Conference Paper

Deficit Irrigation in Peach Orchards under Water Scarcity Conditions

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Abstract

The irrigation patterns in two peach orchards, located in the central eastern region of Portugal, called "Beira Interior", and the effect of different amounts of irrigation on the total production and fruit quality were evaluated. The experiment was conducted in 2016, in two different orchards, and included three treatments correspondent to three different flow rates per tree: 8, 12 and 16 l/hour. The water balance, which included the water supplied by rain and irrigation and the crop evapotranspiration, was developed. At harvest, crop production, pulp firmness and percentage of the total soluble solids were evaluated. There were no significant differences between treatments in the average production per tree. However, in one of the orchards production increased with the volume of irrigation. In the same orchard, fruit firmness decreased with the increasing water supply. Total soluble solids had decreased with the increasing water supply in both orchards, probably as a consequence of the dilution effect due, directly, to the water incorporated in the fruits, or, indirectly, to the larger fruits produced by the trees that were irrigated more. In general, the treatments used in this study as well as in the farmers' practices, the supplied water was in deficit, but the farmers tend empirically to follow closely the evolution of evapotranspiration.

Keywords: Deficit irrigation, Peach tree, Production, Total soluble solids, Fruit firmness

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1. Introduction

Deficit irrigation can be achieved by supplying water below the crop needs that can be represented by its evapotranspiration [1]. In stone fruits, (e.g. peaches), the deficit irrigation strategies have been used to control the excessive vegetative growing [2]. There are several approaches to deficit irrigation strategy, such as High Frequency Deficit Irrigation and Controlled Deficit Irrigation. In the first one, the water is supplied to the plants below their needs, but with an irrigation frequency that restricts the water stress signs [3]. On the other hand, the Controlled Deficit Irrigation with water restrictions is only applied in the crop development phases where this deficit has the lowest impact in production and quality [4], [5]. Both of these strategies, if correctly implemented, result in improved water use, which is especially important when that resource is scarce and crop productivity limiting [3], [6]. Additionally, the deficit irrigation strategies helps to decrease nitrate leaching, to reduce the energy consumption by the irrigation system, possibly increasing fruit quality that, consequently, can be reflected on the farmers income [7].

Water management is particularly important in the Beira Interior region of Portugal where the water is often a scarce resource.

There are several ways to quantify water use efficiency (WUE), which can be defined as the ratio between production parameters, such as the total weight of the harvested fruits or productivity, and the total water supplied to the crop [8]. In this study, *WUE* was determined by the ratio between productivity (weight of harvested fruits per area unit) and the water received by the crop (volume of water provided by rain and irrigation per area unit), as shown in Equation (1).

$$WUE = \frac{\text{Productivity}}{\text{Water Supply}} \quad (1)$$

Additionally, the restriction of the water provided to the crop may have a positive effect on fruits quality contributing, for example, to the increase in total soluble solids (TSS) [9], [10]. In order to be correctly implemented an irrigation strategy (deficit or not) should be based on soil water balance, which can provide information not only on the applied water flow rates, but also on the correct moment to irrigate. Water balance can be determined through the evaluation of the crop evapotranspiration (Et_c) and soil water content, which can result from the measurement or which can be estimated by the knowledge of the water stress (or comfort) felt by the plants. It is usually useful to combine several of these strategies [3].

The water balance methods do not require the use of costly equipment, and can be automatized through a spreadsheet with tabulated and meteorological data, which is an advantage. Equation (2) synthetizes this process [11]. θ_i represents the soil water content at day *i*, θ_{i-1} the soil water content at day *i-1*, P_i the precipitation at day *i*, SF_i the surface flow at day *i*, I_i the water provided by irrigation at day *i*, CA_i the capillary ascension by the aquifer level at day *i*, DP_i the deep percolation at day *i*, and ETc_i the crop evapotranspiration at day *i*.

$$\theta_i = \theta_{i-1} + P_i - SF_i + I_i + CA_i - DP_i - ETc_i \quad (2)$$

In many fruit trees, and particularly in peach trees, the main objectives of the water balance are to determine the irrigation schedule and the quantification of the water needs. For low moisture levels in the soil, the *CA* and the *DP* can be ignored without compromising the accuracy of the method. Contrastingly, considering the drip irrigation system (which is the most common in orchards) and the low probability of there occurring heavy rain episodes, the *SF* can be ignored as well. In this way, the equation (3) is the simplified equation of the soil water balance.

$$\theta_i = \theta_{i-1} + P_i + I_i - ETc_i \quad (3)$$

The value of θ_{i-1}, needed to start the balance, can be considered equal to field capacity (*FC*) after a period of heavy irrigation or precipitation [11].

The evapotranspiration (*ET*) consists in the total water vapour flow between of the plant surface and the atmosphere. This definition covers the water losses by transpiration and by evaporation, both from soil and wet plant surfaces [12]. The ET_c can be determined by the product of the crop coefficient K_c (tabulated) and the reference evapotranspiration, ET_0, as shown by Equation (4).

$$ET_c = K_c.\ ET_0 \quad (4)$$

When the water deficit in soil exceeds a critical level, beyond that, the plant water stress begins, it is necessary to include a stress coefficient (*Ks*) to the Equation (4), as shown in Equation (5) and suggested by FAO [11].

$$ET_c = K_c.\ K_s.\ ET_0 \quad (5)$$

In this study, ET_0 was determined by the Penmann-Monteith method [11].

The main goals of the present work was to characterize the irrigation practices in two peach orchards from the southern part of the “Beira Interior” region of Portugal, to evaluate the accuracy of the soil water content determination θ, through the simplified water balance, and to evaluate the effect of different water drip flows in fruit production and quality.

2. Materials and Methods

In pursuance of the objectives of this study two Trial Fields (TF) were implemented, in Soalheira (TF 404) and in Póvoa da Atalaia (TF 405), both located at the southern part of the Beira Interior, which is in the central eastern region of Portugal (Figure 1).

The layout of the orchard was, approximately, 2.5 m between trees in the row, and per 5 m between rows. The peach cultivars ‘Catherine’ (TF 404) and ‘Sweet Dream’ (TF 405) were used.

The meteorological conditions are typical from a Csa climate (moist, temperate with hot dry summers) according to Koppen classification and usually identified as a Mediterranean climate [13].

Figure 1: Location of the trial fields in Beira Interior region.

Three distinct treatments, corresponding to different flow rates per tree, namely T8 (8 l/h), T12 (12 l/h) e T16 (16 l/h) were implemented, achieved by the combination of 4 and 8 l/h drippers. The flow rate of each one of the drippers was verified *in loco* by direct measurement.

Each treatment had three repetitions, each one with 5 trees that includes 3 monitored trees and 2 border trees between the other treatments. The tree lines near the treatments had driplines equipped with incorporated 2.2 l/h drippers, spaced by 0.5 m (farmer irrigation system). The water supply for the driplines was located in the middle of the treeline, from where two driplines (one for each side of the tree line) were mounted. At the beginning of each dripline a water counter was placed, that allows for the determination of the total amount of water, expressed in mm, that flowed in each dripline and, consequently, that was provided to each treatment. All the treatments were subjected to the same irrigation times, defined by the farmer.

The daily water balance was determined considering the θ at 2016-05-12 equal to field capacity, because that day was preceded by heavy precipitation events which totalized 151 mm since the beginning of May. According to the soil water content determination methodology, the water provided by precipitation and by irrigation (which begins at 2016-06- 09 in the TF 404 and in 2016-06-06 in the TF 405) was added and the ET_c. was subtracted to the initial soil water content. ET_0 was determined by the meteorological data collected by the automated meteorological station (AMS), belonging to the Ministério da Agricultura, Florestas e Desenvolvimento Rural (MAFDR) and located near TF 404.

The harvest was on July 22nd and 28th, and on August 1st (TF 404) and at August 1st and 9th (TF 405). On each harvest date the number of fruits/tree and weight/tree were measured and recorded. Additionally, a sample of 3 fruits/tree was collected in order to evaluate their firmness and *TSS*. The firmness was measured with a fruit firmness tester (Penefel) with an 8 mm (diameter) test point. *TSS* was determined with the digital refractometer Palette PR 201 (Atago), using a juice drop taken from the two points were firmness was measured. Statistical treatment of the variables productivity, firmness, *TSS* and *WUE* was carried out through an analysis of variance (ANOVA) at a significance level of 5%. Means were ordered by the post- hoc Scheffé.

3. Results and Discussion

3.1. Soil water balance

One way to increase the water use efficiency in the agriculture sector is to link the water management to the crop water needs, estimated by the development of a soil water balance [14]. Nevertheless, some authors highlight that some difficulties could arise when applying deficit irrigation strategies in soils with high buffering capacity, particularly for some stress levels and time periods. The Figures 2 and 3 show the soil water content predicted by the daily water balance, resulting from water provided by irrigation and precipitation as water supply and crop evapotranspiration (ET_c) as the soil water losses.

In TF 404, the treatments T8 and T12 correspond to θ below the readily available water (*RAW*) since the beginning of June until the middle of October and just near the lower limit because of the scarce precipitation. In T16 treatment, the water deficit was lower. Nevertheless, even in this treatment, the θ was below the *RAW* limit from June to October. Considering the moment when θ equals the *RAW* limit as the indicator for the irrigation timing, the beginning of irrigation in this TF was late (end of the first week of June). In contrast, treatment T12 being the one which is closest to the farmer practice, the water provided to the crop was in a deficit amount, which might have been a limiting factor for the crop productivity.

The gross irrigation practiced in each treatment and in comparison to the non-water stress (treatment P1, 500.9 mm) were 177.9 mm in T8 (35.5% of P1), 305.2 mm in T12 (60.9% of P1), and 355.8 mm in T16 (71% of P1). Some of the water deficits applied in this

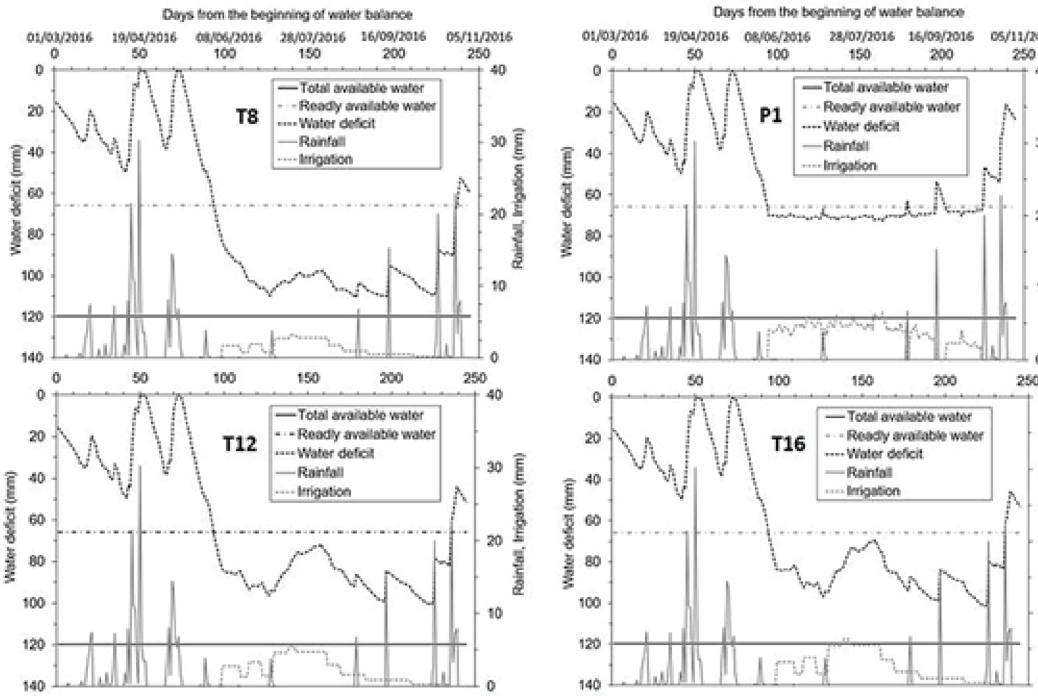

Figure 2: Water balance in the trial field 404, to the treatments T8 (8 l/h), T12 (12 l/h), T16 (16 l/h), and P1 (programmed irrigation, trees without water stress).

study relatively to the no water restriction treatment, were also used by other authors in similar studies [6].

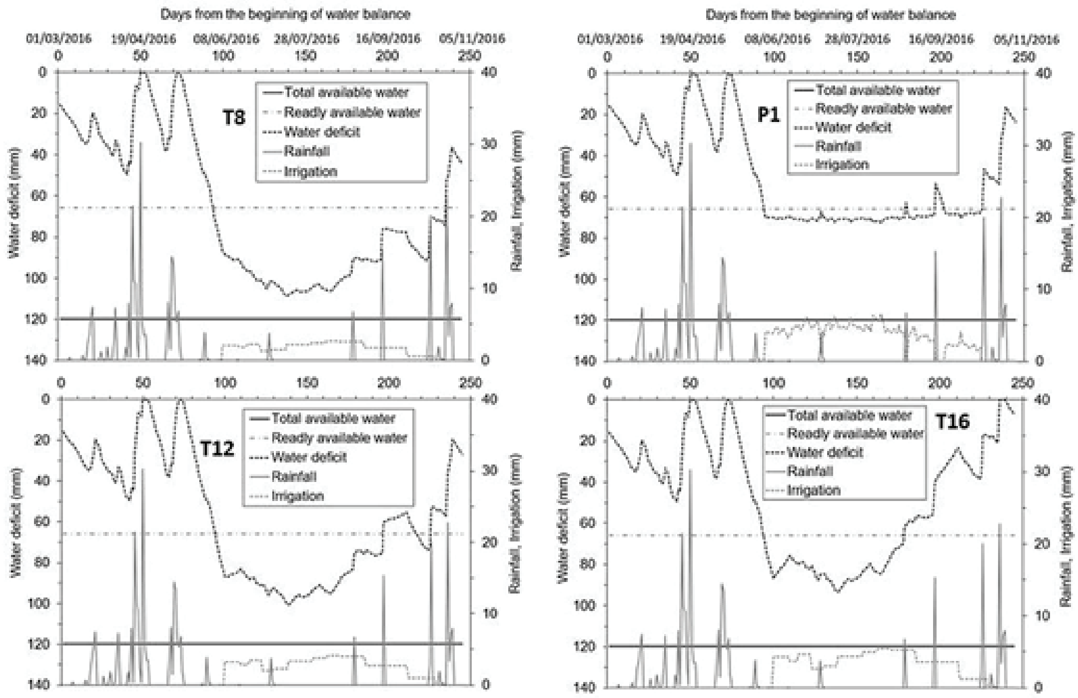

Figure 3: Water balance in the trial field 405, to the treatments T8 (8 l/h), T12 (12 l/h), T16 (16 l/h), and P1 (programmed irrigation, trees without water stress).

Similarly to the TF 404, the TF 405 farmer started the irrigation in the end of the first week of June, which was late concerning soil water content. The irrigation management between the two TF was similar and showed the farmer's empirical knowledge of trees water needs and of the periods when water needs are higher. Since the TF 405 had more water available than TF 404, the θ was systematically higher in the first TF. When compared to the non-water stress (P1; 500.9 mm), the gross irrigation practiced in each treatment were the following: T8, 245.0 mm (48.9% P1); T12, 374.2 mm (74.7% P1); T16, 490.0 mm (97.8% P1). It was clear that

the TF 405 farmer applied more water to the crop during the irrigation season probably because of having more water available than the farmer from TF 404.

3.2. Deficit irrigation

The water supply was almost always in deficit for the irrigation treatments and trial fields, with the exception of treatment T16 from TF 405. The water deficit level was higher in TF 404 than in TF 405 in all treatments, including the irrigation practised by the farmer. T12 was the closest to farmer's treatment for both TF.

The analysis of the evolution of water supply (irrigation and precipitation) and water losses (ET) shows that the deficit occurred generally in all treatments and during all the period of the study, due to water scarcity. But, in critical periods, namely in the third fruit growth stage, the water supply almost reaches the water requirement needs to prevent high water deficits that compromise the production [1], [6]. Only the treatment T16 from TF 405 showed water volume higher than the existing water, but only in the final period, in October, far beyond the fruit growing and harvesting phases.

Despite the existence of an irrigation deficit for both TF, the daily water volume that had been supplied to the plants followed a pattern that was similar to the ET_c (Figure 4). This behaviour shows that farmers had an empirical knowledge of the irrigation timing. Nevertheless, in some periods, there was insufficient water supplied to the plants in order to reset the water losses by ET [6]. This situation was particularly visible in TF 404 (Soalheira).

3.3. WUE evaluation

Relatively to the WUE indicator, as the ratio between yield and the amount of water supplied to the crop (irrigation+rainfall), no statistical differences were found between treatments in TF 404 (Table 1). In contrast with the expected, this result can be explained

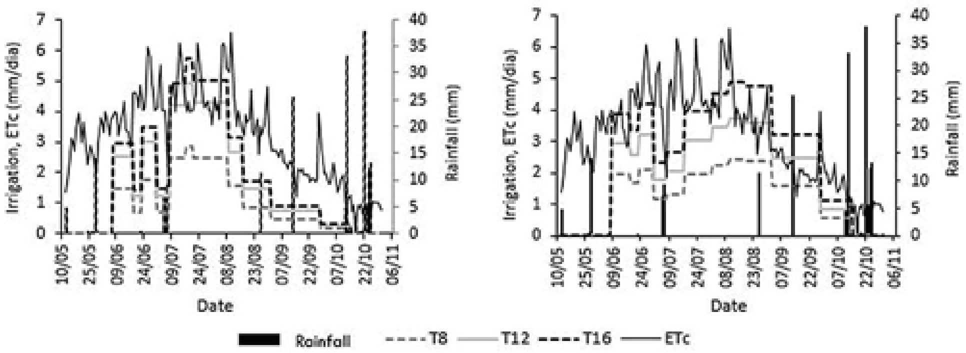

Figure 4: Precipitation, cultural evapotranspiration and irrigation for each treatment.

by the severe intensity and duration of the water stress, and the impact in vegetative growth that reducing the tree size and the number of fruit, in all treatments, the same occurred in the study of [15]. In TF 405 the treatment which received less water (T8) showed a higher WUE than the treatment with the highest flow rate (T16), a result which is similar to that described by [16]. Some authors, in semi-arid climatic conditions, achieve similar values of WUE using higher amounts of applied water, or less water deficit [6], [17]. For example, in the same study, in the treatment of regulated deficit irrigation, with a water amount of 522 mm (15% water saving relative to control), the WUE was 5.6 [6].

Table 1: Water supplied, water saving to treatment P1, yield, and water use efficiency in each treatment and trial fields.

	TF 404				TF 405			
	Water supplied	Water Saving	Yield	WUE	Water supplied	Water Saving	Yield	WUE
	(mm)	(%)	(kg tree^{-1})	(kg m^{-3})	(mm)	(%)	(kg tree^{-1})	(kg m^{-3})
T8	177.9	64.5	29.0 a	4.68 a	245.0	51.1	30.1 a	4.77 a
T12	305.2	39.1	34.7 a	4.54 a	374.2	25.3	30.0 a	3.87 ab
T16	355.8	29.0	36.3 a	4.43 a	490.0	2.2	27.8 a	3.07 b
p			0.418	0.949			0.771	0.007

Different letters in the same column indicates statistical differences at α <0.05.

3.4. Yield and fruit quality

The fruit quality was evaluated using 28 fruits/treatment, based on 3 fruits/tree. After harvesting the samples were analyzed in laboratory. The statistical differences between treatments were observed in the case of fruit firmness and total soluble solids (TSS) parameters (Table 2).

Table 2: Productivity, firmness and total soluble solids (TSS), in each treatment and trial fields.

	TF 404			TF 405		
	Productivity	Firmness	TSS	Productivity	Firmness	TSS
	(t ha^{-1})	(kg 0.5 cm^{-2})	(^{o}Brix)	(t ha^{-1})	(kg 0.5 cm^{-2})	(^{o}Brix)
T8	23.20 a	3.8 a	13.1 a	24.10 a	5.8 a	15.6 a
T12	27.80 a	3.5 ab	12.1 b	24.20 a	5.9 a	15.5 ab
T16	29.10 a	3.4 b	12.1 b	22.20 a	5.8 a	14.8 b
p	0.420	0.034	0.002	0.690	0.341	0.028

Different letters in the same column indicates statistical differences at α <0.05.

No statistical differences were observed between treatments in the case of productivity parameter in both TF, as referred in similar studies with the same objective [6], [18]. Nevertheless, TF 404 showed an increase in productivity with the increase in the water supplied, from 23.2 t/ha (treatment T8) to 29.1 t/ha (treatment T16). Considering 0.40€/kg as the average price paid to the farmer, this difference could represent 2360 €/ha more for treatment T16, when compared with treatment T8.

The firmness of the fruits in TF 404 (between 3.4 and 3.8 kg 0.5 cm^{-2}) was lower than the optimum, as described by [10] which refer to the values between 5-6 as a limit to ensure resistance to handling. This results may be related to the late harvest. However, that is not a problem because it is a cultivar mainly used for the processing industry. Faci *et al* (2014) obtained firmness values ranged between 3.3 and 3.9 kg 0.5 cm-^{2} in a study with different irrigation regimes in a semi-arid environment. The firmness of the fruits harvested in TF 405 (between 5.8 and 5.9 kg 0.5 cm^{-2}) was comprised between the interval classified as optimum according the conclusion in the study of [10]. In TF 404 significant differences were found in firmness between treatments. In that TF, the firmness of the fruits decreases from 3.8 (T8) to 3.4 kg 0.5 cm^{-2} (T16) as the supplied water increases. That result might be related with an expansion of the cells volume, resulting in a softer pulp [19]. There were significant differences between treatments for TSS in each TF. In both TF, the fruits from the treatment which received less water (T8) showed TSS values (13.1 and 15.6 ^{o}Brix for, respectively, TF 404 and 405) higher than the treatment which received more water (T16; 12.1 and 14.8 °Brix for, respectively, TF 404 and 405). It can be found studies, done in similar conditions, that confirm the results achieved in this study (Rosa *et al*, 2016), and others that found significant differences in the total soluble solids between different irrigation treatments [18]. In fact, TSS are influenced not only by the water availability, but also by the maturation stage of the fruits. In the TF 404, the firmness decreased as the water supply increase, which might indicate that the dilution effect that resulted from the increase in the water content of the fruits was an important cause for the decrease of the TSS in the TF 404. That result was similar to what was described by [10]. It should be pointed out that an increase in TSS values of fruits is not commonly related with a higher income for the farmer, despite what happens with productivity. However, an increase in the TSS values can be useful for cultivars with low TSS as it is usually the case of the ones which mature earlier.

4. Conclusions

The soil water content monitoring and its position in the water balance are essential for a rational water management, especially in regions where that resource is scarce. The determination of water balance achieved by meteorological data, for ET evaluation, and by the knowledge of the amount of water supplied by irrigation is a low cost method, with the additional advantages of being easily automatized and simple to perform. Despite the fact that the results obtained in this study confirm the viability of this methodology, it would be interesting to deepen the knowledge about its accuracy and limits of applicability.

Water is clearly a limiting factor in some of the farms from the region where the TF were located. However, the irrigation practices performed by the farmers followed the evolution of ET closely.

The WUE determination, expressed by the productivity per water received by the crop, showed that the treatment with the lowest water supply had the highest efficiency and that the WUE decreases as the water supply increases.

There were no statistical differences in productivity between treatments in either TF. However, in one of them, the productivity increase with the increase of the water supply. Statistical differences were found in the fruit firmness between treatments in one of the TF. In that TF, the firmness decreased with the increase in the water supply probably because of the softening of the fruit texture. TSS decreased with the increase of the water supply in both TF, as described in other studies.

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References

[1] Fereres, E., and Soriano, M.A. (2007). Deficit irrigation for reducing agricultural water use. J. Exp. Bot., 58(2), 147-159.

[2] Ruiz-Sánchez, M., Domingo, R., and Castel, J. (2010). Review: deficit irrigation in fruit trees and vines in Spain. Span. J. Agric. 8, 5–20.

[3] Duarte, A.C. (2016). A rega da cultura do pessegueiro. In +Pêssego - Guia prático da produção. M. P. Simões, coord. (Alcobaça: Centro Operativo e Tecnológico Hortofrutícola Nacional), pp. 123-144.

[4] Chalmers, D.J., Mitchell, P.D., and Van Heek, L. (1981). Control of peach tree growth andproductivity by regulated water supply: tree density and summer pruning. J.Am. Soc. Hortic. Sci. 106, 307–312.

[5] Buesa, I., Badal, E., Guerra, D., Ballester, C., Bonet, L., and Intringliolo, D.S. (2013). Regulated deficit irrigation in persimmon trees (Diospyros kaki) cv 'RojoBrillante'. Sci. Hortic. 159, 134–142.

[6] Rosa, J.M., Conesa, M.R., Domingo, R., Aguayo, E., Falagán, N., and Pérez-Pastor, A. (2016). Combined effects of deficit irrigation and crop level on early nectarine trees, Agric. Water Manag., 170, 120-132.

[7] Falagán, N., Artés, F., Artés-Hernández, F., Gómez, P.A., Pérez-Pastor, A., and Aguayo, E. (2015). Comparative study on postharvest performance of nectarines grownunder regulated deficit irrigation. Postharv. Biol. Technol. 110, 24–32.

[8] Costa, M., Ortuno, M.F., and Chaves, M.M. (2007). Deficit Irrigation as a strategy to save water: physiology and potential application to horticulture. J. Integr. Plant Biol. 49(10), 1421- 1434.

[9] Reddy, P. (2016). Sustainable intensification of crop production, (Singapore: Springer), pp. 404.

[10] Simões, M.P., and Ferreira, D. (2016). Qualidade dos frutos. In +Pêssego - Guia prático da produção. M. P. Simões, coord. (Alcobaça: Centro Operativo e Tecnológico Hortofrutícola Nacional), pp. 193-214

[11] Allen, R.G., Pereira, L.S., Raes, D., and Smith, M. (1998). Crop evapotranspiration. Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper No. 56, Rome.

[12] Ferreira, M.I. (1996). Evapotranspiração e stress hídrico em cobertos arbóreo-arbustivos numa perspectiva de gestão da água em região mediterrânica. An. Inst. Sup. Agron., 45, 343- 385.

[13] A.E.M., I.M. (Agencia Estatal de Metereología and Instituto de Meteorologia) (2011). Iberian climate atlas. http://www.ipma.pt/resources.www/docs_pontuais/ocorrencias/2011/atlas_clima_iberico.pdf.

[14] Saccon, P. (2018). Water for agriculture, irrigation management. Appl. Soil Ecol., 123, 793-796

[15] Pérez-Pastor, A., Ruiz-Sánchez, M.C., and Domingo, R. (2014). Effects of timing andintensity of deficit irrigation on vegetative and fruit growth of apricot trees. Agric. Water Manag., 134, 110–118.

[16] Blum, A. (2005). Drought resistance, water-use efficiency, and yield potential – are they compatible, dissonant, or mutually exclusive? Aust. J. Agr. Res. 56(11), 1159-1168.

[17] Samperio, A., Moñino, M.J., Vivas, A., Blanco-Cipollone, F., Martín, A.G., and Prieto, M.H. (2015). Effect of deficit irrigation during stage II and post-harvest on tree water status, vegetative growth, yield and economic assessment in 'Angeleno' Japanese plum. Agric. Water Manag., 217, 81-97.

[18] Faci, J.M., Medina, E.T., Martínez-Cob, A., and Alonso, J.M. (2014). Fruit yield and quality response of a late season peach orchard to different irrigation regimes in a semi-arid environment. Agr. Water Manag., *143*, 102-112.

[19] Guizani, M., Dabbou, S., Maatallah, S., Montevecchi, G., Hajlaoui, H., Rezig, M., Helal, A., and Kilani-Jaziri, S. (2019). Physiological responses and fruit quality of four peach cultivars under sustained and cyclic deficit irrigation in center-west of Tunisia, Agr. Water Manag., *217*, 81-97.