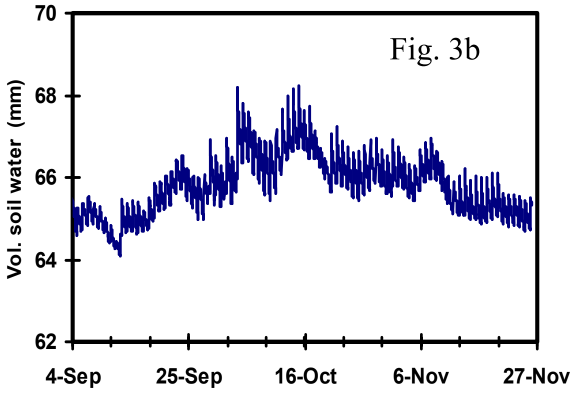
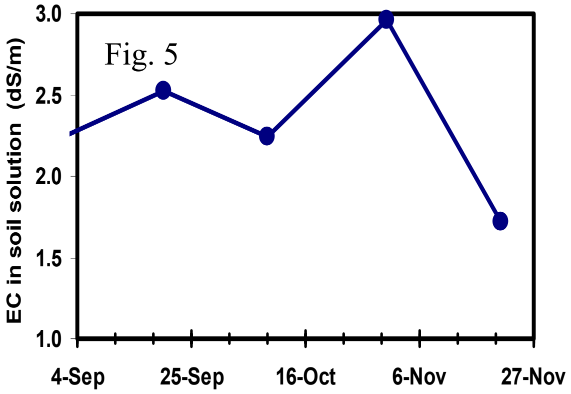


Figure 2. Tomato. Soil matric potential (10 cm depth) measured daily at 8 a.m. The black and grey lines are, respectively, the CSMM and tensiometer managed irrigation treatments.









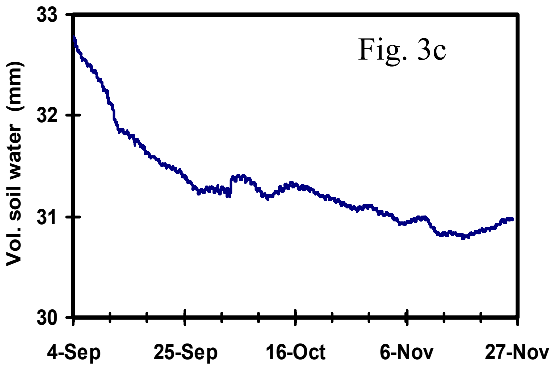


Fig. 3. Pepper, CSMM managed treatment. Volumetric soil water content (mm), (a) at 0–30 cm close to dripper, (b) 0–20 cm at edge of bulb, and (c) at 30–40 cm depth close to dripper.

Fig. 4. Pepper, CSMM managed treatment. Soil matric potential measured with electro-tensiometers at 10 cm depth, close to dripper. Daily average: black unbroken line, daily maximum: black broken line, daily minimum: grey unbroken line.

Fig. 5. Pepper, CSMM managed treatment. Electrical conductivity of soil solution, obtained at 10 cm depth, close to dripper.