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Response of tomato plants to deficit irrigation under surface or subsurface drip irrigation

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Abstract

Field studies were conducted to compare the yield and fruit quality of processing tomatoes in surface and subsurface drip irrigation, with 100 and 50% of crop evapotranspiration (ETc). The results showed that when irrigation was reduced by 50% ETc the subsurface treatment showed higher water content at root depth compared with the on-surface treatment. At 50% ETc subsurface irrigation yield increased by 66.5% compared with the surface treatment. However at 100% ETc no significant difference in total fruit yield was observed between irrigation methods. The superficial and water-stressed treatment increased the pH and the acidity of the fruits but the subsurface treatment did not show differences with respect to the full-irrigation treatments. Our results show that the subsurface drip irrigation method could be reasonably applied for processing tomato when water resources are limited.

Key words: Yield, crop quality, total soluble solids (TSS), drought, stress, *Solanum lycopersicon* L.

Introduction

The scarcity of water in arid and semi-arid regions has increased the search for technology with improved water use efficiency. Drip irrigation is widely used in processing tomato cultivation in areas with dry and warm summers and high evapotranspiration rates throughout the growing season. Subsurface drip irrigation has evolved into an irrigation method with high potential for efficient and economical productivity and its use has progressed from being a novelty employed by researchers to an accepted method of irrigation for both perennial and annual crops (Ayars *et al.,* 1999). It has been found that subsurface drip irrigation reduced evaporation from the soil and increased the wetted soil volume and surface area more than surface systems allowing a deeper rooting pattern (Oliveira *et al.,* 1996; Phene, 1995).

Tomato plants are sensitive to water stress and show high correlation between evapotranspiration (ET) and crop yield (Nuruddin *et al.*, 2003). Thus yield reductions can be expected if ET is reduced due to insufficient soil moisture. Though, growth being impaired due to water stress (Kamgar, 1980; Wolf and Rudich, 1988), fruit quality parameters like colour or total soluble solids usually improve (Shinohara, *et al.,* 1995) and, therefore, establishment of methods to control the extent of stress, based on the focused yield and Brix value is important. The aim of this study was to evaluate subsurface drip irrigation as an efficient water-saving irrigation technique versus the surface system and to analyse the response of tomato fruit when water stress was imposed under different irrigation techniques.

Materials and methods

Experimental site: The experiment was conducted in Calcaric Fluvisol (FAO-UNESCO system) with a high permeability. Soil properties and meteorological data (absolute maximum and minimum values) during the experiment are summarised in Tables 1 and 2, respectively. Soil electrical conductivity was measured in the saturated paste extract. The soil showed a low nutrient level (Marx *et al.*, 1999)

Experimental design and treatments: Four treatments: two depths (surface and subsurface at 40 cm depth) and two irrigation treatments at 100 and 50% ETc (crop evapotranspiration) were arranged in a spit-plot experimental design with three replications. Total water applied in the 100% ETc treatment was 7967 $m^3\ ha^{-1}$. Initially, from May 16 (transplanting date) to June 14 a total of 871 $m^3\ ha^{-1}$ was applied in order to guarantee plant establishment, especially for the subsurface treatment. Each treatment had 18 lines of plants, with two lines of plants per line of drip irrigation. A total of 1770 tomato (*Solanum lycopersicon* L.) cv. Hypeel 244A seedlings was transplanted at the experimental site. RAM emitters (2.3 $L\ h^{-1}$) were placed 30 cm apart.

Soil moisture determination: Soil water content was calculated with a neutron probe (Troxler Electronic Laboratories Inc. model 3332). Eight aluminium tubes were placed in the experimental

Table 1. Soil physical and chemical characteristics of the experimental site

Parameter	Depth (cm)	
	0-50	51-100
EC (dSm^{-1})	0.61	0.52
pH (H_2O)	7.79	7.88
Organic matter (%)	1.41	1.67
N (%)	0.75	1.02
K (mmol kg^{-1})	7.20	4.80
Ca (mmol kg^{-1})	111.60	132.80
Mg (mmol kg^{-1})	29.00	37.30
Na (mmol kg^{-1})	1.20	1.10
Sand (%)	22.00	7.70
Silt (%)	41.00	50.90
Clay (%)	37.00	41.40

Table 2. Monthly rainfall and air temperature (absolute values) during the crop season

Month	Rainfall (mm)	Temperature (ºC)	
		Maximum	Mininimum
May	1	32.5	8.0
June	38	32.8	10.2
July	3	37.4	11.8
August	31	40.4	15.1
September	4	33.5	-1.1

site. One-meter-long tubes were placed at 15 cm from the dripper in each replicate. The neutron probe was calibrated and readings were compared with water content in the soil at 20, 40, 60 and 80 cm depth. Soil samples were dried in an oven for 24 h at 110ºC and water content determined by weighing.

Crop yield and quality: The central line of each replicate was selected for determination of yield and fruit quality. 16 plants per treatment were hand-harvested and 30 fruits per treatment were taken for quality analysis. Fruit quality parameters determined in the homogenised juice samples were pH, total soluble solids (TSS) content and acidity. TSS was determined by an Atago N-1E refractometer and expressed as ºBrix at 20ºC. Titratable acidity (% citric acid equivalent) was analysed by potentiometric titration with 0.1 N NaOH to pH 8.5, using 10 mL of juice. Fruit dry matter was determined after drying for 72 h at 65ºC in an oven. The data were subjected to analysis of variance and means were separated using Duncan's multiple range test at P=0.05 (SPSS, version 7.5).

Results and discussion

Moisture distribution in the soil profile initially showed higher water content in all the treatments due to the starting irrigation dosage for the transplanting stage (Fig. 1). One of the greatest challenges faced by growers using subsurface drip irrigation (SB) is crop establishment. Establishment with SB relies on unsaturated water movement from the buried source to the seed or seedling. Establishment is therefore affected by distance from source, soil texture, structure and antecedent water content (Charlesworth and Muirhead, 2003). Based on soils characteristic, climate and emitter depth, a total of 871 m^3 ha^{-1} was applied to this crop stage. Moisture was directly correlated with the amount of water applied at full or half-irrigated treatments. At 20 cm depth, the superficial and fully-irrigated treatment (SP100) had the higher soil moisture followed by the subsurface treatment (SB100). But, from 40 cm onwards, SB100 showed higher water content than the surface treatment. With respect to the water-stressed treatments, the subsurface method (SB50) showed higher water content in the soil profile especially at 40 cm depth and kept this difference until the end of the crop cycle. This difference in water content could affect the rooting pattern among irrigation methods. Phene *et al.* (1989) and Ben-Asher and Phene (1993) have reported that specific characteristics of the subsurface system allowed a spherical and larger volume of a wetted soil. This could result in a large concentration of roots at the depth of the irrigation emitter as found for several crops like tomato (Bar-Yosef *et al.*,1991), maize (Mitchell, 1981; Phene, 1991) or cotton (Plaut *et al.,* 1996). Our result agreed with those findings in the wetting patterns especially at limited irrigation dosage.

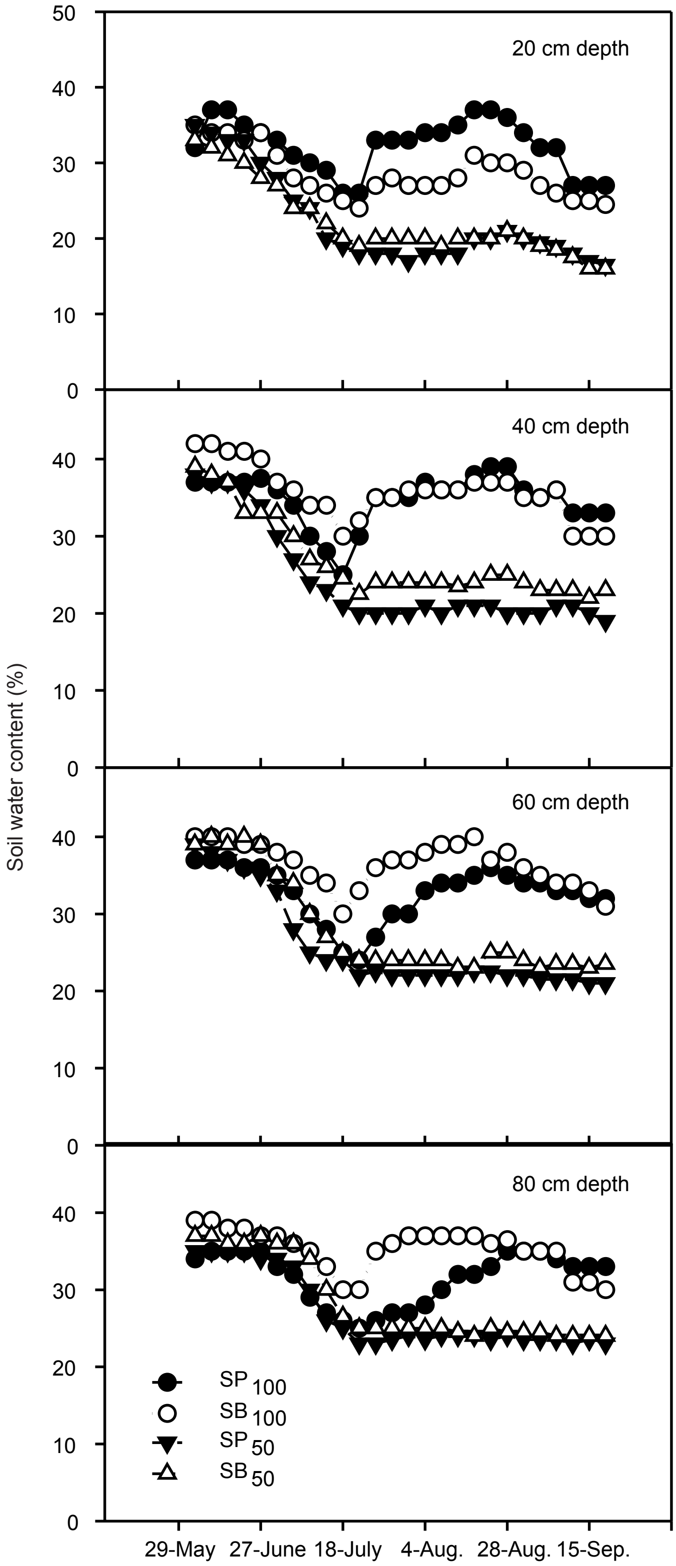

Fig. 1. Soil water content at 20, 40, 60 and 80 cm depth, 15 cm from the dripper. Treatments: Superficial (SP) or subsurface (SB) drip irrigation at two irrigation regimes (100 and 50% Etc).

Subsurface irrigation increased total yield compared with the superficial method (Fig. 2) but statistical significance was observed only for the water-stressed treatments. Thus, at 100% ETc, subsurface drip irrigation only increased yield by 8.3% but at 50% ETc this method increased yield by 66.5% with respect to the superficial treatment under the similar conditions, indicating the higher water use efficiency of this irrigation system. Other

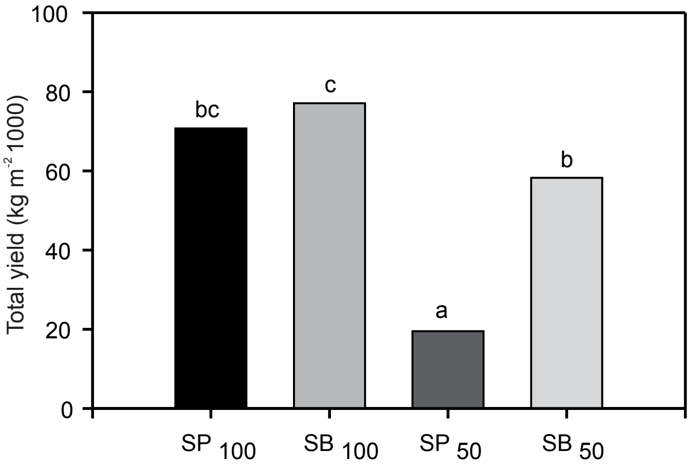

Fig. 2. Effect of the irrigation methods, superficial (SP) or subsurface (SB) drip irrigation at two irrigation regimes (100 and 50%Etc), on total fruit yield. Treatments with the same letter are not significantly different (Duncan test, $P<0.05$).

studies of irrigation and fertilisation management demonstrated significant yield and water use efficiency increase for the subsurface method in vegetable crops (Ayars *et al.,* 1999; Enciso-Medina *et al.,* 2002). Machado *et al.* (2003) found slightly higher commercial yield of processing tomatoes when the subsurface method was used, compared with surface irrigation, under non-stressed conditions.

As a result of the lower water availability for the roots in the surface treatment at 50% ETc (SP50), with respect to the subsurface treatment (SB50), fruit quality especially pH and acidity were significantly affected (Fig. 3). The surface and water-stress treatment increased TSS by 18.9%, pH by 13.2% and fruit dry matter by 17.2% but reduced acidity by 30% compared to the subsurface treatment at the same water regime. Variations in the concentration of dry matter have been coupled with the conditions of climate and root medium (Guichard *et al.,* 2001). For processing tomatoes, higher solids content in fruits is a target characteristic as this would reduce the cost for processing. The dry matter content of the ripe fruit is generally inversely related to the fruit size (Davies and Hobson, 1981). Furthermore, the dry mater content is positively related to the total sugar content of the fruit (Ho, 1988). The dry matter content as a percentage is also determined by the balance of the accumulation of assimilates and water (Marschner, 1995). Thus, while the import of assimilates depends on the effect of light on canopy photosynthesis and of temperature on fruit metabolism, the import of water is affected by plant water relations, which are affected by root water absorption and leaf transpiration. Water stress relatively imposed in the superficial treatment could promote the translocation of photosynthates into fruit and improve the fruit quality, whereas it inhibits photosynthesis and transpiration (Shinohara *et al.,* 1995) and total fruit yield is reduced.

Many southern areas of Europe and US are facing a dramatic decrease of water resources for agriculture due to both an increase of long-lasting drought periods and a considerable competition for water from new residential areas. Saving of water is a constant concern and new methods and irrigation strategies are foreseen. This study shows that, when water is strongly reduced throughout the crop season, total yield reduction could be reasonably overcome using subsurface irrigation due to its higher water use efficiency. Further work and continuous monitoring is still required to find a proper equilibrium between yield and quality, using the special advantages of this irrigation system.

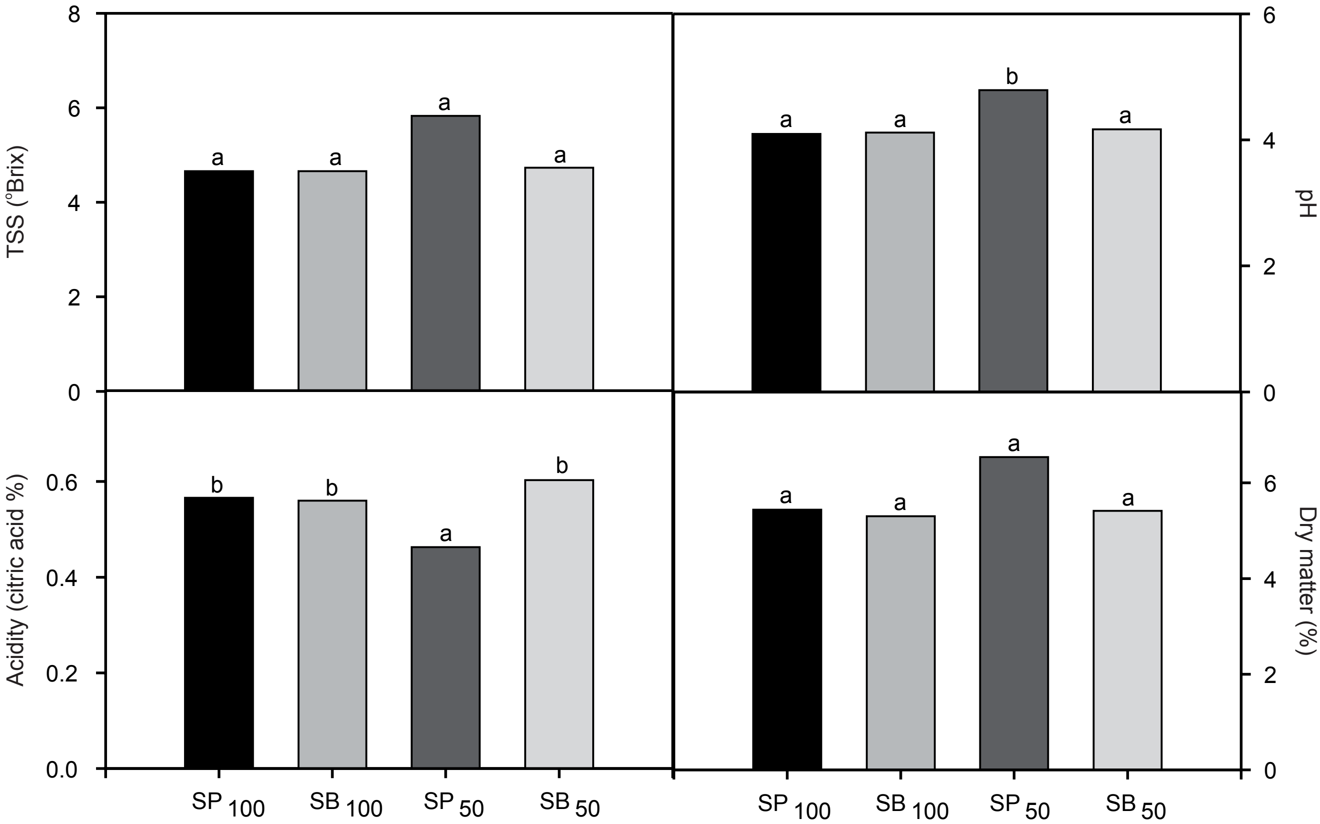

Fig. 3. Effect of the irrigation methods, superficial (SP) or subsurface (SB) drip irrigation at two irrigation regimes (100 and 50%ETc), on tomato fruit quality parameters. Treatments with the same letter are not significantly different ($P\leq0.05$).

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