Does irrigation method affect both root physiology and orchard ecology?

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Abstract

Irrigation methods differ in terms of fraction of wetted soil surface. Soil moisture is among the most dominant variable affecting plant water relations, and other soil processes which ultimately affect CO_2 soil emissions. This study compared the influence of microjet (MJ) and drip irrigation method (D) on levels of absisic acid concentration in roots ([ABA]) and on soil CO_2 emissions. Two plots were identified at a nectarine orchard (1666 p ha^{-1}) located in southern Italy, and irrigated by MJ (~35 L h^{-1}) and D (~16 L h^{-1}). Plant water status (pre-dawn leaf water potential) was kept optimal in both plots. Preliminary results revealed that ABA increased in inter-row roots at the D plot (D-inter) being 2.35-fold higher than those of MJ, despite both plots having similar water status. The CO_2 soil emissions were substantially 27.78% lower in D plot compared to the MJ one. Information on impact of irrigation methods on shoot elongation, fruit size are also discussed.

Keywords: abscisic acid, drought stress, hormonal interactions, soil CO_2 emissions, water use efficiency

INTRODUCTION

When plants are growing in drying soil the abscisic acid (ABA) concentration in roots increases affecting some parameters of leaf gas exchange, e.g., decreasing stomatal conductance (g_s), increasing water use efficiency (WUE) (Davies et al., 2000; Wilkinson and Davies, 2002). Several irrigation methods and water management techniques have been proposed in order to decrease irrigation water volumes, which is expected to improve plant WUE.

Partial root-zone drying (PRD), is an irrigation technique where the water is being supplied to the half of the root-zone constantly or by alternating the irrigated and rain-fed part of the soil (alternated PRD). The non-irrigated part of roots can increase [ABA] which in turn reduces plant water consumption mainly by decreasing g_s (Davies and Zhang, 1991). This irrigation method has mainly been compared to full irrigation and thus its efficiency could be based on PRD being a deficit irrigation technique (Fernández et al., 2006). Likewise, localised irrigation (drip or sub-irrigation) is an even more efficient method in which water is being supplied in even lower quantities than PRD, leading to higher reductions of plant water consuption (Ayars et al., 2003; Xiloyannis et al., 2012).

During summer, in drip-irrigated (D) orchards, soil moisture under the emitters (i.e., along the rows) is usually optimal, while at the inter-row alley it dries reaching low values (close to the wilting point) (Davies et al., 2000; dos Santos et al., 2003; Xiloyannis et al., 2012). Although an optimal plant water status can be maintained in D trees, we hypothesise that in roots of trees located in the inter-row portion of the root system the [ABA] increases, leading to a higher WUE.

Carbon (C) cycle in terrestrial ecosystems can influence the C release into the atmosphere. During the last years scientists have indicated the need of using new methodologies and technologies in order to reduce CO_2 emissions by increasing carbon sequestration in the soils (Smith, 2004). Recently, there is increased attention on the potential role of fruit orchards to contribute to the mitigation of climate change via

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increasing soil carbon (C) input and reducing soil CO_2 efflux (Montanaro et al., 2012). Irrigation methods may have also an ecological significance soil moisture being involved in CO_2 soil emission. The positive effect of increased soil moisture on soil CO_2 emissions via increasing C oxidation by soil microorganisms has been documented (Fang and Moncrieff, 2001). Likewise, root metabolism and biomass can be highly correlated to CO_2 fluxes from the soil while irrigation management can affect its growth and density substantially (Reth et al., 2005; Sainju et al., 2008). In addition, considering that root density at the row position of D trees increases because of localised irrigation (Ruiz-Sánchez et al., 2005), we also tested if the rates of soil CO_2 emissions at row are higher than that at inter-row (non-irrigated) due to the combined effect of increased root density and soil moisture.

Moreover, we examine whether D reduces soil CO_2 emissions per tree compared to MJ, by monitoring spatial variations within 2 consecutive growing seasons.

MATERIALS AND METHODS

Plant material and experimental site

The experiment was conducted during 2012 and 2013 at a nectarine orchard (1.5×4 m spacing distance, 'Big Bang' grafted on GF677) planted in 2008 in Metaponto, southern Italy (40°23'58,13"N; 16°45'43,50"E). The area is characterized by dry summers (annual rainfall average 590 mm mostly occurring during winter) (SAL Service, ALSIA Basilicata Region). Two blocks were chosen with fourteen trees each. Drip irrigation was installed in the first block (16 L h^{-1} $tree^{-1}$) while microjet sprinklers (35 L h^{-1} $tree^{-1}$) were placed in the second block (MJ). Irrigation was scheduled according to reference ET_o released by local weather station and K_c calculated according to Dichio et al. (2011). Microjets were able to wet the whole soil surface, whereas drippers wetted only a 20% of the soil surface (D-row), while the remaining part of soil was rain-fed (D-inter).

Soil CO_2 efflux measurements, leaf gas exchanges and water use efficiency

Soil CO_2 emissions were monitored (2012-2013) using the Li-6400 (LI-COR, Lincoln, NE, USA) equipped with a soil respiration chamber (Model Li-6400-09) by fitting the chamber to a PVC collar (a 6-cm long section of 10 cm ID PVC pipe). A total of 12 collars per treatment have been installed in row to inter row direction at 40, 80 and 150 cm from the trunk. The grass inside the collars was removed before measurements in order to avoid detection of photorespiration. Soil CO_2 efflux measurements took place at midday in 4 days from May to end of July during both years.

Leaf gas exchanges were measured on five mature leaves per tree using an open-flow portable system equipped with a leaf chamber fluorometer (LI-6400-40; Li-Cor Inc., NE, USA) operated at 500 μmol s^{-1} flow rates. Temperature inside the leaf chamber was maintained equal to environmental air temperature, mean water use efficiency (WUE) was then calculated as the net photosynthesis: transpiration ratio (μmol CO_2 $mmol^{-1}$ H_2O) as the average of measurements sampled at 5 times during the day (from 7.00 to 18.00 h solar time) at approximately 3 h interval time.

Dry root mass density (DRMD)

Three randomly chosen trees per block were excavated (2012 year) at 0-30 cm depth. Roots were manually separated from 30×30×30 cm soil blocks and collected in the field and their length was measured manually in the lab using a ruler before being dried in a ventilated oven at 70°C to determine the dry weigh (DW). Total DW of roots <0.6 mm diameter was determined at 0, 60, 120, 150 cm distance from the trunk (row) toward the inter-row.

Shoot and fruit growth

Seasonal shoot elongation was measured in the 2013 growing season, using a tape measurement, in 15 branches per treatment, on a total of 80 annual fruiting shoots growing on that branches. Fruit size (diameter) was also measured by a digital caliper on approximately 50 fruits per treatment at the harvest day.

Stem water potential

Stem water potential was measured at pre-dawn (Ψ_{pd}) by a Scholander pressure chamber (Model 600; PMS Instrument, Albany, OR, USA) using 3 leaves per tree on 3 trees per treatment.

Root sampling and hormonal determination

At middle summer (end July) roots from row and inter-row positions (0-20 cm depth) were sampled from three plants per treatment. Afterwards, roots were manually separated and cleaned from soil and stored at -80°C in order to determine ABA concentration ($[ABA]_{roots}$) according to Sofo et al. (2011) (ELISA method).

Statistical analysis

All experimental results were statistically analyzed using Minitab 16 statistical software (Minitab Inc, State College, Pennsylvania, USA). Mean comparison between the treatments was carried out using the two sample *t*-test at $P \leq 0.05$. The number of replicates (*n*) for each measured parameter is specified throughout the text, and in the table and figure captions.

RESULTS AND DISCUSSION

Pre-dawn stem water potential (Ψ_{pd}) had similar values in both irrigation treatments during the whole experimental season confirming that the irrigation schedule kept the trees under comparable water status. The average values ranged between -0.32 and -0.45 and between -0.26 and -0.34 MPa for D and MJ, respectively.

Water use efficiency measured on two different days (average of five values measured throughout each day) during summer in D trees was approximately 11.38% higher than that of MJ ones (data not shown).

In D trees, [ABA] measured in roots grown along the inter-row position was on average about 1.54-fold significantly higher than that of D-row (10.48 and 6.79 pmol g FW^{-1}, respectively) and 3.25 and 1.84-fold significantly higher than that found in roots sampled from the row potition in MJ (MJ-row) and that in inter-row (MJ-inter), respectively (Figure 1). This increase in [ABA] in the inter-row part (non-irrigated soil) of the D trees is probably correlated to the lower soil moisture and higher soil temperature than the other (irrigated) parts of the soil (data not shown). Moreover, the increased ABA levels in this part of the root system could provide the generation of a root signal (Davies et al., 2000), which plants could have used in order to adapt to the differentiated soil characteristics compared to the MJ plot.

At harvest (June 8, 2013), fruit diameter was similar in both treatments, reaching an average value of 52.10 and 50.02 mm for MJ and D trees, respectively (Figure 2). However, shoot length was 1.36-fold significantly higher in MJ than D trees, being 45.00 and 33.16 cm, respectively (Figure 2). These results indicate that reduced irrigation by drip method could decrease excessive vegetation while maintaining fruit growth comparable to that of MJ irrigated trees. This effect on shoot elongation could be beneficial for a better nutrient balance and whole-plant water use, in addition it can help a better light trasmission within the canopy improving fruit transpiration and in turn their mineral composition (Montanaro et al., 2010).

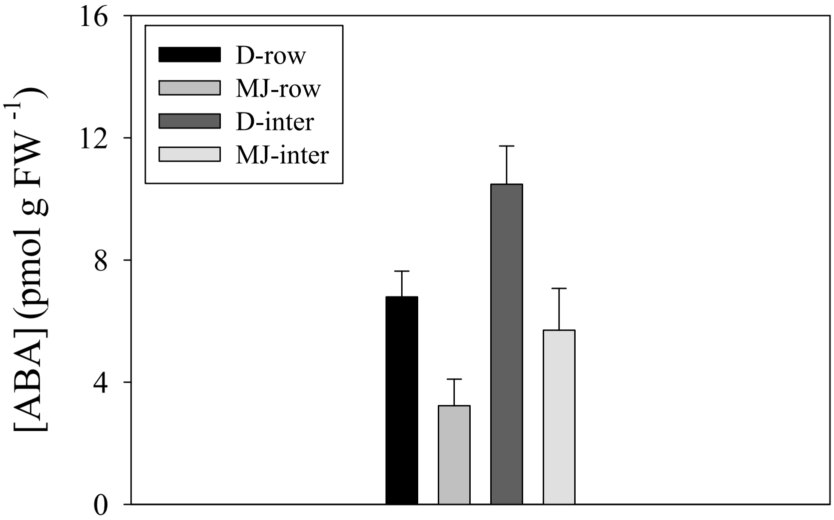

Figure 1. Abscisic acid concentration in roots ($[ABA]_{roots}$) meaured at row and inter-row (inter) positions in drip (D) and microjet (MJ) irrigated nectarine trees. Mean values (*n*=6) ± standard error (SE) with different letters are significantly different at $P \leq 0.05$ between the two irrigation treatments and the root sampling positions at $P \leq 0.05$.

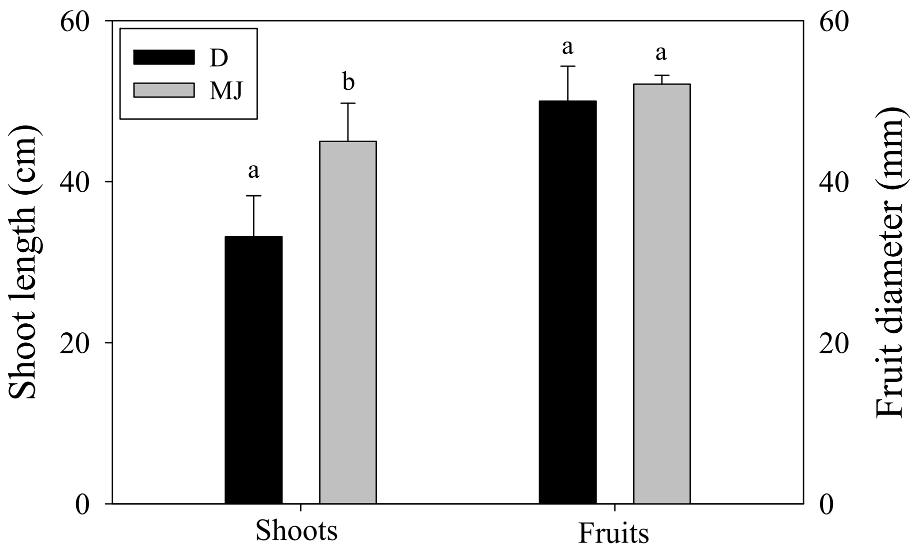

Figure 2. Average shoot length (cm) and fruit diameter (mm) measured in August of 2013 in drip (D; black bars) and microjet (MJ; grey bars) irrigated nectarine trees. Different letters indicate significant differences between the two irrigation treatments at $P \leq 0.05$, mean values for shoots (*n*=80) and fruits (*n*=50) ±SE.

Results on the dry root mass density (DRMD) at 0-30 cm depth of the soil, show that DRDM measure in D-row was approximately 3.77% higher than that of the MJ-row, being 1.43 and 1.38 kg m^{-3}, respectively (Figure 3). Results also reveal a gradient of the DRMD from row toward inter-row direction in both the irrigation systems, however, DRMD of MJ trees was always sgnificantly higher than that of D ones. This possibly occurred because of the different values of soil moisture and temperature at the different points of the soil (not shown). At 60 cm distance DRMD decreased by 35.62 (D) and 22.87% (MJ) compared to values measured at row. At 120 cm distance, DRMD further decreased reaching the minimum values which were comparable to that measured at inter-row position (i.e., 150 cm distance) (Figure 3).

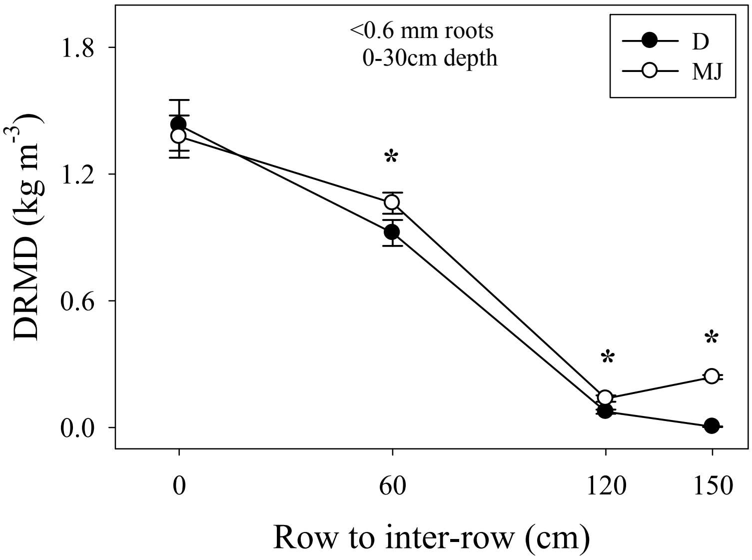

Figure 3. Dry root mass density (DRMD) (kg m^{-3}) of roots minus of 0.6 mm diameter measured at 0-30 cm depth of the soil for the drip (D; •) and microjet irrigated block (MJ; o) on October 2, 2012. Asterisks (*) indicate a statistically significant difference between treatments (n=3, P≤0.05). Error bars represent SE.

Lower soil moisture and higher soil temperature at the non-irrigated parts of the D plot (60, 120 and 150 cm distance form trunk) (data not shown) could have also led to lower root growth and soil microbial activity causing a reduction in soil respiration.

Efflux rates of CO_2 measured at D-row were about 1.61-fold higher (0.88 g CO_2 m^{-2} h^{-1}) higher than those measured at MJ-row (0.55 g CO_2 m^{-2} h^{-1}) (Figure 4A). On the contrary, soil CO_2 emissions for the MJ-inter were approximately 1.64-fold higher than that monitored at the D-inter and had increasing values throughout the summer period (Figure 4B). Soil CO_2 efflux rates were also monitored at four different positions between row and inter-row. We noticed significantly ~1.82-fold higher soil respiration at 0-20 cm distance from the D trees compared to MJ ones (Table 1). Moreover, no significant differences were shown between the two treatments at the soil surface of 20-40 cm distance from the trees, whereas soil CO_2 emissions were significantly 2-fold and1.64-fold lower for D trees than MJ ones at 40-80 cm and 80-150 cm from the trunk, respectively. The blocks showed significant differences in total CO_2 emissions. More specifically, we noticed about 27.78% lower CO_2 soil emissions in D block, which reached total values of ~2.60 CO_2 g m^{-2} h^{-1} $tree^{-1}$ compared to ~3.60 CO_2 g m^{-2} h^{-1} $tree^{-1}$ in MJ block (Table 1). These data are in accordance with previous results gained in similar experimental condition (Montanaro et al., 2012) showing that when the rainfed portion of soil dries during summer, the CO_2 soil emissions are reduced compared to the irrigated portion.

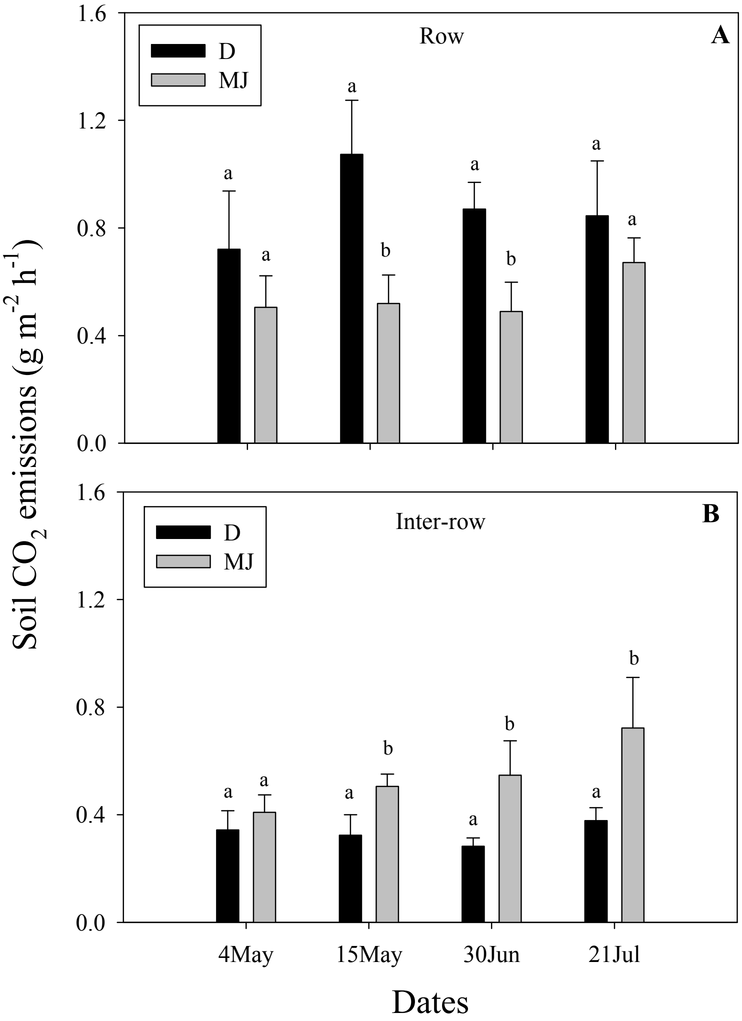

Figure 4. Soil CO_2 emissions ($g\ m^{-2}\ h^{-1}$) measured at soil surface of the soil in the drip (black bars) and microjet irrigated trees (grey bars) at row (A) and inter-row (B) on midday (11.30-12.30) at 4 different days during May to August of 2012 and 2013. Different letters indicate statistically significant differences between treatments ($P \le 0.05$, $n=3$). Bars represent standard errors.

Table 1. Total soil respiration ($g\ m^{-2}\ h^{-1}$) calculated for 4 different soil surfaces between row and inter-row, for the drip (D) and microjet (MJ) irrigated block. Measurements took place on midday (11.30-12.30) during 4 different days of summers 2012 and 2013 (May to August). Values in parenthesis indicate the number of samples while ± values represent SE. Different letters indicate a statistically significant difference between the treatments ($n=24$, $P \le 0.05$).

Row to inter-row (cm)	MJ	D
	CO_2 ($g\ m^{-2}\ h^{-1}$)	
0-20	0.33±0.04 a	0.60±0.13 b
20-40	0.88±0.14 a	0.72±0.14 a
40-80	1.00±0.13 a	0.50±0.09 b
80-150	1.39±0.21 a	0.85±0.07 b
Total	**3.60±0.51 a**	**2.60±0.42 b**

CONCLUSIONS

Our preliminary results suggest that in drip irrigated nectarine trees, despite a roughly optimal Ψ_{pd}, the low soil moisture at inter-row position induced an increase in ABA concentration in roots growing in that portion of soil. This contributed to improve WUE with no negative impact on fruit size at harvest as compared to MJ irrigated trees.

The preliminary results here obtained improved our knowledge on the biochemical signal between irrigated and non-irrigated roots of the same root system. This could assist to better describe and understand changes in plant physiology under drought conditions, improving plant WUE, and ultimately fruit productivity and quality.

This study reveals also that drip irrigation reduces soil CO_2 emissions in a nectarine orchard growing under semi-arid conditions contributing to the mitigation of climate change. Likewise, drip irrigation can also contribute in consuming lower amounts of irrigation water as less water is being evaporated from the soil to the atmosphere.

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