Agricultural Water Management 178 (2016) 171–179

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Lysimetry methods for monitoring soil solution electrical conductivity and nutrient concentration in greenhouse tomato crops

Francisco Javier Cabrera Corral[a], Santiago Bonachela Castaño[a,*], María Dolores Fernández Fernández[b], María Rosa Granados García[a], Juan Carlos López Hernández[b]

[a] Departamento de Agronomía, Centro de Investigación en Biotecnología Agroalimentaria (BITAL), Campus de Excelencia Internacional Agroalimentario (ceiA3), Universidad de Almería, La Cañada de San Urbano s/n, Almería E04120, Spain
[b] Estación Experimental Las Palmerillas (Fundación Cajamar-Grupo Cooperativo), 04710 El Ejido, Almería, Spain

ARTICLE INFO

Article history:
Received 10 May 2016
Received in revised form
16 September 2016
Accepted 25 September 2016

Keywords:
Quick-test
Soil matric potential
Soil improver
Suction cup
Water front detector

ABSTRACT

In intensive agricultural systems, such as Mediterranean greenhouses, monitoring soil nutrient and salt status is essential for optimising vegetable production and minimising soil and water pollution. This work analyses the dynamics of electrical conductivity (EC_{SS}) and nutrient concentration in soil solution collected simultaneously with various zero-tension lysimeters and a suction cup (a tension lysimeter) throughout two greenhouse tomato crops. The EC_{SS} obtained with zero-tension lysimeters (funnel and plate lysimeter) was generally lower than that with the suction cup, irrespective of soil depth. Moreover, the soil solution concentration of potassium, calcium, magnesium, sodium, chloride and sulphate obtained with funnel lysimeter (FullStop^{TM}) was generally lower than that with suction cup throughout both cycles, while no clear differences were found for the nitrate concentration at 0.25 m depth in the 2013/14 cycle or at 0.38 m depth in the 2015 one. Overall, it appears that the soil solutions collected with the suction cup and the funnel lysimeter represent different soil solution status and processes. The funnel lysimeter collects freely draining soil solution, and it may therefore provide better information about the movement of elements between soil horizons, whereas the suction cup can sample soil solution from soil pores with longer residence times, especially under unsaturated flow conditions, and might represent better the available element concentrations for plant nutrition studies. The differential response found for nitrate could be due to the fact that it is a very mobile element within the soil. The soil water matric potential was slightly higher in the soil with zero-tension lysimeters throughout most of the 2013/14 cycle, and so these devices might alter soil solution movement and water and nutrient availability. On the other hand, in general, a good fit was found between the soil solution concentration of nitrate, potassium, calcium and sodium measured with a rapid analysis system (Laqua^{TM}) and that measured using the reference laboratory method. This rapid system, in combination with the suction cup, can facilitate the farmers' control of soil nutrient and salt status.

1. Introduction

Monitoring the concentration and transport of solutes in agricultural soils is usually a difficult problem for farmers, because soil solute concentration is not easy to measure. In heavily fertigated, intensive agricultural systems, such as the greenhouse horticultural crops on the SE Spanish Mediterranean coast, the development of feasible soil sampling methods and protocols for a better fertigation control is becoming essential for optimising vegetable production and irrigation water use, and, especially, for minimising soil and water pollution. This might be especially relevant in irrigation areas with water of low or medium quality, such as the SE Spanish Mediterranean coast, where the groundwater, the main agricultural water source, is becoming increasingly salinised due to seawater intrusion. In this area, over-irrigation is a common practice in greenhouse crops irrigated with water of low or medium quality in order to reduce the concentration of salts in the soil occupied by the roots.

The total concentration of dissolved salts in the soil solution is a measurement of soil salinity, and in intensive agricultural systems, such as greenhouses, it is also a measurement of the availability of

* Corresponding author.
E-mail addresses: fjcabrera@ual.es (F.J. Cabrera Corral), bonache@ual.es (S. Bonachela Castaño), mdoloresfernandez@fundacioncajamar.com (M.D. Fernández Fernández), mgranado@ual.es (M.R. Granados García), juancarloslopez@fundacioncajamar.com (J.C. López Hernández).

http://dx.doi.org/10.1016/j.agwat.2016.09.024
0378-3774/

nutrients, which contribute substantially to the soil salt concentration (Sonneveld and Vogt, 2009). Total concentration of dissolved salts in soil solution is usually determined from the electrical conductivity of the soil solution (EC_{SS}), a good measurement of the electrical conductivity "felt" by the plant regarding salinity and nutrient availability. The EC_{SS} can be determined (Hendrickx et al., 2002) in soil water extracts using various soil:water ratios, such as the soil saturation extract, but these methods are laborious, destructive and time-consuming for monitoring solute soil concentration in intensive agricultural systems. The EC_{SS} can also be measured (Hendrickx et al., 2002) *in situ*, usually with tension or zero-tension lysimeters. The most common tension lysimeter is the suction cup, which utilises vacuum to draw soil solution into the lysimeter *via* capillary connections. It is a low-cost method that allows periodic sampling of soil solution with minimal soil disturbance, but requires soils with relatively high soil water content (limited to matric potentials higher than −100 kPa) and good soil-lysimeter contact (Weihermüller et al., 2007). In natural ecosystem studies, tension lysimeters are considered to be more appropriate for plant nutrition or soil-solution equilibrium studies (Marques et al., 1996; Nieminen et al., 2013), as they can sample soil solution under unsaturated flow conditions more efficiently and from soil pores with longer residence times (Haines et al., 1982; Nieminen et al., 2013). Zero-tension lysimeters are devices inserted into the soil to collect the soil solution draining freely under gravity, and they are considered to provide better information about the movement of elements between soil horizons for input-output studies (Haines et al., 1982; Nieminen et al., 2013). However, zero-tension lysimeters might cause greater soil disturbance during installation, and permanent soil hydrological changes thereafter (Haines et al., 1982).

In Mediterranean greenhouses from SE Spain, lysimetry methods are increasingly used by farmers for controlling crop fertigation by monitoring soil nutrient and salt status (Fernández et al., 2015; Thompson et al., 2009). The suction cup is, by far, the most common lysimetry method, but zero-tension lysimeters (pan or plate lysimeter and, especially, wetting front detector or funnel lysimeter) have also been introduced recently. The wetting front detector is a buried funnel-shaped container that can be used for both irrigation scheduling and fertigation control (Stirzaker, 2003). When the wetting front reaches the device, the unsaturated flow lines converge towards the base of the funnel, where soil water content reaches saturation and free water forms. This water, which can be extracted, activates a visual indicator. The wetting front detector appears to be a useful method for monitoring nitrate leaching (van der Laan et al., 2010; Salazar et al., 2014). On the other hand, greenhouse vegetable farmers need, in combination with lysimetry methods, rapid systems of analysing the soil solution concentration of nutrients and salts (Hartz et al., 1993; Thompson et al., 2009) for a corrective fertigation management.

This work was mainly aimed at comparing lysimetry methods for studying the electrical conductivity and the concentration of the main nutrients in the soil solution of two drip-irrigated greenhouse tomato crops grown under a representative range of irrigation and fertigation scenarios. Additionally, quick-test methods of analysing the main soil nutrients were evaluated, since these methodologies can facilitate the implementation of lysimetry methods in the field.

2. Material and methods

2.1. Site and experiment

Two tomato crop cycles (*Solanum lycopersicum* L.) were grown at 'Las Palmerillas-Cajamar' research station (2°43′_W; 36°47′_N; 155 ma.s.l.), on the Almería coast, SE Spain. Experiments were carried out in a Parral-type greenhouse (low-cost structure covered with plastic film) with an artificially layered soil, known as *enarenado* and widespread in the region (Wittwer and Castilla, 1995). The soil consisted of the naturally occurring, gravelly sandy-loam soil covered with a 0.3-m layer of imported silty-clay loam soil (27.6 clay and 46.9 silt), a 0.02-m layer of dried manure, and finally a 0.1-m mulch layer of coarse sand and fine gravel particles (Fig. 1). The manure layer was mineralised and disappeared with time and use, and the 0.1-m upper part of the imported soil layer mixed with sand and gravel particles from the top layer due to previous, common tillage operations. The upper limit of drained water content (field capacity) for the imported soil layer was 0.37 $m^3 m^{-3}$, and the lower limit (wilting point) was 0.14 $m^3 m^{-3}$. These parameters were measured in unaltered soil samples using HYPROP and WP4C (Decagon Devices Inc., Washington, USA). The first tomato crop (cultivar 'Valkiriaí) was grown from 18 October 2013 to 5 May 2014 (autumn-winter cycle), and plants were transplanted 0.5 m apart, with 1.0 m between rows (2 plants m^{-2}) The mean daily greenhouse air temperature during this tomato cycle was 16.4 °C, while the integral of the outside solar radiation was 2909 MJ m^{-2}. In the second crop (cultivar 'Genioí), grown from 3 February to 6 July, 2015 (spring cycle), plants were also 0.5 m apart, but with 1.5 m between rows (1.33 plants m^{-2}). The mean daily greenhouse air temperature during this crop cycle was 20.3 °C, while the integral of the outside solar radiation was 3252 MJ m^{-2}.

Irrigation water of about 1.6 (first crop) and 1.7 (second crop) dS m^{-1} EC mixed with fertilizers was applied (Table 1) through a surface drip system with over 90% distribution uniformity. Inserted emitters (one per plant) of 3.1 L h^{-1} of nominal flow at 100 kPa

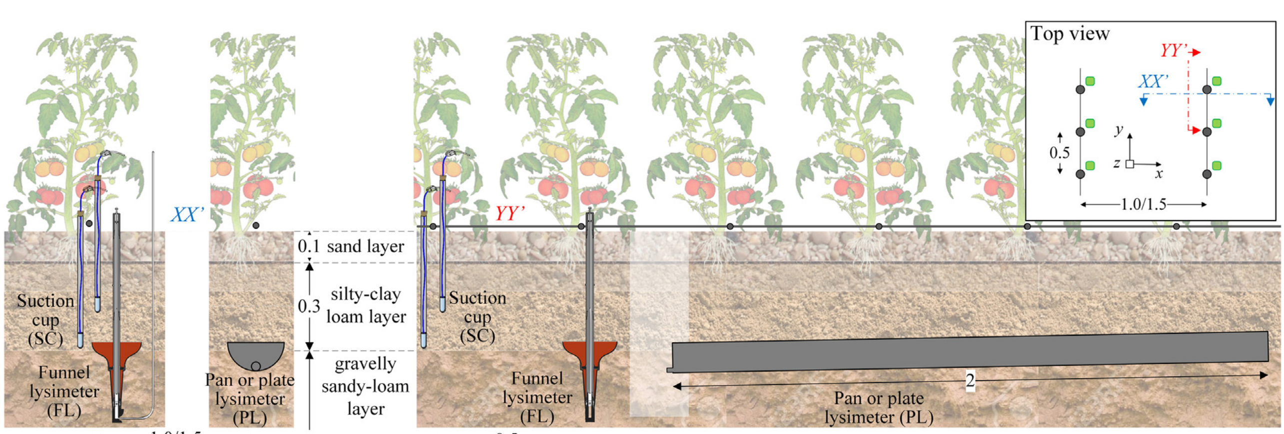

Fig. 1. Soil location of suction cup, funnel lysimeter and plate lisimeter.