

Citrus Yield Response and Irrigation Water Use Efficiency under Partial Root Drying Irrigation in a Pilot Exploitation in the Triffa Plain (Eastern Morocco)

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ABSTRACT

In our experiment we have studied the effects of partial root-zone drying (PRD) on plant physiological response, plant soil water dynamics, yield and fruit quality of mature clementine trees (*Citrus clementina*) during the irrigation seasons 2017 and 2018 in an orchard located in Triffa plain (north-east Morocco). Two irrigation treatments were applied: (i) full irrigation where trees were irrigated with enough water to replace 100% of crop evapotranspiration (ET_c), and (ii) alternate partial root-zone drying (PRD) with trees irrigated at 75% ET_c (applied on one side of the root-zone while the other side was kept dry, alternating the sides every week). Results show that PRD at 75% of crop water demand (ET_c) decreased the fruit yield by 17% in 2017 and 7% in 2018 compared with the Full irrigation treatment and did not induce significant loss of crop yield. The PRD irrigation treatment, induces not only a reduction of the wetted soil volumes and transpiration rate, but also represented the highest Irrigation Water Use Efficiency (IWUE) with an increase of 11 and 21% for 2017 and 2018 respectively. Both fruit size and fruit weight decrease significantly in PRD treatment by 12–10% and 11–12% compared to Full irrigation respectively for 2017 and 2018. Titrable acidity (TA) and total soluble solids percentage (TSS) increased significantly in PRD fruit by 9–11% and 1.2–1.4% respectively for 2017 and 2018. Juice percentage decreased significantly in the first year for PRD treatment by 6% whereas in 2018 the PRD fruit had the highest juice percentage with significant difference of 3% compared to Full irrigation statically significant. Results show clear difference of rooting between irrigation strategies with an increase of the root number by the PRD treatment.

Keywords: citrus plants, irrigation efficiency, partial root drying irrigation, pilot experimentation, Triffa plain, Morocco

INTRODUCTION

Water is an essential component of agriculture and food production, which ensures food security, improves nutrition and promotes sustainable agriculture. While shortages and lack of water can have a serious impact on agriculture and food production (UN, 2018). Population growth increases demand for water for food production. According to FAO (2011), between 2011 and 2050, rising population and incomes are expected to result in

a 70% increase in global demand for agricultural production. indeed food security can only be ensured largely by irrigated agriculture which allows yields to be twice as high as those of rainfed crops (Sepaskhah and Ahmadi, 2010). However, water has become the most precious of natural resources in many areas of the world and agriculture is the largest water user worldwide, on average accounting for 70% of total freshwater withdrawals, but these amounts can reach as much as 95% in some developing countries (FAO, 2017).

Due to this effect, high crop water use efficiency through irrigation methods is of great importance in water-scarce regions. Deficit irrigation (DI) is one of the most promising strategies that would help attain this goal. It may reduce water use without significant yield reduction, but this technique requires prior knowledge of specific crop-growth stages tolerant to water stress and its effective use can be difficult for growers (Kirda et al., 2007). Past research has revealed that partial root drying (PRD) is an alternative irrigation practice to conventional DI, which involves irrigating only part of the root zone leaving the other part to dry to a predetermined level before the next irrigation.

PRD aims to impose soil moisture heterogeneity by allowing a periodic irrigation of half of the root system, while the other half is left under dry soil and time cycle alternance of wetted and dried sides of the root system depend to the type of crop, its growing stages and existing soil water content (Romero-Conde et al., 2014; Consoli et al., 2016). Indeed, in dry soil the roots can synthesize abscisic acid (ABA) which is considered as a chemical signal that can be transported to the shoot, and which can trigger a partial closure of the stomata (Zhang and Davies, 1989) as well as causes activation of genes that increase drought tolerance (Bray et al., 1999). Increased concentration of abscisic acid (ABA) in the xylem flow from roots to the leaves triggers closure of stomata (Davies and Zhang, 1991; Gowing et al., 1993) and activates genes for drought tolerance (Bray et al., 1999). Jones (1992) was shown that Partial stomatal closure could effectively reduce transpiration without limiting photosynthesis.

Citrus is an important fruit for human health and nutrition, is the most widely produced fruit and is grown in more than 80 countries (Gross et al., 2014) with a worldwide annual revenues account for more than 9.5 billion of USD. Thus, the major producers regions include arid and semi-arid areas of the Mediterranean basin such as Spain, Italy, Greece, Egypt, Turkey and Morocco (Romero-Conde et al., 2014). In these regions, annual rainfall is generally lower than crop water demands, or rainfall temporal distribution does not satisfy seasonal demands during fruit growth, that is why citrus yields heavily depend on irrigation in these areas (Consoli et al., 2016).

In Morocco, the citrus sector plays a very important socio-economic role, with an estimated area of 125 000 ha and a production of around 2.3 million T, considered as an important source

of currency and generates a lot of employment (INRA, 2017). Citrus growing consumes a lot of water and the intensification planned under the Green Morocco Plan will double or even triple the amount of irrigation water consumed by this crop (INRA, 2017). The irrigated perimeters of the lower Moulouya which include 4 plains (Triffa, Zébra, Garet and Bouareg), are considered among the most fertile areas of Morocco where the clementine and by far the most important crop, both in terms of area planted and in value (USAID, 2013). In 2012, 12187 hectares were estimated as the area of clementine originally cultivated from 54000 ha cultivated and are the first export product of the region to foreign markets (USAID, 2013). The irrigation water applied within these perimeters of the lower Moulouya comes essentially from the Mohamed V dam and the capacity of this latter is currently only 250 hm³ instead of 700 hm³ because of siltation (Feltz, 2016). The total area actually irrigated from the Mohamed V dam represents a total of around 65000 ha and for this area, the average net demand for irrigation water therefore reaches 369 hm³/year (Feltz, 2016). These contributions insufficient for agricultural needs push the farmers to make additional pumpings in the underground water table to make up for the deficit, which is reflected in addition to the droughts on the piezometric level of this one (El-Ayachi and El Mansouri, 2018).

The region's water resources are therefore under pressure, which explains the growing interest in questions relating to the use of irrigation water to remedy this situation of water shortage. As such, the application of the PRD deficit irrigation technique on citrus is of great importance since it PRD has been successfully used in several studies which indicating the benefits of this irrigation technique for fruit tree production: olive (Wahbi et al., 2005; Ghrab et al., 2013); grapevine (Santos et al., 2003, 2007; de la Hera et al., 2007); peach (Goldhamer et al., 2002); mango (Spreer et al., 2009; Jovanovic and Stick, 2018); apple (Leib et al., 2006; Zegbe et al 2007; Talluto et al., 2008); pomegranate (Parvizi et al., 2014; Noitsakis et al., 2016); Pear (Kang et al., 2002), and Citrus (Kirda et al., 2007; Panigrahi et al., 2013; Consoli et al., 2014, 2017). The objective of this work is to study the effects of PRD irrigation on physiological responses, water exchanges in the soil-plant system, crop yield and fruit quality of citrus trees in citrus orchard located in Eastern Morocco.

MATERIALS AND METHODS

Study area

The study site is an orchard with clementine trees (*Citrus clementina*), in a pilot plot of 0.4 ha located in the middle of the SLIMANIA farm with a total area of 18 ha in Triffa plain (latitude 34°55 N, longitude 2°19 O) at Berkane province. The Triffa plain, with an average altitude of 75 m and a total area of 750 km², is located in the northeast of Morocco, along the Moroccan-Algerian border (Figure 1), in the lower Moulouya basin and is bounded to the south by the Bni Snassens Mountains, which culminate at 1535 m, to the west by the Moulouya wadi, to the east by the Kiss wadi, which also delimits the border between Morocco and Algeria, and to the north by the hills of Ouled Mansour. This region is characterized by a warm semi-arid climate in the southern part, while the northwest part is semi-arid cold. The rainfall average is 329 mm, mostly distributed from September to May with a high inter-annual variability and the temperature averages alternate between 11 °C in winter, and 25 °C in summer (Alonso et al., 2019).

21-year-old trees planted in the experimental site at a spacing of 5 by 5 meters and an area pertaining to each tree of 25 m². The weather conditions of the experimental site (i.e. radiation, relative humidity, temperatures, air temperature and wind speed) were collected from the local office

which manages a meteorological station within the experimental site.

Another automatic weather station is installed between the citrus trees where data to calculate trees transpiration are logged hourly on a Campbell Scientific CR1000 datalogger during the experiments (Figures 2 and 3). The meteorological data were used to calculate daily reference evapotranspiration (ET₀) by FAO Penman Monteith method, using decision support software CROPWAT 8.0 developed by FAO.

Irrigation treatments

The trees were subjected to two irrigation treatments: a control treatment or full irrigated at 100% of crop evapotranspiration (ET_c) in which both soil compartments were watered, and a partial root-zone drying treatment irrigated at 75% of ET_c on one side of the root-zone while the other side was kept dry with alternation of the sides every week. The irrigation period was (April-October 2017 and May – October 2018). Trees of all treatments were drip irrigated using two surface lateral pipes per tree row located at 1.5 meters on each side of the tree line with 4 L·h⁻¹ emitters (spaced 0.75 m). To provide three replications, the irrigation treatments were applied to whole row of trees. During the irrigation period, water was applied every day of the week in the early morning and there is no irrigation for a few days when there is heavy rain.

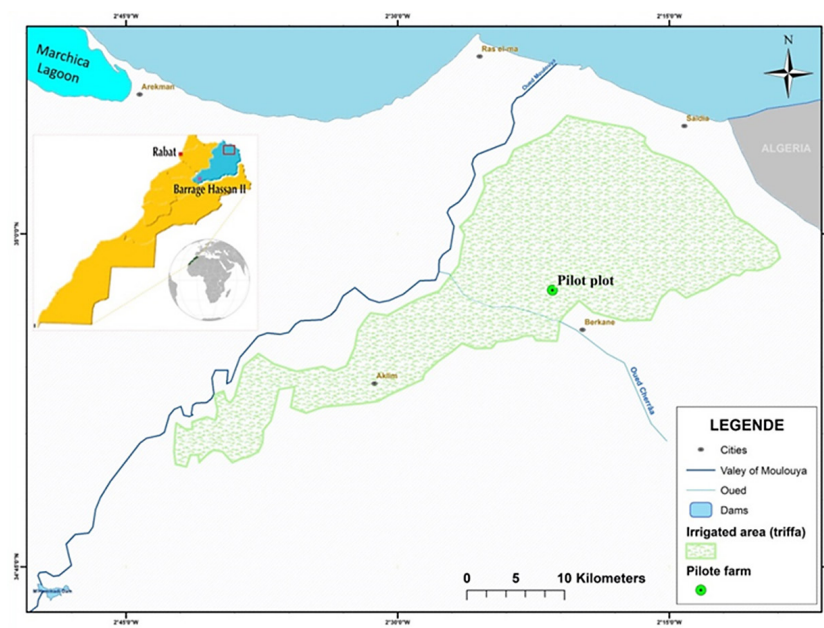


Figure 1. Map showing the location of the case study area



Figure 2. Photo of the experimental station with the measurement probes

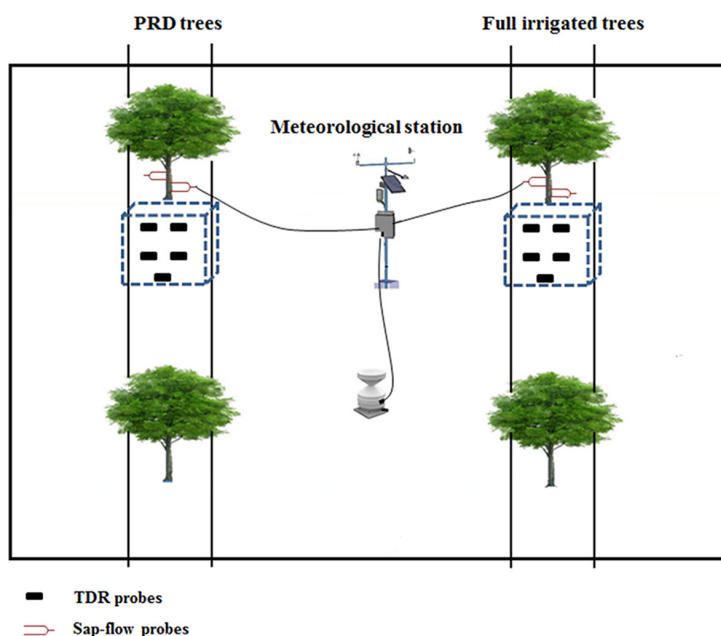


Figure 3. Diagram of the experimental station

Soil analysis and moisture content

Soil texture was determined using the Robinson pipette method (Robinson, 1922). Granulometric analysis requires application of pre-treatments to remove flocculating and cementing agents, sample dispersion, and quantification of fractions (Ruiz, 2005), for that samples are pre-treated with H_2O_2 and HCL so as to eliminate all organic matter and calcium carbonate and dispersion with sodium hexametaphosphate. Soil bulk density was measured using a small cylinder of 100 cm^3 . Soil moisture content was measured once a week by TDR (“Time Domain Reflectometry”).

Probes used in this study are Campbell Scientific CS630s and the length of the TDR probe spikes is 15 cm was calibrated for this type of soil to determine the volumetric water content. TDR probes were installed for two trees each representing a treatment (Figure 4) between two rows of drippers in the extension of the tree lines in order to be representative of the three soil horizons.

Sap flow measurements

In this study, the heat dissipation method introduced by Granier (1985) was used. This technic consists to measures sap velocity as the

temperature difference between heated and unheated probes inserted radially into the stem. Heat dissipation increases and the temperature difference between the heated and unheated probe. The material used consists of probes “sap flow” TDP100 from the Dynamax brand. The system consists of a bottom probe that serves as a reference while the top probe contains a heating element. Each of the probes contains three thermocouples for measuring the temperature. The thermocouples are at three depths, which are the same for both probes: 15, 50 and 90 mm. The probes have a total length of 100 mm and are connected to the data-logger (CR1000, Campbell Sci., USA) which records the data every hour. Two trees were selected for this purpose, one for each treatment (Full irrigation and PRD irrigation) where two probes were installed for each tree radially in the tree trunks and on opposite sides (north and south) at 15 and 20 cm from the ground for control and 35 and 40 cm at the ground for PRD treatment (Figure 4).

Fruit yield and quality

Yield and number of fruit per tree and fruit weight were determined at the time of harvest. To obtain representative samples, 30 fruits were harvested at the stage of maturity, in a random manner, at the level of all the trees of the same treatment. Picking was done on the four directions of the tree and the inner and outer stratum of the foliage. Fruits with defects have been eliminated (sun burns, damage caused by insects or diseases, etc.). After, the samples taken were analyzed at the

laboratory level in the National Institute for Agricultural Research (INRA). The juice content expressed as a percentage by mass is given by the formula (weight of the juice extracted from 30 fruits \times 100/total weight of fruits), the extraction of the juice was carried out by a rotary extractor and the collected juice is filtered through a plastic filter and weighed. Irrigation Water use efficiency (IWUE) was calculated as yield divided by irrigation applied. Juice total soluble solids content (TSS) was measured with refractometry with ABBE digital refractometer (ABBE, WYA-2S), and juice titratable acidity (TA) was determined by a titration with 0.1 N NaOH. The maturity index (MI) was expressed as ratio TSS (Brix°)/TA (citric acid %).

Root measurements

In order to evaluate the behavior of roots at different levels of irrigation, the root distribution was quantified using root count observations by using the standard trench profile wall method (Böhm, 1979), which allows an estimate of the degree of colonization of the soil by the roots without using soil samples. This consists of counting roots exposed on in the trench walls. In this respect, foursquare pits (two perpendiculars and two parallels to the shaft line of each treatment) of 1 \times 1 meter on the surface and up to about 1 meter were manually dug and the working surface was smoothed out.

Afterwards, a frame with a 5 cm square mesh grid was placed on the pit wall to facilitate the counting process and to determine the root density (number of roots/5 cm) according to each layer

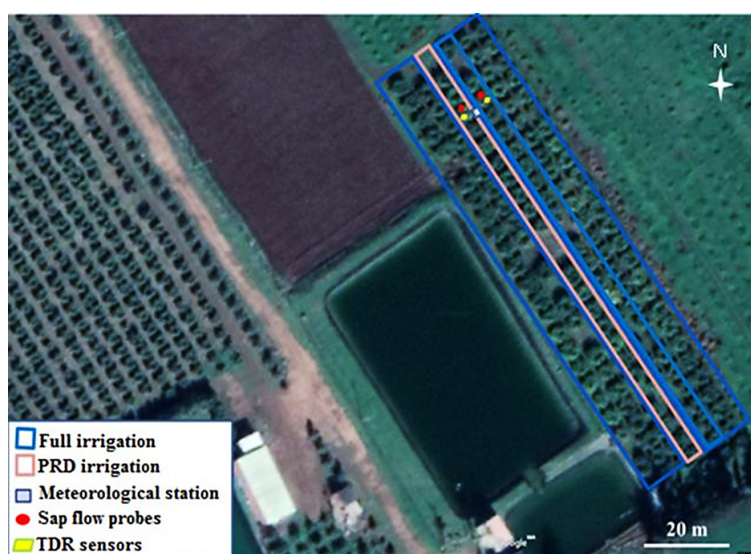


Figure 4. Experimental site with the indication of the installed equipment

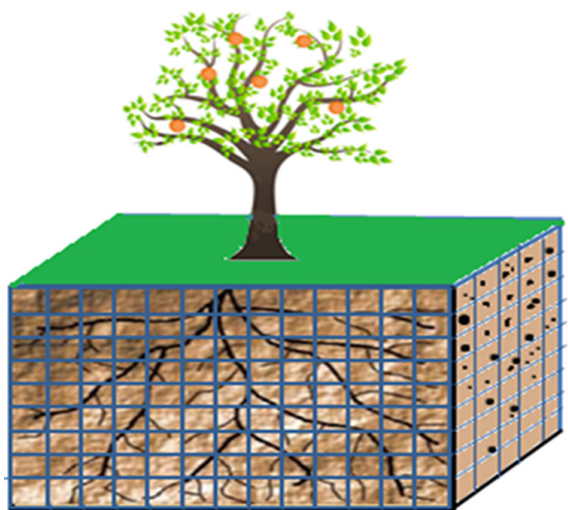


Figure 5. Scheme of position of the root profiles at the experimental site

of depth.; 0–5 cm, 5–10 cm, 10–15 cm, 15–20 cm, 20–25 cm, 25–30 cm, 30–35 cm, 35–40 cm, 40–45 cm, 45–50 cm, 50–55 cm, 55–60, 60–65, 65–70 cm, 70–75 cm, 75–80 cm, 80–85 and 85–90 (Figure 5).

In addition a distinction is made between different classes of root diameter measured using a vernier caliper. In our study, three classes of diameters were found: less than 2 mm, between 2 and 5 mm and greater than 5 mm. Observations were made after harvest for both years of study and only the results of roots smaller than 2 mm that are presented since they represent the large percentage of total roots.

Statistical analysis

Data were analyzed using SPSS software (IBM SPSS Statistics 25). Analysis of variance was performed and mean values were compared by Student test at $P = 5\%$.

RESULTS AND DISCUSSION

Climate, soil analysis and water content

The Annual mean reference evapotranspiration and rainfall in the period of study 2017 and 2018 are about 1119 mm and 312 mm respectively (Figure 6). The maximum temperature in summer during daytime often reaches 37–38 °C. Mean daily reference evapotranspiration for the study period (April–October 2017 and May–October 2018) was about $4.09 \text{ mm} \cdot \text{d}^{-1}$.

The evaporative demand (reference ET_0 rate) during the investigated irrigation seasons (April–October) in 2017 and (May–October) in 2018 was 873.76 mm and 754.4 mm, respectively. Total rainfall during the study period equal to about 41.4 and 63.6 mm, respectively.

The amount of irrigation water applied in the experimental treatments (PRD and full irrigation) is reported in Table 1.

A total of 641.1 mm and 480.8 mm of irrigation water applied to the full irrigation and PRD treatment respectively in the first year of experiment 2017, with 25% water saving. In 2018 the applied amount of irrigation water was 491.7 mm and 368.8 mm for full and PRD irrigation with always 25% water saving. The difference between amount of irrigation applied for two years due to the climatic conditions who were not very similar because in the April 2018 it was an important rainfall (126 mm) consequently irrigation doesn't applied in this month. Soil at the site was classified as a clay texture and soil bulk density of the samples is shown in Table 2. Changes in mean volumetric soil water content of each treatment of the three soil horizons during follow-up seasons 2017 and 2018 are illustrated in (Figure 7). Volumetric soil water content was not similaire for treatments. There is differences observed in the soil water distribution for the trees of two irrigation schedules. We find that under Full irrigation treatment the average soil water content for the entire monitoring period remained higher than that of PRD treatment for the 3 soil horizons. The average volumetric soil water content of the PRD treatment was lower by 42%, 28%, 14% and 41%, 24%, 14% respectively for the horizons 1, 2, 3 and for years 2017 and 2018.

Soil water content was the highest in the second horizon for the 2 irrigation treatments and for the two years of experimentation, with an average of $0.33 \text{ cm}^3/\text{cm}^3$, $0.24 \text{ cm}^3/\text{cm}^3$, respectively, for full and PRD irrigation in 2017 and $0.35 \text{ cm}^3/\text{cm}^3$, $0.27 \text{ cm}^3/\text{cm}^3$ for full and PRD irrigation in 2018. However, we find that the 1st horizon has

Table 1. Irrigation rates (mm), applied during the experimental periods of the years 2017 and 2018 for the different treatments

Years	Irrigation (mm)	
	Full irrigation	PRD irrigation
2017	641.1	480.8
2018	491.7	386.8

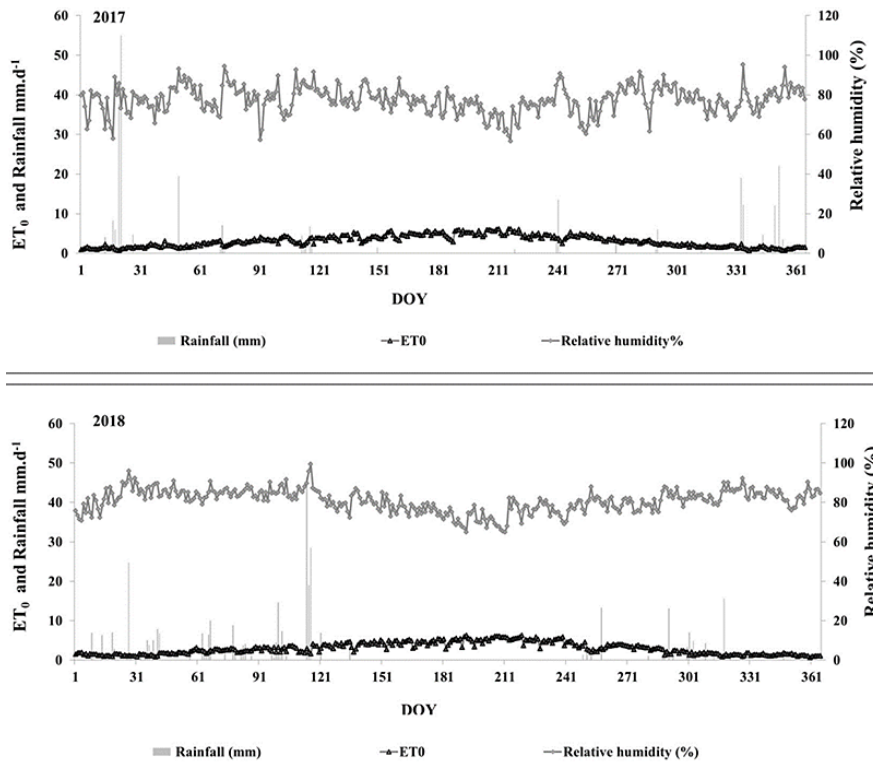


Figure 6. Climatic data recorded at the experimental site in 2017 and 2018

Table 2. Texture and bulk density of the experimental soil

Depth	Texture	Sand (%)	Silt (%)	Clay (%)	Bulk density (g·cm ⁻³)
Horizon 1	Clay	23.8	27.8	48.4	1.28
Horizon 2	Clay	19.4	24.6	56.0	1.33
Horizon 3	Clay	14.6	20.8	64.6	1.51

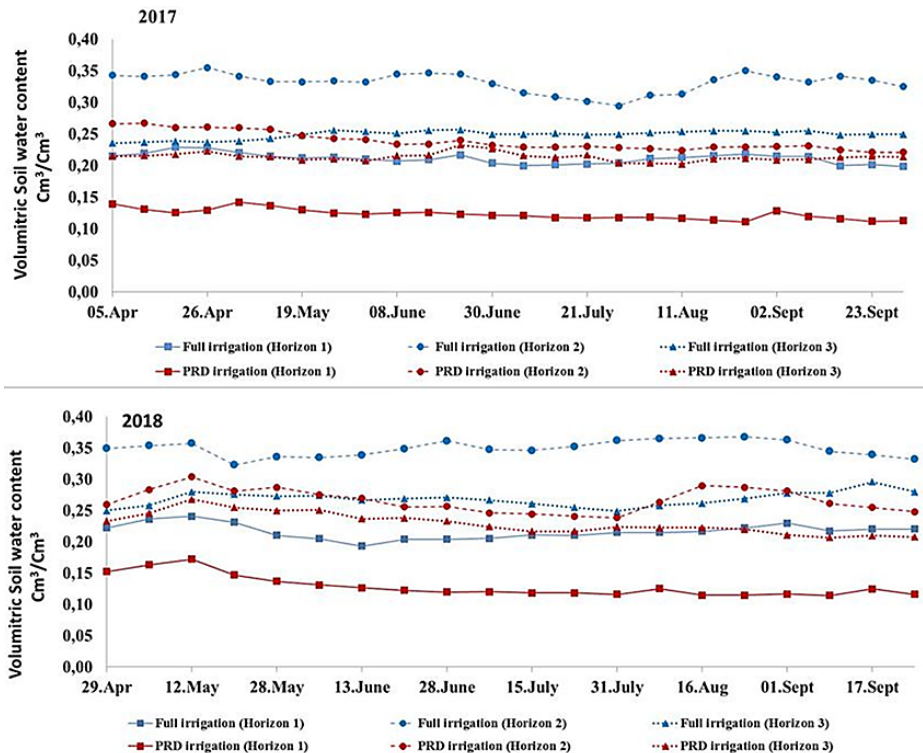


Figure 7. Evolution of soil water content in the PRD and full irrigation treatment in 2017 and 2018

the lowest value of soil water content with an average of $0.21 \text{ cm}^3/\text{cm}^3$ and $0.12 \text{ cm}^3/\text{cm}^3$ for full and PRD irrigation for the year 2017 and $0.22 \text{ cm}^3/\text{cm}^3$ and $0.13 \text{ cm}^3/\text{cm}^3$ for the year 2018. From these results, we can clearly see that the soil water content average of the control treatment is much higher than that of the PRD treatment. The soil water content values observed in other studies were generally lower for PRD treatment, compared to those for full irrigation; Savić et al. (2009) found that the average soil water content of the whole pot of the tomato was very similar to that of DI where the soil water content values were significantly lower. As for the tomato, Kirda et al. (2004) found that under both DI and the PRD treatments, soil water storage was 20–25% less than the Full treatment throughout the season. For pear trees Kang et al. (2003) indicated that the average soil water content of the whole rootzone in Full irrigation was significantly larger than that in PRD. Perez-Perez et al. (2011) found that the soil moisture content of the wet soil fraction of PRD was consistently lower than that of well-irrigated trees in citrus trees, which is also provided by the results of the study made by Consoli et al. (2017) on citrus trees. Kang et al. (2002) reported

that the soil water content on the wet side of the row of PRD plants is depleted more rapidly than the same side of the control plants, as well as they mentioned that the root system can partially compensate for water availability increasingly limited on the dry side of the row.

Sap flow measurements

It can be seen from the analysis of the daily variation in average transpiration sap flow values of treatments that PRD deviates from the Full irrigated treatment (Figure 8). The two trees of both treatments begin transpiration around 9:00 AM local time and end at almost 8:00 PM. Sap fluxes were relatively stable for much of the period from noon to 4 PM. For daily cumulative transpiration flows the values were $1.46 \text{ mm}\cdot\text{d}^{-1}$ and $0.78 \text{ mm}\cdot\text{d}^{-1}$ in 2017 and $1.32 \text{ mm}\cdot\text{d}^{-1}$ and $0.92 \text{ mm}\cdot\text{d}^{-1}$ in 2018 for full irrigation and PRD, respectively. The mean transpiration fluxes in the PRD treatment differ from that of full irrigation by approximately 46% during the first year of experience (2017) and by 30.3% in the second year (2018) (Figure 9), which corresponds to the percentage of water saved thanks to the PRD

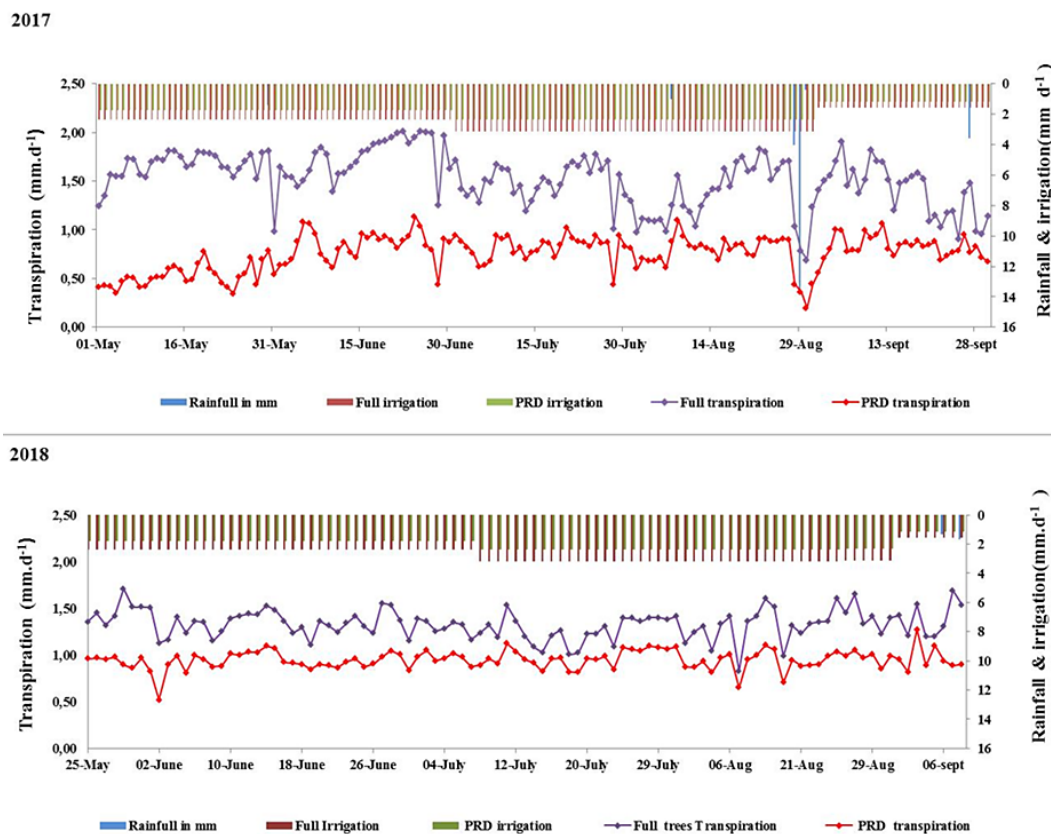


Figure 8. Evolution of trees transpiration in the full irrigation and the PRD irrigation in 2017 and 2018 with irrigation rates and rainfall

irrigation. The highest transpiration values were always recorded in the morning, contrary to the afternoon when these values began to decrease. Consoli et al. (2017) found the similar result in their study where they compared the daily variation in Vapor Pressure Deficit (VPD) and the transpiration of citrus trees and found a significant difference between morning and afternoon and that transpiration values were higher in the morning than in the afternoon, regardless of the value of the VPD. Zheng et al. (2014) explained this difference by the fact that the water supply capacity of the plants and the soil in the morning is larger than that in the afternoon. As they cited the effect of dew that appears on the exposed surfaces of plants and soil in the morning or evening as a result of condensation can also likely contribute to increasing the water supply capacity thus producing an transpiration higher in the morning than in the afternoon. Still in the citrus trees Mossad et al. (2018) found in their study that PRD and DI orange trees leaves transpired less than CI leaves and control trees consumed

significantly more (19%) water by transpiration than PRD and DI trees. In pomegranate plants, Rodríguez et al. (2012) showed that deficit irrigation and water withholding treatments reduced the leaf conductance in order to control water loss via transpiration and to avoid leaf turgor loss. Also in tomato Campos et al. (2009) found that stomatal conductance and transpiration rate were lower, up to 31% and 18%, respectively, in PRD plants compared with control.

Root distribution

It is found that the root distribution differs from one treatment to another. PRD treatment has improved the number of fine roots (<2 mm) more compared to the fully irrigated trees. It is also noted that there is even a difference between the profiles of each treatment. In fact we find that the parallel pits (under drippers) at the tree line have fewer roots compared to those perpendicular to the tree line (between the ramps) (Figure 10 and 11). In addition we can observe that the roots

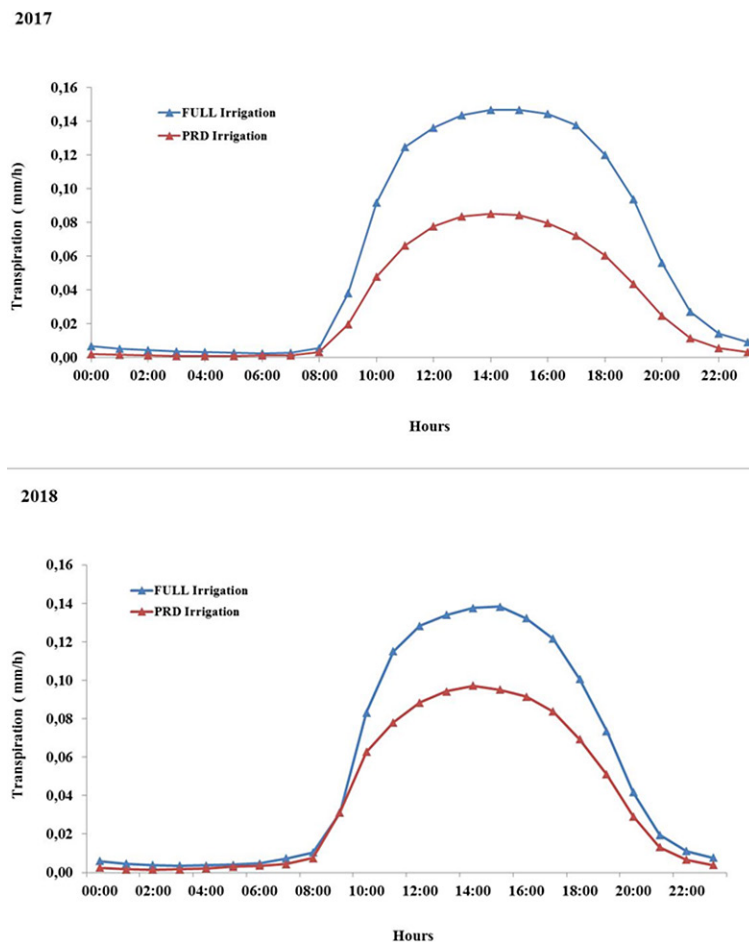


Figure 9. Diurnal changes of transpiration in citrus trees irrigated at full and by PRD irrigation during 2017 and 2018. Each data-point represents the average of all the values in the observation period

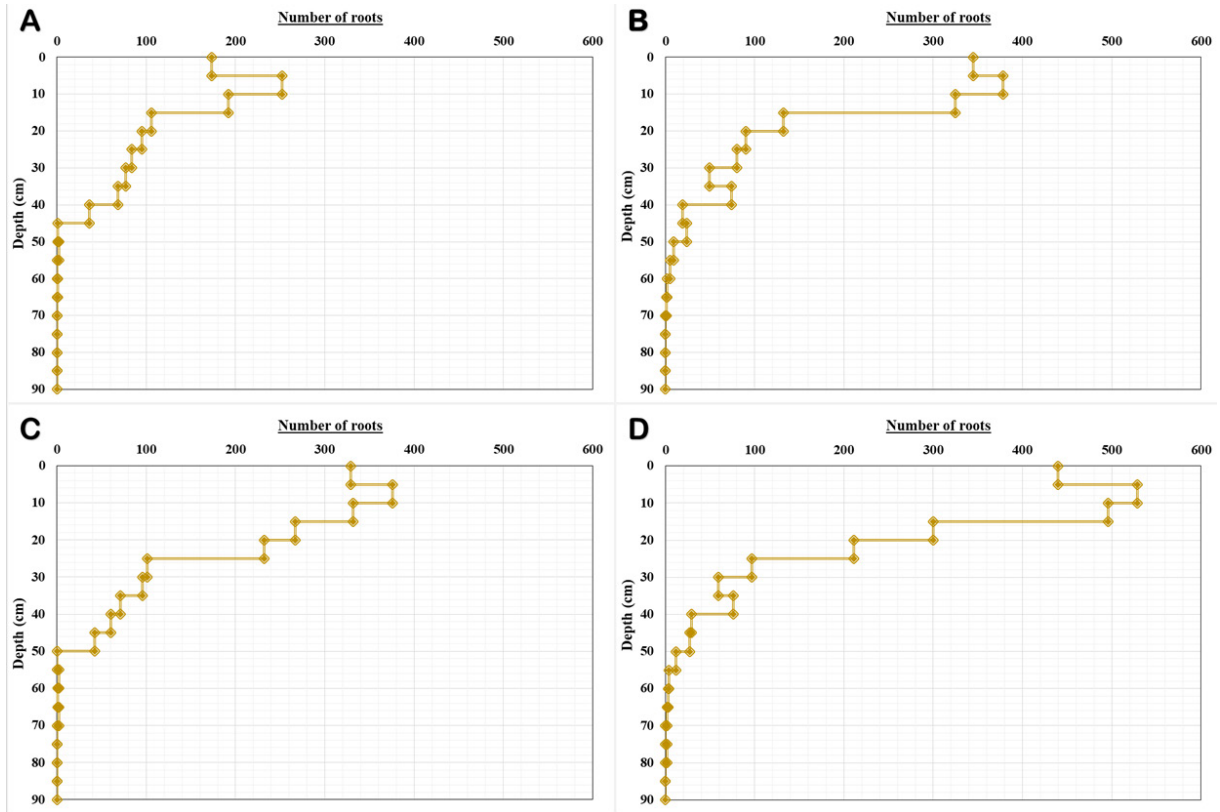


Figure 10. Parallel root profile (A) perpendicular (B) to the full irrigated trees and parallel (C) perpendicular (D) to PRD trees for the year 2018

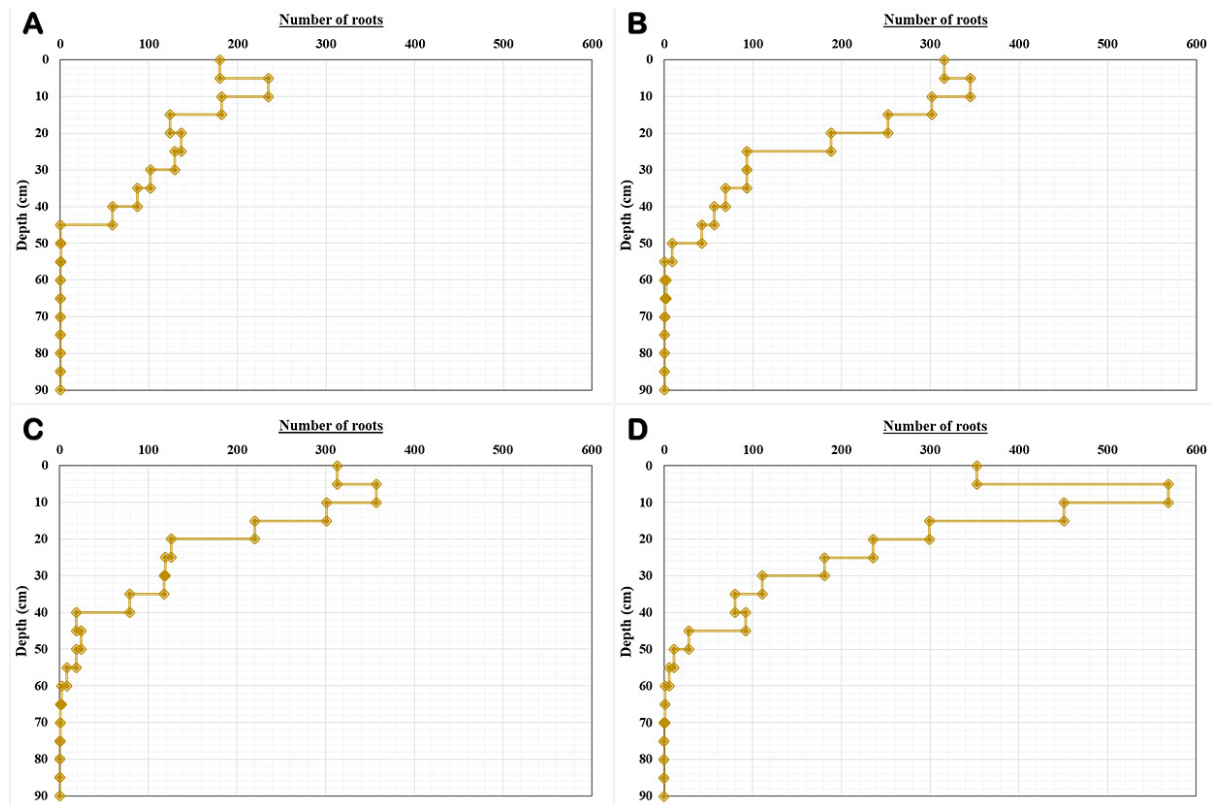


Figure 11. Parallel root profile (A) perpendicular (B) to the full irrigated trees and parallel (C) perpendicular (D) to PRD trees for the year 2019

are preferentially at the level of the first two horizons, and are generally more numerous than the roots of larger diameter, with more than 90% in the first 40 cm of the soil for both treatments and during the two years of study. Hutton et al. (2011) also found that the majority of the root zone for orange trees was limited to the top 40 cm of the soil profile for both control and PRD treatment. Mingo et al. (2004) cited that PRD induce greater root proliferation. Indeed the drying and rewetting cycle by PRD induce new roots as has been described (Kang et al., 2000; Kang and Zhang, 2004; dos Santos et al. 2007; El-Sadek, 2014; Al-emu, 2020). Melgar et al. (2010) showed that the total root length of Citrus seedlings decreased in DI treatment with respect to the control, but PRD did not affect any growth characteristics compared to control plants. The dry root zone of the PRD treatment had a higher specific root length, longer roots per dry weight, than the wet root zone. The results of a study also done for citrus (Mary et al. 2019) show clear differences in rooting between different irrigation strategies with a deeper root zone where the roots are active for PRD but not for irrigation, as well as mentioning that the rooting strategy to adapt to drought may have resulted in the formation of deeper roots. Alves et al. (2012) showed that under water deficiency, plant growth is readily inhibited and growth of roots is favored over that of leaves. However Pérez-Pérez et al. (2018) found in their study a significant change in the root distribution of citrus plants in PRD compared to control because the irrigated root zone had more root biomass than the dried portion and that root growth was stimulated in the irrigated pot with a higher biomass than PRD.

Fruit yield and quality

The effect of different irrigation treatments on fruit yields is shown in Table 3. It is found that the maximum yield was always obtained in the Full irrigation treatment. Reduction in the volume of irrigation water by 25% in PRD treatment was associated with 17 and 7% reductions in fruit yield compared with Full irrigation for 2017 and 2018 respectively but the difference is not statistically significant. In 2018, the fruit yield was about 9% lower than that of 2017 for the control trees however the PRD had a slight increase of about 1% during the same period, this difference between the two years of experience is common in orange orchards and is due to the alternating effect. Pérez-Pérez et al. (2012), Hutton and Loveys (2011), and Kirda et al. (2007) also reported that citrus yield decreased without significant loss under PRD practice. However Shahabian et al. (2012) and Consoli et al. (2017) reported that maximum yield was obtained for PRD treatment for citrus fruits.

The results of the fruit quality analysis indicate a significant increase in the percentage of total soluble solids (TSS) and titratable acidity (TA) in PRD irrigated trees but the Maturity Index (MI) decreased significantly. The PRD treatment gave higher IWUE than the Full irrigation with a difference of 10% and 19% respectively for 2017 and 2018. IWUE not being statistically significant ($P > 0.05$) in 2017, contrarily in 2018 where the difference was statistically significant. Analysis of juice percentage data indicated a reduction statistically significant in 2017, however in 2018 the juice percentage of PRD fruit was the highest with significant difference. The

Table 3. Yield, fruit quality and water use efficiency (IWUE) of full irrigated and PRD trees during the monitoring in 2017 and 2018

Year	Treatment	Yield (T/ha)	Fruit weight (g)	Calibre (mm)	Juice (%)	TA (%)	TSS (Brix°)	MI	IWUE (kg/ha/mm)
2017	Full irrigation	14.7	81.4	56.5	43.4	0.80	13.9	17.4	23
	PRD	12.3	72.7	49.7	40.9	0.88	14.1	16.0	26
Analysis of variance		ns	*	*	**	**	**	*	ns
2018	Full irrigation	13.4	90.64	58.0	40.8	0.86	13.8	16.1	27.2
	PRD	12.4	79.71	51.9	42.0	0.97	14.0	14.5	33.7
Analysis of variance		ns	*	**	*	**	*	**	*

Note: Significance levels: ns – not significant; TA – titratable acidity; TSS – total soluble solids; MI – maturity index; IWUE – Irrigation water use efficiency; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$. Separation by Student test at 95% confidence level.

PRD treatment decreases both fruit weight and diameter during the two years of study and differences was statistically significant relative to Full irrigation. Kirda et al. (2007) found similar results and mentioned that this difference is due to the strong correlation of fruit weight and size with quantity of irrigation water applied. From our results, it was found that crop yield was not significantly affected and IWUE increased due to reduced irrigation water use for PRD treatment, Hutton et al. (2011) explicated this by partial closure of stomata and reduction of wet soil volume. Also fruit quality did not affected by PRD irrigation.

CONCLUSION

Developing productive agriculture to feed a population that continues to grow while maintaining the sustainability of water resources is one of the most important challenges. As such, the sustainable use of water resources as well as adequate irrigation systems to preserve water resources and increase agricultural productivity is therefore of great importance. So the application of irrigation systems that allow good efficiency is of paramount importance in terms of minimizing the quantities of water supplied to crops. PRD irrigation is a new strategy that has been adapted over the last decade to a wide range of agronomic and horticultural crops allowing the increase of water productivity, the possibility of increasing the efficiency of use of water and in some cases maintaining or even increasing their yield and improving the quality of fruit.

Our experiment on citrus trees has shown that the physiological activity of plants as well as their productivity depends strongly on the availability of water. PRD irrigation had a significant negative impact on the average size and weight of a fruit compared to full irrigated trees. Indeed the reduction of irrigation water caused a reduction in fruit weight and size. However TSS and TA increased by PRD irrigation as well as the juice content of PRD fruit increased significantly compared to that of control trees during the second year of treatment. Citrus yield was not significantly reduced by PRD irrigation. Water use was reduced due both to reduced wetted soil volume and reduced transpiration rate by PRD trees and consequently, Irrigation water use efficiency was increased. There were also effects of PRD in root

distribution since this treatment caused an increase in number of roots compared to the control.

It can be concluded that Savings of irrigation water can be achieved if the PRD with 75% of ETc irrigation practices are adopted. PRD is water savings technique that we can use without significant losses at the yield and fruit quality in the Mediterranean regions with water scarcity to increased IWUE.

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