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Irrigation Management of Greenhouse Tomato and Cucumber Using Tensiometer: Effects on Yield, Quality and Water Use

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Abstract

Irrigation is a crucial practice that operators often perform empirically, relying on their own experience, especially in productive areas characterized by low technology agriculture (i.e. several parts of Mediterranean countries). One of the possible approach for proper irrigation scheduling is measuring the soil water potential, simple and easy to manage. The purpose of this research was to examine the effects of two different irrigation regimes (obtained by the use of tensiometers connected to a relay controller) on yield, fruit quality and water consumption of greenhouse tomato (*Solanum lycopersicum* L. cv Naxos) and cucumber (*Cucumis sativus* L., cv Sarig, in the first cropping cycle, and the local landrace 'Mezzo lungo di Polignano', in the second one) grown on a silty-clay soil in Mediterranean conditions.
For each species, two tests (August-February and February-July cycle) were carried out in a plastic greenhouse-tunnel.
Drip irrigation was adopted, with automated schedule based on tensiometer readings. Two water potential irrigation set-points were compared: -100 and -400 hPa for tomato and -100 and -300 hPa for cucumber, in both cycles. Yield (marketable and unmarketable) and quality traits of fruits (soluble solids, dry matter and titratable acidity) were determined. Water consumption was calculated at the end of each crop cycle.
In the first cycle, the two water regimes did not affect the yield of tomato and cucumber. The cucumber irrigated at the lowest soil water potential set-point produced fruits with 8% higher dry matter. In the second cycle, the tomato irrigated at the potential of -400 hPa showed a 40% lower yield (mainly due to the lower fruit size) compared to that of plants irrigated at -100 hPa. However, the fruits of tomato plants irrigated at -400 hPa showed total soluble solids, dry matter and titratable acidity, respectively 41, 45 and 59% higher than plants irrigated at -100 hPa.
In both crop cycles, a water saving of 35% and 46%, on average, for tomato and cucumber, respectively, was obtained using the lowest potential as irrigation set-point.
Proper use of tensiometer could allow a better use of water resource. Selection of proper water potential set-points according to the cultivation season is crucial for satisfactory results. The positive effects of a controlled and moderate water stress on fruit quality should be taken into account.

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Keywrds: Tension switch, cavitation, WUE, soil matric potential, water saving.

1. Introduction

Water is becoming an economic scarce resource in many areas of the world, especially in arid and semi-arid regions, such as the Mediterranean basin (Stanghellini *et al*., 2003). Agriculture is the largest consumer of global freshwater, accounting for around 70% of withdrawals as irrigation (WWAP, 2009). Increasing the efficiency of water use within agriculture systems is important in order to secure water for agricultural production, municipal and industrial purposes and ecosystem function (Jacobsen *et al*., 2012). As potential water saving strategies in European agriculture, it has been estimated that better irrigation scheduling and use of drip irrigation in row crops may save 20% of the water consumption (EU Water Saving Potential, 2007).

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Proper irrigation scheduling results in increasing water use efficiency (WUE) (Gencoglan *et al*., 2006). WUE relates to how much yield is obtained per unit of applied water (Howell, 2003).

Scheduling water application is very critical, as excessive or inadequate irrigations reduce yield, while inadequate irrigation also causes water stress (Locascio and Smajstrla, 1996).

Availability of adequate soil moisture levels at critical stages of plant growth not only optimizes the metabolic process in plant cells but also increases the effectiveness of the mineral nutrients applied to the crop. On the contrary, any degree of water stress may produce deleterious effects on growth and yield of the crop (Saif *et al*., 2003). Deficit water budgets lead to numerous physiological changes such as altered root to shoot ratio, reduced leaf area or number of leaves, and finally reduce plant growth and yield. Fresh fruit yields of cucumber and tomato are highly affected by the total amount of irrigation water at all growth stages (Mao *et al*., 2003; Patanè *et al*., 2011).

Several irrigation management systems, although largely investigated and adopted at experimental level, are expensive and difficult to transfer at farm level. It is the case of the approach based on measuring plant water status. This is generally difficult and expensive to measure. In addition, changes in plant water status are not necessarily indicative of changes in water availability in the root zone of the plant. As a more feasible approach, irrigation decision can be based on direct measurements of soil water status. This approach has the advantage to be relatively easy to make and to automate (Van Iersel *et al*., 2013), resulting more feasible for application at farm level. Soil water status can be referred to soil water content or soil matric potential. Soil water content sensors measure the amount of water in the soil (new generation of low-cost sensors generally measure volumetric water content), while matric potential sensors give a measurement of how easy it is for plants to extract water from the soil. Direct measurements of soil water potential in the field are generally performed by soil tensiometers for relatively low soil water tension or wet range, whereas indirect measurements can be done by thermocouple psicrometers, gypsum blocks, granular matrix sensors, filter paper method or heat dissipation sensors for the high soil water tension or dry range (Young and Sisson, 2002; Durner and Or, 2006).

Tensiometers are rapid, cheap and easy devices for monitoring the water status of substrate and useful for fertirrigation scheduling (Hodnett *et al*., 1990). They are often preferred to other type of substrate moisture sensors because of their low cost, simplicity of use, high accuracy of measurement, not influence of temperature and soil osmotic potential, and the possibility of electronic data acquisition through differential pressure transducers (Thalheimer, 2003). All this render them suitable also for automated fertirrigation control. However, tensiometers must be operated carefully in order to avoid the formation of air bubbles in the shaft; they must be protected from frost and need regular maintenance, for instance to refill the water in the tube and to avoid the contamination by algae. Possible cavitation in very dry conditions is also a drawback, possibly occurring when the soil dries to matric potential values lower than about -850 hPa or when air flows through the porous cup. Although the tensiometric technique is straightforward, relatively easy to use and its range of measurement is adequate for most of the agronomic applications (Young and Sisson, 2002), it does not cover the entire range of interest and is unsuited for some applications where soil water limits plant growth, for instance (Durner and Or, 2006).

Under high frequency drip irrigation, it is possible to maintain a small wetted soil zone sufficient for crop water uptake, while keeping a much larger zone dry (Wang *et al*., 2007). This condition is similar to what generally occurs in soilless pot culture, where tensiometer has been proposed to be used with growing media near to their maximum water holding capacity (Montesano *et al*. 2005; Montesano *et al*., 2010). However, also in this case, some precautions are necessary in order to assure a good contact between the porous tip and the substrate, in particular in soilless conditions, and to achieve a correct sensor positioning taking into account root distribution and the place of nozzle(s) (Pardossi *et al*., 2009).

The purpose of this research was to evaluate the possibility of using the tensiometer to rationalize the supply of irrigation water in the cultivation of cucumber (*Cucumis sativus* L.) and tomato (*Solanum lycopersicum* L.) in greenhouse drip irrigation system, by defining proper water potential set-points to avoid cavitation problems of the instrument, to improve WUE and reduce water consumption.

2. Material and Methods

This research was carried out in the framework of the research project “Rational use of water and fertilizer in greenhouse vegetable crops” supported by Apulia Region Administration.

The experiment was conducted at the Experimental Farm “La Noria” of the Institute of Sciences of Food Production of the Italian National Research Council (CNR), located in Mola di Bari (BA, Southern Italy), in a plastic-greenhouse tunnel in a clay soil mulched with PE black film (50 µm thickness).

Two cropping cycles (fall-winter and spring-summer) and two independent experiments on tomato (cv Naxos for both cycles) and cucumber (cv Sarig in the first cycle and the local landrace Mezzo lungo di Polignano in the second one) took place.

Drip irrigation with automated schedule based on tensiometer (LT1 28 cm, Tensio-Technik, Geisenheim, Germany) was adopted in all the experiments. Tensiometers were connected to an electronic tensioswitch (400C, Tensio-Technik) which controlled the beginning and the end of irrigation based on soil water potential: irrigations started when a specific water potential set-point was reached and was automatically stopped when water potential was back above the set-point.

The tensiometer porous cup was placed at 30 cm dept, where most of the roots are generally present, in proximity of the plant and of the drip emitter. In both cycles, two water potential irrigation set-points were compared: -100 and -400 hPa, for tomato, and -100 and -300 hPa for cucumber.

A completely randomized block design with three replications was adopted for each experiment. For every vegetable crops, each elementary experimental unit was represented by a row with 18 plants, with 26 cm between plants and 130 cm between rows (planting density = 2.96 plants m^{-2}). The nutrient solutions were distributed using a drip irrigation system, with pressure-compensated emitters (8 L h^{-1}). The nutrient solution contained 10.4 mM N, 5.6 mM K, 1.3 mM P, 1.0 mM Mg, 1.0 mM S, and 3.0 mM Ca; it was prepared using rain water previously collected and the following fertilizer salts: $Ca(NO_3)_2 4H_2O$, KNO_3, KH_2PO_4, and $MgSO_4$ $7H_2O$. Micronutrients were supplied according to Johnson *et al*. (1957). Plants were trained vertically. The minimum temperature inside the greenhouse was set to ≥ 13 °C.

WUE was calculated according to FAO (1982) as follows:

$$\text{WUE} = \text{yield (kg)} / \text{total water applied } (m^3) \tag{1}$$

Total soluble solid (TSS) content, dry matter (DM) percentage and titratable acidity (TA) were assessed on fruits. TSS content was determined using a portable refractometer (Brixstix BX 100 Hs, Techniquip Corp., Livermore, CA, USA). Fruits were dried to constant weight at 65 °C in a forced-draft oven to determine their DM contents. TA was measured on filtrates of homogenised samples by potentiometric titration with 0.1 M NaOH. The results were expressed as the percentage of citric acid in the juice.

Statistical analysis

All data were analysed using ANOVA, by means of the SAS-GLM procedure (SAS Institute, Cary, NC, USA). Means separation was performed with the least significant difference (LSD) test (P = 0.05).

3. Results and discussion

In the fall-winter cycle, the two water regimes did not affect the yield of both tomato (3.6 kg $plant^{-1}$, on average) and cucumber (3.2 kg $plant^{-1}$, on average). The quality traits of tomato fruits, TSS, DM and TA, were similar regardless of the water regime used (on average, 3.7 °Brix, 4.6 g 100 g^{-1} FW and 0.4 g citric acid 100 mL^{-1} juice, respectively). The cucumber irrigated at the lowest soil water potential set-point produced fruits with 8% higher DM percentage, while TA and TSS were not affected by the water potential (on average, 0.11 g citric acid 100 mL^{-1} and 3.3 °Brix, respectively) (table not shown).

In the spring-summer cycle, the cucumber yield (6.8 kg $plant^{-1}$, on average) and quality traits (2.9 °Brix, 4.5 g DM100 g^{-1} FW and 0.11 g citric acid 100 mL^{-1} juice) were not influenced by treatments, whereas tomato irrigated at the potential of -400 hPa showed a 40% lower yield (mainly due to the lower fruit size) compared to plants irrigated at -100 hPa. The fruits of tomato plants irrigated at -400 hPa, however, showed TSS, DM percentage and TA, respectively, of 41, 45 and 59% higher than plants irrigated at -100 hPa (Table 1).

In both growing cycles, when the lowest water potential set-point was imposed, water consumption was reduced by 40 and 46% in tomato and by 49 and 42% in cucumber, respectively, in fall-winter and spring-summer cycle. The WUE was 65 and 14% higher in tomato and 96 and 73% in cucumber, respectively, in fall-winter and spring-summer growing cycle (Table 2). However, while the yield and the fruit quality, for both species, were not different between treatments in the fall-winter cycle, in the spring-summer cycle the reduced water supply resulted in a better quality and lower yield. Similar results were found in previous experiments where the adoption of deficit irrigation strategies allowed to save water improving the WUE, minimizing fruit losses and maintaining high fruit quality levels (Wang *et al*., 2007; Patanè *et al*., 2011). Shae *et al*. (1999) suggested that tensiometer based methods produce yields and quality potato equivalent to those from reference treatments with significant savings in seasonal irrigation totals.

An additional strength of using tensiometer, and in general soil water status sensors, for irrigation decision, potentially resulting in larger applications, is the fact that this approach results in a simple feedback system: a low soil water content will trigger irrigation, which increases soil water content and indicates that irrigation is no longer needed, until the water reservoir will be again depleted. Measuring soil water potential has the advantage of a direct determination of the soil water availability to the plants (Van Iersel *et al*., 2013). The determination of the appropriate threshold for a particular crop remains a fundamental point for efficient irrigation management (Lemay *et al*., 2012).

Table 1 Fruit number, mean fruit weight, total fruit yield, total soluble solids (TSS), titratable acidity (TA), and dry matter (DM) of tomato fruits in spring-summer cycle at different irrigation set-points based on soil water potential.

Irrigation set-points	Fruit number	Mean fruit weight	Total fruit yield	TSS	TA	DM
	n. $plant^{-1}$	g	kg $plant^{-1}$	°Brix	g 100 mL^{-1}	g 100 g^{-1} FW
-100 hPa	58.7	116	6.8	4.4	0.34	6.1
-400 hPa	60.3	70	4.2	6.2	0.54	8.8
Significance[a]	ns	***	***	***	***	***

[a] ns and ***, non significant at P≤0.05 or significant at P≤0.001, respectively

Table 2 Water consumption and water use efficiency (WUE) of tomato and cucumber in fall-winter and spring-summer cycle at different irrigation set-points based on soil water potential.

Irrigation set-points	Water consumption (L plant^{-1})		WUE (kg m^{-3})	
	fall-winter cycle	spring-summer cycle	fall-winter cycle	spring-summer cycle
Tomato				
-100 hPa	136	133	26.5	51.1
-400 hPa	82	72	43.9	58.3
Significance [(a)]	***	***	***	***
Cucumber				
-100 hPa	140	114	22.9	59.6
-300 hPa	71	66	45.1	103.0
Significance [(a)]	***	***	***	***

[(a)] ***significant at $P \leq 0.001$.

4. Conclusions

The irrigation management system used in this study, the water potential irrigation set-points and the proper tensiometer and drip emitter positions, made the irrigation scheduling management similar to that of a soilless cultivation, with a relatively small wet growing medium volume and small volumes of irrigation water per plant. It was possible to identify proper soil water potential set-points, to obtain frequent and small volume irrigations, without incurring in problems of cavitation, and then automate irrigation management with a simple system. Proper use of tensiometer could allow a better use of water resource. Selection of proper water potential set-points according to the cultivation season is crucial for satisfactory results. The positive effects of a controlled stress on quality should be taken into account.

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