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Assessment of yield and water use efficiency of Clementine trees under surface and subsurface drip irrigation

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Abstract

Irrigation systems aimed to optimize water use efficiency in agriculture have become essential due to the increasing water limitations that agriculture is facing. Assessment of crop responses to different irrigation systems and strategies are therefore encouraged to find the most efficient options in each specific case. The main objective of this study was to assess the performance of a citrus crop under a surface (S) and subsurface (SS) drip irrigation systems with 7 (S_7, SS_7) or 14 emitters (S_{14}, SS_4) per plant, as well as a third SS treatment (SS_A), identical to the SS_7 but equipped with and additional drip line buried between the tree rows. Evaluations were made in terms of yield, fruit composition, irrigation water use efficiency (IWUE) and achieved water savings. Results showed that on average, water savings were 23.0% in the SS treatment compared to the S treatment without significant differences in either yield or fruit composition. For similar irrigation volumes applied, treatments with 14 emitters per plant generally allowed a better distribution of water than those with a lower number of emitters and was characterized by the highest IWUE. SS_A was the treatment with the lowest irrigation volumes and the highest yield and compared to S_7 allowed, in the three years, water saving in the range between 22.4 and 27.9%. Results from this study illustrate that there is opportunity to substantially save water in citrus production and that further research in this direction is needed to contribute to better optimize the water resources in agriculture.

Key-words: Irrigation Water Use Efficiency, Soil/Plant water status, Yield, Fruit quality

1. Introduction

According to data from the Food and Agriculture Organization (www.fao.org), two-thirds of the world population are expected to live in regions with water stress conditions by 2025 (between 500 and 1000 m^3 per year per capita). Agriculture, which is the largest water-consuming sector, has to adopt methods and strategies to improve crop sustainability (Provenzano et al., 2014). Using irrigation techniques allowing water saving without significantly reducing crop yield, as well as maximizing economic benefits and protecting environmental quality, have been proposed as a possible strategy to approach this challenge (Rodriguez-Sinobas et al., 2016).

Spain is one of the largest citrus producers in Europe, with annual productions higher than 5 million tonnes during the last decade (www.fao.org). The main citrus producing region is the Valencian Community with nearly 3 million tons per year, equivalent to 60% of Spanish citrus production (http://gipcitricos.ivia.es/citricultura-valenciana). Because of the semi-arid climate of the area and the high crop water requirements, among farmers there is a growing interest to implement strategies aimed to improve the sustainability of citrus productions. Adoption of efficient irrigation systems associated to water saving strategies, based on either simple periodic estimations of the soil water balance terms or precise assessments of temporal and spatial distribution of water exchange processes within the soil-plant-atmosphere system (Provenzano et al., 2013), may lead to improve crop sustainability.

Compared to other irrigation methods, drip irrigation systems give the possibility to apply lower volumes of water, more frequently and efficiently. If well designed, these systems make it possible to apply slow, steady and uniform amounts of water and nutrients only to the plant's root zone, while minimizing deep percolation and maintaining high productivity levels (Rallo et al., 2011). During the last decades, the interest of using subsurface drip irrigation (SS) in woody perennial crops has been increasing. SS enables to uniformly apply water directly to the root zone while maintaining a dry soil surface. SS offers important advantages compared to surface drip irrigation (S), such as less water lost from surface evaporation and prevention of weeds growth (Provenzano, 2007). Moreover, SS typically results in a larger wetted soil volume in which root proliferation easily occurs (Phene, 1999). When SS has been compared to other irrigation systems, such as furrow or surface drip irrigation, it has usually led to higher crop yields, lower water applications and consequently higher water use efficiency (Stephens, 1994; Camp, 1998; Ayars et al., 1999; Phene, 1999). However, SS has been also associated with high initial cost, potential for rodent damage, salt accumulation between drip lines and soil surface and particularly high potential for emitter plugging (Phene et al., 1986 and 1993; Phene, 1995).

In drip irrigation systems, the number of emitters per plant affects the number and dimensions of wetted bulbs, in which roots are mainly concentrated. Root growth conditions inside the wetting bulbs are considered close to the optimum, as water and nutrients are readily available to the plant, as result of the high-frequency irrigation (Pereira et al., 2010). In tree crops, the number of emitters per plant and the spacing between them can be flexible, as long as an adequate volume of root zone is provided with enough water to meet canopy water requirement (Evans et al., 2007). Smaller the emitter spacing, bigger the soil wetted volume and higher is the crop water availability (Shan et al., 2011). Recently García-Tejera et al. (2017) concluded that under deficit irrigation the wetted area on the soil surface should be reduced in order to decrease soil evaporation, but under full irrigation, to maximize trees transpiration was necessary to wet at least 30-40% of allotted soil per tree. A reduced volume of wetted soil implies that a greater fraction of the root system is in dry soil, particularly towards the end of season. This explains the reason why in horticultural studies, lower midday stem water potential (ψ_{stem}) values have been often observed under drip irrigation (Lampinen et al., 2001; Intrigliolo and Castel, 2005) than under furrow irrigation (McCutchan and Shackele, 1992; Fereres and Goldhamer, 2003).

The main objective of the work was to assess the performance of citrus trees in terms of plant water status, yield, fruit quality and irrigation water use efficiency when: i) trees were grown under S and SS irrigation systems; ii) soil wetted volume was modified by doubling, from 7 to 14, the number of emitters per plant in both irrigation systems, and; iii) an additional third line was added in SS treatment, in the middle of tree rows.

2. Materials and methods

2.1. Experimental plot

The study was conducted during 2014, 2015 and 2016 in a commercial citrus orchard planted with C*itrus clementina*, Hort. ex Tan. ‘Arrufatina’, located in Alberique (39º 7’ 31.33” N, 0º 33’ 17.06” W), Valencia, Spain. Trees were grafted onto Citrange Carrizo (*Citrus sinensis*, Osb. x *Poncirus trifoliata*, Raf.) and planted at spacing of 5.50 m x 4.25 m. At the beginning of the experiment, the canopy ground cover was equal, on average, to 39.4±4.1%.

The soil was classified as loam, clay loam and sandy clay loam, according to the USDA classification system, with percentages of sand, silt, and clay ranging from 34.4 to 51.6%, 22.6 to 38.4% and 21.8 to 33.8%, respectively. Soil organic matter was on average of 1.25% and total organic carbon of 0.73%. Irrigation water had electrical conductivity of 1.33 dS m^{-1} and pH equal to 7.9 at 25°C.

Irrigation system was installed in March 2014 and included, in each sub-plot, automatic control valves and flow meters to monitor the amount of water applied during each irrigation event. Irrigation was applied by means of two or three drip lines per tree row located either above (surface, S treatments) or below the soil surface at 0.30 m depth (subsurface, SS treatments), one meter apart from tree rows. Drip laterals were equipped with pressure compensating emitters discharging flow rates of 2.2 l h^{-1}. In order to avoid differences among treatments due to the possible root damage while installing drip lines in SS treatments two extra trenches at each side of tree rows, similarly to SS, were excavated in S treatments,. Other agronomic practices, including standard fertilization, were controlled by the farmer and followed the ordinary management of the surrounding area.

2.2. Irrigation strategies and experimental design

Five irrigation treatments replicated three times (15 sub-plots) were set according to a complete randomized design (Figure 1). Each sub-plot consisted of four rows of 6-7 trees in which 8-10 central trees were selected for sampling purposes. Within the five irrigation treatments, two S and two SS treatments were equipped with drip laterals containing 7 (S_7 and SS_7) or 14 (S_{14} and SS_{14}) emitters per tree, spaced 1.2 and 0.6 m, respectively; a further SS treatment (SS_A), similar to SS_7, was equipped with an additional drip line located between the tree rows, so that this treatment had a total of 10-11 emitters per plant.

In S treatments irrigation was scheduled based on the maximum crop evapotranspiration, ET_c, estimated with the single crop coefficient approach (Allen et al.,1998) and adjusted by accounting for the dynamic of soil water contents ($\Delta\theta$), ψ_{stem} and weather forecast (temperature, wind speed and rainfall). Reference evapotranspiration (ET_0) was estimated with the Penman-Monteith equation in the version modified by FAO (Allen et al., 1998), by using the meteorological observations acquired by two automatic weather stations located nearby the orchard. According to the canopy ground cover, the seasonal crop coefficient (K_c) was assumed variable from a minimum of 0.36 in May to a maximum of 0.56 in October, in line with the plant physiological stages (Castel, 2000). On the other hand, in SS treatments irrigation volumes were scheduled as a fraction of 80-85% of the amount provided in S treatments and adjusted weekly according to the measured ψ_{stem}. The applied reduction of irrigation doses was based on the results of previous studies in which soil evaporation was estimated as a fraction, variable between 5 and 25%, of the whole orchard ET (Fereres et al., 2003; Orgaz et al., 2006; Alves et al., 2007).

2.3. Monitoring soil and plant water status

Frequency domain reflectometry (FDR) water-content-profile probes (EnviroScan, Sentek, Stepney, Australia) were installed in treatments S_7 and SS_7, to monitor soil water contents at 0.1, 0.3, 0.5 and 0.7 m depths, at 30 min time-step. Measurements were used to monitor that soil water content at 0.1, 0.3 and 0.5 cm ranged between field capacity (θ_{FC}) and a lower limit of 80% of θ_{FC} as suggested by Martín de Santa Olalla and De Juan (1993). Readings at 70 cm depth were used to verify that there were no water losses due to deep percolation.

Midday stem water potential was measured in six trees per treatment (two trees per each sub-plot) by using a Scholander pressure chamber (Model 600, PMS Instrument Co., USA). Measurements were carried out weekly during the months of high evaporative demand and with a lower frequency during the rest of the season. In each tree, ψ_{stem} were measured in two mature leaves bagged in aluminum foil bags at least one hour before the measurements (Turner, 1981).

These measurements were used to calculate the Water Stress Integral ($S_{\psi stem}$, MPa·day), that is considered as a link between short-term stress and long-term growth response (Myers, 1988):

$$S_{\psi_{stem}} = \left| \sum_{i=1}^{t} \left(\overline{\psi_{stem_i}} - c \right) n \right|$$

where ψ_{stem_i} is the mean midday steam water potential at any time interval (*i*), *c* is a threshold of ψ_{stem} below which conditions of water stress occur, and *n* is the number of days in the interval. The threshold *c* was defined by assuming the occurrence of mild stress conditions during the year. In particular, a value of -0.9 MPa was assumed from January to the end of June and a value of -1.1 MPa for the following period, until December. The use of these thresholds is based on previous research carried out in the area and aimed to test different irrigation regimes (Ballester et al. 2014)

2.4. Yield, irrigation water use efficiency and fruit quality

Yield, number of fruit per tree (NF) and average fruit fresh weight (FW) were determined at the time of commercial harvest in all the sampled trees (fig.1). FW was determined from the total weight and the number of fruits of each tree. Irrigation water use efficiency (IWUE, kg/m^3) was calculated as ratio between crop yield and seasonal irrigation volumes applied.

Fruit quality was measured at harvest by sampling 25 fruits per sub-plot (three independent samples per treatment) randomly collected from all the sampled trees of each treatment. Fruit was weighed, squeezed with a juice machine (Zumonat, Model C-40, Barcelona, Spain) and filtered. Juice titratable acidity (TA) was determined by titration with 0.1 N NaOH (Metrohm, 785 DMP Titrino) and juice total soluble solids content (TSS) was measured with a temperature compensated digital refractometer (Atago, Palette PR-101). The maturity index (MI) was calculated as the ratio between soluble solids and acidity.

2.5. Data analysis

Data were analyzed using ANOVA and least significant difference (LSD) procedures with Statgraphics X64. In both methods, values of $P<0.05$ were chosen as standard level of significance to claim statistically significant effects. The relationships between yield and seasonal irrigation depth were also explored.

3. Results

3.1. Meteorological data and seasonal irrigation volumes

For the examined years, the average precipitation and ET_0 recorded during the three phases of fruit growth and the whole season are summarized in table 1. It was assumed that phase I of fruit growth started on day of the year (DOY) 121 in 2014, on DOY 127 in 2015, and on DOY 124 in 2016. Phase II was considered to cover from DOY 190 to 262 in 2014, from DOY 181 to 258 in 2015, and from DOY 180 to 258 in 2016. Finally, phase III was considered to take place from the end of phase II until harvesting, which occurred on DOY 309, 300 and 295 in 2014, 2015 and 2016, respectively.

Among years, 2015 was the rainiest year (309.5 mm) with rainfall mainly occurring in phases II and III of the fruit growth. On the other hand, seasonal ET_0 was characterized by a limited variability, with values ranging between 758 to 780 mm in the three years.

Average irrigation depths in all treatments were 389.4, 265.4 and 357.6 mm in 2014, 2015 and 2016, respectively, with remarkable differences between treatments compared to S_7 that was considered as the control (Table 2). On average, SS treatments allowed achieving water saving of 21.8, 24.7 and 22.4% respectively in 2014, 2015 and 2016, when compared to S treatments.

In the three years, SS system allowed reductions of total irrigation depth on average equal to 23.0%. The highest water saving was obtained in the treatment with the additional drip line between rows, SS_A, which received 25.3% less water than treatment S_7.

3.2. Soil water content and plant water status

Figure 2 shows the seasonal variation of soil water content expressed as percentage of field capacity in the four probes installed in S_7 and SS_7 treatments (Fig.1). Similar θ readings were recorded in probes installed within the same treatment. Soil water content followed the same trend in both S and SS treatments over the years. Although values of θ/θ_{FC} tended to increase during summer, the levels of soil water content in the root zone (10-50 cm depth) resulted always around the field capacity (θ/θ_{FC} = 100%).

Figure 3 shows the temporal patterns of ψ_{stem} in all treatments during 2014, 2015 and 2016. In the same figure, thresholds of ψ_{stem} used to evaluate the water stress integral, as well as rainfall events are also indicated. As it can be observed, ψ_{stem} resulted generally higher than the established thresholds (-0.9 and -1.1 MPa), except during spring and summer, when values were occasionally lower. Similar trends were observed in all the treatments, although slightly lower ψ_{stem} generally occurred in SS treatments when compared to S. Likewise, treatments with seven emitters per tree had in some periods values of ψ_{stem} lower (more negative) than those in which the number of emitters per plant was double.

For all treatments, table 3 shows the water stress integral, $S\psi_{stem}$, during the three years, as well as the corresponding values obtained in each of the examined fruit growth phases. It can be noticed that there were phases in which $S\psi_{stem}$ resulted equal to zero, being ψ_{stem} always higher (less negative) than the considered threshold. On the contrary, there were other periods in which $S\psi_{stem}$ gradually increased as a consequence of values of ψ_{stem} lower than threshold. By doubling the emitters per plant, seasonal $S\psi_{stem}$ resulted generally lower, regardless of the drip line position. However, this was not the case during the last experimental season when $S\psi_{stem}$ in treatment S_{14} was greater than the one obtained in S_7. In general, the highest annual $S\psi_{stem}$ values were registered in treatment SS_7, which reached the absolute maximum value in 2015 with 19.9 MPa·day of which 10.8 MPa·day were accumulated during the phase I of fruit growth.

The relationships between crop yield and $S\psi_{stem}$ displayed a general trend, not statistically correlated, of declining crop yield at increasing $S\psi_{stem}$ (data not shown).

3.3. Yield, fruit quality and irrigation water use efficiency

In 2014 and 2016 differences in NF were not statistically different between treatments (Table 2). Nevertheless, in 2015, SS_7 had the lowest NF, with statistically significant differences with respect to treatments S_{14} and SS_A. On the other hand, FW in 2015 was similar in all treatments, while some differences between treatments were observed in the other two seasons. In 2014, FW in treatment S_{14} was significantly higher than in all the SS treatments. In the last experimental season, SS_A was the treatment with the highest FW, with statistically significant differences compared to treatments S_7, SS_7 and SS_{14}.

In spite of these differences in FW registered in 2014 and 2016, no differences in yield were observed between treatments in those years. Only in 2015, when yield was systematically lower than 2014 and 2016, the different treatments produced a certain effect on crop yield. In particular, SS_7 treatment had the lowest yield, that resulted significantly lower to that observed in S_{14} and SS_A. The SS_A treatment had the highest average crop yield (61.9 kg tree^{-1}) in the three years, although with no statistically significant differences with the other treatments. In general, the highest average IWUE was obtained in the SS treatment (Table 2), increasing efficiency to 16.5, 22.9 and 34.3% in 2014, 2015 and 2016, respectively, compared to the S treatment. The highest average IWUE, 8.89 kg m^{-3}, was obtained in treatment SS_A.

Table 4 shows the parameters of fruit quality determined, in each season, at the time of harvest. Irrigation systems and number of emitters per tree led to significant differences in TSS, TA and MI between treatments. In 2014 and 2016, SS_7 was the treatment with the highest values of TSS and MI in contrast with the S_{14} treatment, which had the lowest values. In 2015, S_{14} was again the treatment with the lowest maturity index.

4. Discussion

The main objective of this study was to compare citrus crop performance under surface, S, and subsurface, SS, drip irrigation systems, as well as the tree response to a different numbers of emitters. FDR probes were used to monitor θ, while ψ_{stem} was determined periodically to detect plant water status in all treatments. Despite the fact that FDR probes usually require soil-specific calibration to provide accurate estimates of soil water content, for coarse-textured soils the default calibration equation proposed by the manufacturer can be considered valid and fairly accurate (Provenzano et al., 2015). FDR probes are usually used in the farming practice as a tool to manage water supply, even to prevent deep percolation. Determination of plant water status through ψ_{stem} or other methods, on the other hand, is less common in commercial productions and quite often reserved to research purposes. In the present study, FDR readings showed that soil water contents, expressed as a percentage of field capacity, were close to 100% for most of the time during summer, in both S_7 and SS_7 treatments (Figure 2). However, ψ_{stem} measurements indicated that plant water status between treatments was slightly different, with lower ψ_{stem} generally observed in treatments SS and only occasionally in treatments S (Figure 3). This result highlights the importance of monitoring the soil-plant-atmosphere continuum when scheduling irrigation under deficit conditions. Indeed, if only FDR readings had been considered in this study, plant water needs would have been underestimated in treatment SS and crop performance most likely impaired.

Over the three seasons, the SS system compared to treatment S allowed water saving of 23.0%. As mentioned above, this reduction of seasonal volume had a slightly decreasing effect on ψ_{stem}, mainly when atmospheric evaporative demand was high. However, the average reduction of seasonal volumes applied to SS treatments did not negatively affect crop yield in most of cases. Yield standard deviation resulted similar among treatments and in the three years, with values variable between about 16% and 27%. These quite high values are consequent, among others, to the variability associated to plant physiology and soil physical characteristics. Only a significant reduction in fruit number and yield was observed in 2015 in SS_7 treatment, which was likely due to the high annual $S\psi_{stem}$, most of which concentrated in phase I of fruit growth that, for citrus crop, is the most sensitive to water stress (Castel and Buj, 1993; González Altozano and Castel 2000). Moreover, on May 14, 2015, a maximum temperature of 44.5°C was recorded in the study area, which could have affected the seasonal crop performance. In fact, yield in 2015 was significantly lower than in 2014 and 2016.

Since different irrigation volumes applied to SS and S treatments did not determine different yields (with the exception of the SS_7 treatment in 2015), it could be then speculated that under the investigated conditions soil evaporation rates resulted around 20% of the entire orchard evapotranspiration. Investigations aimed at determining the evaporative fraction of an orchard are scarce. This is due to the complexity to separate the two components of evapotranspiration, as well as to the difficulty to compare studies performed under different conditions. As reported by Bonachela et al. (2001), soil evaporation is a significant part of crop evapotranspiration, particularly when ground cover is small. In a citrus orchard planted in a sandy soil and characterized by a ground cover (GC) of 39%, Villalobos et al. (2008) estimated that evaporation ranged between 32% and 40% of total evapotranspiration. Ruiz-Rodríguez et al. (2017), by simulating the water balance in a sandy clay loam and several citrus orchards with GC ranging between 30 and 40%, obtained evaporation rates between 19.0 and 21.1%, and therefore very close to water savings obtained by using SS systems in this work.

A study carried out nearby Alberique on "Clementina de Nules" citrus trees, reported that under the same amount of water applied, a subsurface drip system increased yield by 8% and IWUE by 21% compared to a conventional drip surface irrigation system (Chi Bacap et al., 2007). Romero et al. (2004) in a study in almond orchard also reported that IWUE associated to subsurface drip irrigation is 13% higher than the corresponding obtained with the same irrigation regime and drip lines laid on the soil surface. In the present work, water savings achieved in treatment SS led, on average, higher IWUE in SS treatments than in S, although differences were not statistically significant (Table 2). Nevertheless, this study only includes the results obtained during three years after the installation of SS irrigation system. Since other factors, such as for instance emitter clogging by either roots or soil particles may have compromised water delivery in SS systems (Evans et al., 2007), further research would be necessary to assess the long term crop response.

Treatments with 14 emitters per tree, as well as the one with the additional drip line had in general higher IWUE than treatments with seven emitters per tree. A larger soil wetted volume determined a positive effect on plant water status, mainly when the atmospheric evaporative demand was high. In fact, treatments S_{14}, SS_{14} and SS_A were in general characterized by the lowest annual $S_{\psi stem}$.

It is interesting to notice that SS_A treatment, which was similar to the SS_7, but with an additional drip line, led to a more efficient use of water. In fact, this treatment was set by assuming that the additional drip lines between the tree rows could have promoted root system development, so facilitating water uptake after irrigation or rainfall events. Even if assessment of root growth that could have confirmed this hypothesis was not conducted, the obtained results induce to think that the additional drip line improves the trees' performance. When compared to treatment SS_7, SS_A was generally subjected to lower crop water stress, as confirmed by the lower annual $S_{\psi stem}$, to which corresponded a significantly higher yield in 2015 and higher FW in 2016, three years after setting the plant. SS_A treatment was the one that allowed the highest water savings with respect to the S_7 and the highest IWUE over the three seasons (Table 2).

Overall, this study shows that substantial water savings can be obtained by modifying the conventional irrigation practices followed in citrus production. Using SS systems in place of the traditional with drip lines laid on the soil surface, irrigation volumes can be reduced more than 20% (25% in SS_A treatment on average for the three seasons) without yield penalty. Water saving of the same order of magnitude of those observed here has been reported to be achievable by using Regulated Deficit Irrigation (RDI) strategies (Ballester et al 2014; Gasque el al., 2009). In semi-arid areas, SS systems coupled with RDI strategies have been used in order to improve water use efficiency in almond trees, with satisfactory productive results (Romero et al. 2004).

There is therefore the possibility for water savings in citrus production by combining SS irrigation and RDI. Further research is however needed to evaluate the potential and practicality of using RDI in commercial SS irrigated citrus orchards.

5. Conclusions

In this study the performance of a citrus orchard in terms of yield, fruit quality and IWUE was assessed by comparing, over three years, five different treatments obtained by using 7 or 14 emitters per plant and drip lines laid on the soil surface or installed below it. Results indicated that the position of the drip lines as well as the number of emitters per plant are important factors affecting water use efficiency. On average, SS treatments enabled water savings without harming production, so to increase IWUE. Water savings achieved in treatments SS (23.0% on average) are indicative of the amount of soil evaporation accounts in a citrus orchard under the semi-arid conditions characterizing the Mediterranean climate. Secondly, two alternative drip systems were assessed, with seven and fourteen emitters per plant and even with an additional line between tree rows. Treatments with a greater number of emitters per plant were characterized by a better plant water status throughout the study. With treatments SS and, especially with SS_A, an efficient irrigation management without significant crop yield losses was achieved. This work brings towards the identification of the best management option, among those considered by the experiment, in terms of IWUE and water savings achievable in citrus orchards. However, a cost-benefit analysis could allow evaluating the financial feasibility of the different irrigation systems design, under different water pricing scenarios.

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Table 1. Precipitation (P) and reference evapotranspiration (ET_0) recorded during the three phased of fruit growth (from fruit setting to harvesting) and during the whole season.

	P [mm]				**ET_0 [mm]**			
	Phase I	Phase II	Phase III	Total	Phase I	Phase II	Phase III	Total
2014	42.8	15.5	66.4	124.6	320.8	358.8	78.2	757.8
2015	48.5	143.7	117.3	309.5	280.6	369.4	111.2	761.3
2016	27.6	18.5	82.1	128.2	316.9	344.0	119.0	779.8

Table 2. Values of annual irrigation depth (I) and corresponding percentages compared to $S_7(D_c)$, seasonal yield (Y), fruits number per tree (NF), fruit fresh

weight (FW), irrigation water use efficiency (IWUE), obtained in all treatments during the three years.

Treatment	**I** [mm]	**D_c** [%]	**Y** [kg tree^{-1}]	**NF** [-]	**FW** [g]	**IWUE** [kg m^{-3}]
			2014			
S_7	451.0 a[1]	100.0	66.9 a	636 a	105.9	6.3 a
S_{14}	445.1 a	98.7	70.2 a	656 a	108.4 c	6.8 a
SS_7	367.0 ab	81.4	60.3 a	592 a	102.6	7.0 a
SS_{14}	348.7 b	77.3	59.4 a	588 a	101.5 a	7.3 a
SS_A	335.1 b	74.3	67.3 a	668 a	101.7 a	8.6 a
			2015			
S_7	316.6 a	100.0	43.1 ab	423 ab	102.6 a	5.8 a
S_{14}	306.7 ab	96.9	50.2 a	487 a	103.4 a	7.0 a
SS_7	245.7 bc	77.6	36.2 b	351 b	102.9 a	6.3 a
SS_{14}	229.7 c	72.6	43.9 ab	415 ab	106.2 a	8.2 a
SS_A	228.2 c	72.1	48.4 a	466 a	105.0 a	9.1 a
			2016			
S_7	428.5 a	100.0	72.1 a	759 a	96.9 ab	7.2 a
S_{14}	411.1 a	95.9	61.7 a	618 a	103.2	6.4 a
SS_7	331.6 b	77.4	72.0 a	773 a	97.6 ab	9.3 a
SS_{14}	313.7 b	73.2	66.8 a	724 a	95.5 ab	9.1 a
SS_A	332.6 b	77.6	69.9 a	673 a	106.4 c	9.0 a

[1] Within each year, different letters indicate statistically significant differences among treatments at P<0.05

Table 3. Water stress integral ($S_{\Psi_{stem}}$) for the whole seasons (2014, 2015, 2016) and for each fruit growth phase.

Treatment	$S_{\Psi_{stem}}$ [MPa·day]			
	Seasonal	**Phase I**	**Phase II**	**Phase III**
2014				
S_7	6.5	0.0	6.5	0.0
S_{14}	3.3	0.0	3.3	0.0
SS_7	20.6	0.2	18.3	2.1
SS_{14}	6.6	0.0	6.6	0.0
SS_A	13.9	0.0	13.9	0.0
2015				
S_7	10.0	6.7	1.9	0.8
S_{14}	9.8	5.9	3.9	0.0
SS_7	19.9	10.8	6.6	1.2
SS_{14}	5.0	3.4	1.5	0.1
SS_A	10.8	5.6	4.8	0.4
2016				
S_7	14.2	0.0	8.0	6.2
S_{14}	19.5	0.0	14.2	5.3
SS_7	15.8	0.0	12.9	2.9
SS_{14}	15.2	0.0	12.2	3.0
SS_A	14.9	0.0	14.8	0.1

Table 4. Total soluble solids (TSS), titratable acidity (TA) and maturity index (MI) determined at harvest in each experimental season.

Treatment	**TSS** [°Brix]	**TA** [gl^{-1}]	**MI** [-]
2014			
S_7	11,5 ab[1]	6,4 a	18,0 a
S_{14}	11,3 a	6,3 ab	17,9 a
SS_7	11,9 b	6,0 b	19,8 b
SS_{14}	11,8 b	6,4 ab	18,6 a
SS_A	11,6 ab	6,2 ab	18,8 ab
2015			
S_7	10,2 bc	8,1 a	12,7 ab
S_{14}	9,9 a	8,2 a	12,1 a
SS_7	10,3 c	8,1 a	12,8 bc
SS_{14}	10,0 abc	7,5 b	13,3 c
SS_A	10,0 ab	7,5 b	13,3 c
2016			
S_7	12,0 ab	6,8 ab	17,7 ab
S_{14}	12,3 ab	7,0 ab	17,5 a
SS_7	12,3 bc	6,6 ab	18,9 b
SS_{14}	12,8 c	7,2 b	17,9 ab
SS_A	11,8 a	6,7 a	17,6 a

[1] Within each year, different letters indicate statistically significant differences among treatments at $P<0.05$

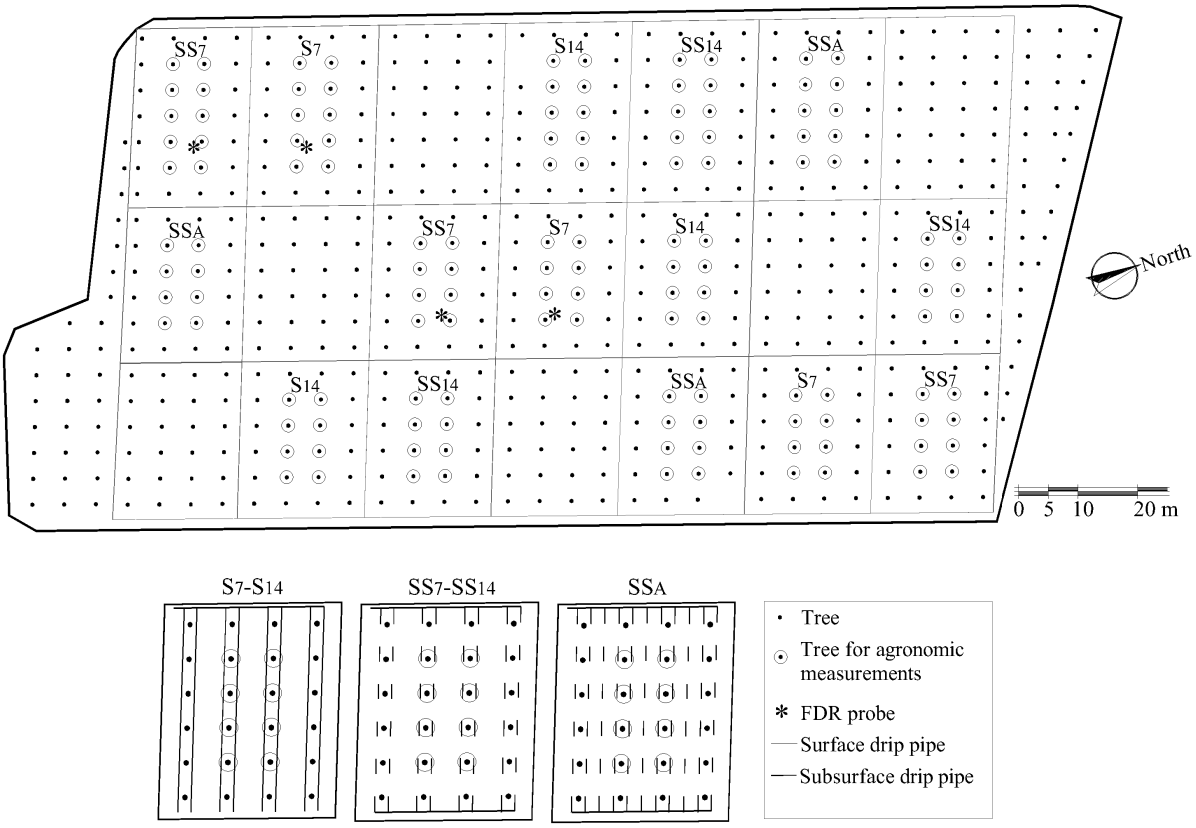

Fig. 1. Experimental layout showing the distribution of treatments in the field and the location of FDR probes and sampled trees.

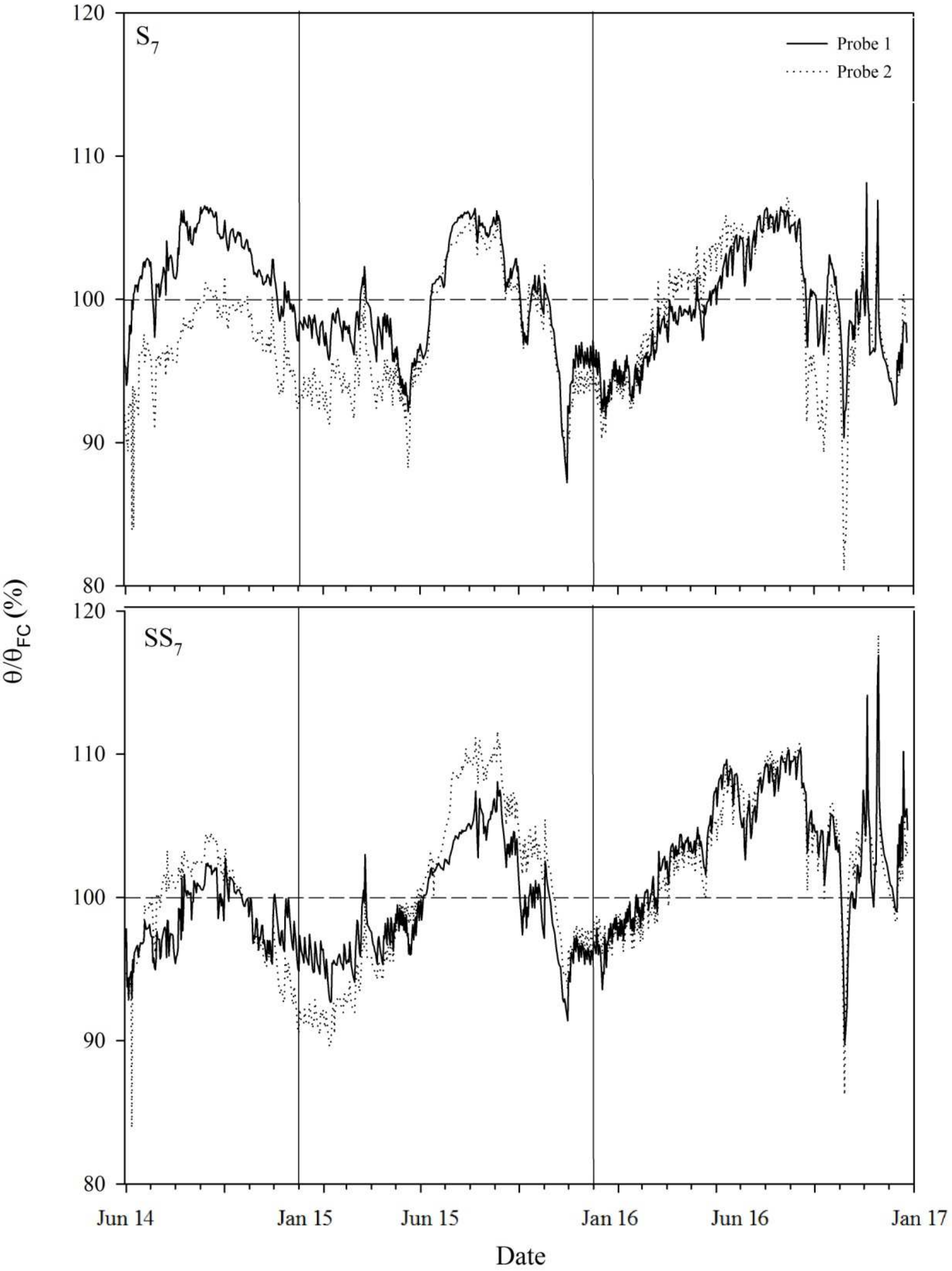

Fig. 2. Seasonal variations of soil water content expressed as percentage of field capacity (θ/θ_{FC}) in the root zone (10-50 cm depth) during 2014, 2015 and 2016. Average values from two FDR probes (probes 1 and 2) installed in S_7 and SS_7 are shown.

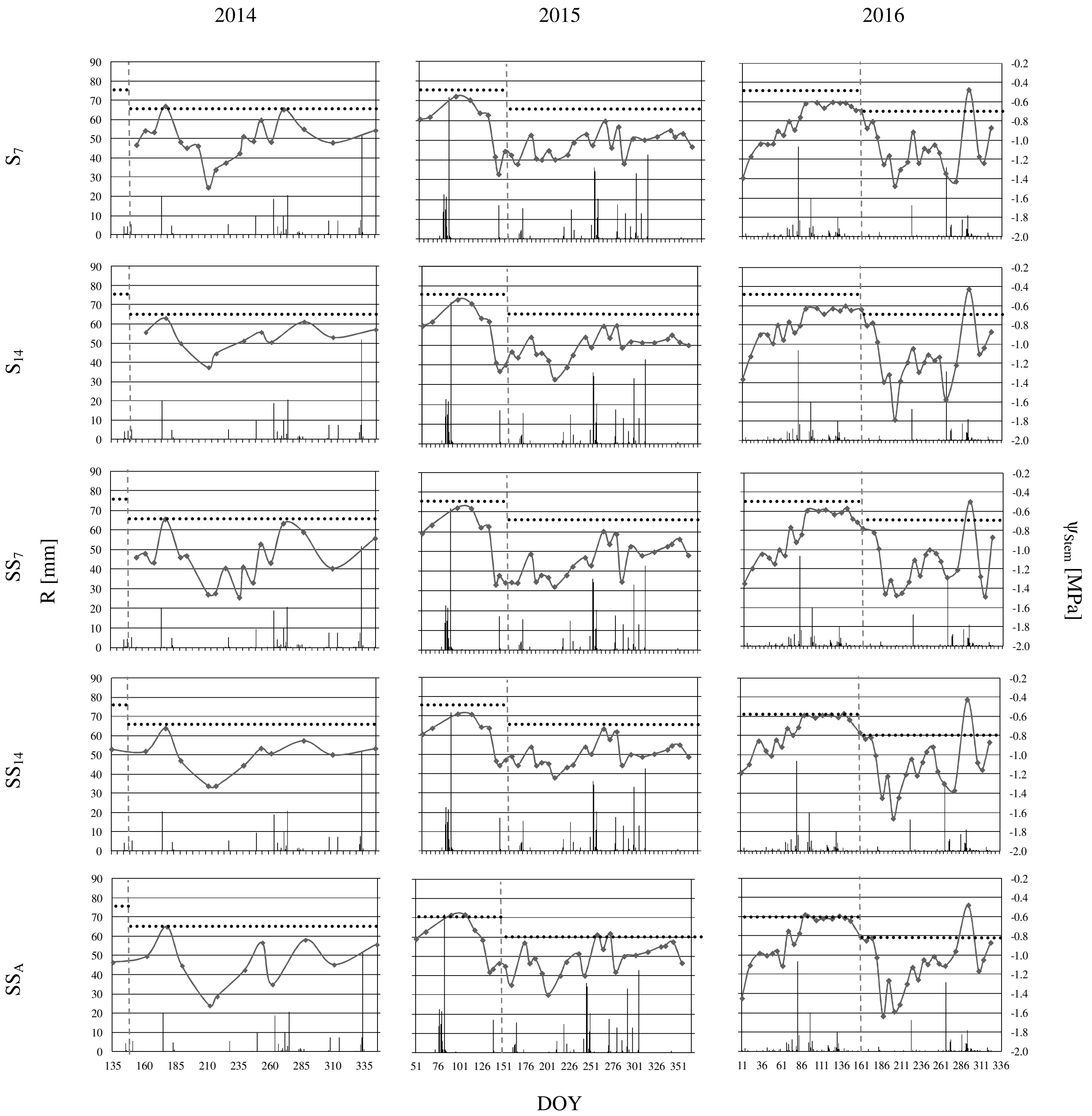

Fig. 3. Temporal patterns of precipitation (vertical bars) and midday stem water potential (ψ_{stem}) in all treatments during 2014, 2015 and 2016. Dotted lines show the thresholds of ψ_{stem} used to evaluate the water stress integral.