Manuscript Details

Manuscript number	AGWAT_2018_1186_R1
Title	Physiological responses and fruit quality of four peach cultivars under sustained and cyclic deficit irrigation in west center of Tunisia
Article type	Research Paper

Abstract

In arid and semi-arid regions, the research and application of new irrigation techniques that economize water without altering tree performance and fruit quality is a challenge. The aim of this study was to investigate the effect of two different deficit irrigation strategies on tree physiology and fruit quality of four Prunus persica cultivars: two early-ripening cultivars (Flordastar and Early Maycrest), a mid-season cultivar (Rubirich), and a late-ripening cultivar (O'Henry). During two consecutive seasons (2016 and 2017), three different irrigation treatments were established: i) Full Irrigation (FI; 100% ETc), ii) Sustained Deficit Irrigation (SDI; 50% ETc) and iii) Cyclic Deficit Irrigation (CDI; trees irrigated at 100 % field capacity whenever the soil moisture dropped to 50% field capacity). Tree water status, gas exchange, yield, fruit pomology and the concentrations of the main sugars and organic acids were determined. Deficit irrigation decreased net photosynthesis rate, stomatal conductance and transpiration rate while it improved instantaneous water use efficiency (WUEins). In O'Henry cultivar, WUEins increased from 3.21 μ mol mmol–1 in FI to 7.04 μmol mmol–1 in CDI during harvest. Deficit irrigation significantly reduced shoot growth in the four cultivars. Furthermore, SDI decreased the yield significantly (from 41 to 26.3 kg in O'Henry cultivar during 2016), fruit size and weight while CDI increased soluble solids and sugar contents and decreased titratable acidity. The total sugar content increased significantly under deficit irrigation in all cultivars studied. In conclusion, CDI seems to be the best strategy in semi-arid regions, since it can save water and improve fruit quality parameters.

Keywords	Prunus persica; Shoot growth; Tree water status; Sugar contents; Organic acids; Water use efficiency
Taxonomy	Agriculture, Environmental Science

Corresponding Author	Monia Guizani
Corresponding Author's Institution	Dentistry Faculty, University of Monastir, Tunisia
Order of Authors	Monia Guizani, samia dabbou, Samira MAATALLAH, Giuseppe Montevecchi, hichem hajlaoui, mourad rezig, Ahmed Noureddine HELAL, Soumaya KILANI-JAZIRI
Suggested reviewers	Xurgo Gago, J M Faci, GERARDO LOPEZ

Submission Files Included in this PDF

File Name [File Type]

cover letter.doc [Cover Letter]

review responses.docx [Response to Reviewers]

Guizani et al. 2018_AGWM hightlited.docx [Revised Manuscript with Changes Marked]

Highlights Guizani et al 2018_AGWM.docx [Highlights]

Graphical abstract Guizani et al.2018 AGWM.pdf [Graphical Abstract]

Guizani et al. 2018_AGWM final version.docx [Manuscript File]

Figures Guizani et al. 2018_AGWM.docx [Figure]

Tabels Guizani et al. 2018 _AGWM.docx [Table]

To view all the submission files, including those not included in the PDF, click on the manuscript title on your EVISE Homepage, then click 'Download zip file'.

Research Data Related to this Submission

There are no linked research data sets for this submission. The following reason is given:
Data will be made available on request

Unit of Bioactive and Natural Substances and Biotechnology UR17ES49, Faculty of Dentistry University of Monastir, Avicenne Street, 5019 Monastir, Tunisia

Pr. *Soumaya KILANI-JAZIRI*

Monastir, 08/02/2019

Editor in chief of Agricultural Water Management

Dear editor,

I have the pleasure to submit for publication **the revised manuscript** referenced **AGWAT_ 2018_1186** in your journal: **Agricultural Water Management**, of our paper according to the instructions to authors, entitled:

"Physiological responses and fruit quality of four peach cultivars under sustained and cyclic deficit irrigation in west center of Tunisia"

By: *Monia GUIZANI, Samia DABBOU, Samira MAATALLAH, Giuseppe MONTEVECCHI, Hichem HAJLAOUI, Mourad REZIG, Ahmed Noureddine HELAL, Soumaya KILANI-JAZIRI*

I confirm that this manuscript was re-submitted solely to this journal and is not published, in press, or submitted elsewhere. I have also prepared my paper and files in accordance with the journal's style and format requirements and all co-authors agree to its publication.

We are willing this paper to be considered for publication in your journal as soon as possible.

Waiting for hearing from you,

Best regards

Pr. ***Soumaya KILANI-JAZIRI***

Université de Monastir, Faculté de Médicine Dentaire , Rue Avicenne 5000 Monastir, Tunisie
Fax: + 216 73 461 150 Tel: + 216 97 316 282; ***e-mail:*** guizanimonia2018@gmail.com

You would find all modifications made in new version of our manuscript typed in red color.

We change the title of the manuscript to ‘’ Physiological responses and fruit quality of four peach cultivars under sustained and cyclic deficit irrigation in west center of Tunisia’’ as suggested the reviewer 1.

In figures and tables

In figure 1: We removed ‘’mm’’ from the legend, as asked by reviewer 1.

In figure 1, we corrected the units of ET0 to ‘’mm month-1‘’ as suggested the reviewer 2. Please see figure 1.

In figures 2, 3 and 4 we chose the same DOY for the three figures and the harvest date for each cultivar was indicated as suggested the reviewer 2. Please see figures 1, 2 and 3.

In figure 2, EMC (2016) we corrected the legend to ‘shoot growth’, as asked the reviewer 3. This was corrected in the revised version.

In figure 5, were corrected legends inside the figures as suggested the reviewer 2; please see Figure 5A and 5B

We corrected the figures legend as suggested the reviewer 2. Please see figure captions page 29 and 30.

Figures were checked and corrected as suggested the reviewer 3. Please see figures.

In the tables, we checked the significance letters in the tables. We had to compare between cultivars and between treatments. So we had chosen (a, b, c, d) to indicate significant differences between the four cultivars for each treatment and (A, B, C) to indicate significance between irrigation treatment. These significance letters was classed according to the importance of the results (a > b > c > d), and these results were analysed with Duncan test.

We changed the title of table 1 to: ‘’ Gas exchange parameters during fruit expansion and harvest for four peach cultivars subjected to three irrigation treatments during two consecutive seasons (2016 and 2017)’’ as asked by reviewer 1

We changed the title of table 2 to: ‘’Peach fruit quality traits for four peach cultivars subjected to three irrigation treatments during two consecutive seasons (2016 and 2017)’’ as asked by reviewer 1

We changed the title of table 3 to: ‘’Sugar contents (g 100 g-1 dry weight) in peel and flesh of peach fruits from four cultivars subjected to three irrigation treatments during two consecutive seasons (2016 and 2017)’’ as asked by reviewer 1

We changed the title of table 4 to: ‘’Organic acid contents (g 100 g-1 dry weight) in peel and flesh of peach fruits from four cultivars subjected to three irrigation treatments during two consecutive seasons (2016 and 2017)’’ as asked by reviewer 1.

We corrected the notation of the ‘’tr’’ over the table 4.

Abstract

We added other results in number as asked by reviewer 1: Please see line 43 – 44, page 2.

We corrected the sentence ‘’ since it can save water without altering fruit quality parameters’’ by ‘’since it can save water and improve fruit quality parameters’’ as asked by reviewer 1. Please see line 47, page 2.

Introduction

We re-wrote the fourth paragraph of the introduction and divided it into three paragraphs. We added supplementary information as asked by the reviewer 1.

The sentence in line 86 – 88, page 4 was removed to the fifth paragraph in line 85, page 4 as asked by the reviewer 1.

We added more details about the other cyclic deficit irrigation in the revised version as asked the reviewer 1. Please see line 97 – 102 and page 4 and 5.

As asked by the reviewer 1 we detail the objectives of this work. Please see line 104 – 107, page 5.

Materials and methods

In this section, we added further important information such as the soil characteristic, the experimental design, the yield and the fruit number for each treatment for the four cultivars studied as asked by the reviewers.

We added the surface of the experimental plot as asked by the Reviewer 1 in line 123, page 5.

We added more data about soil and rooting depth in the revised version as asked by reviewer 1 in line 117 – 124 page 5.

We moved the sentence in line 118 – 119, page 5, to the irrigation treatment section, in line 148, page 6 as suggested reviewer 1.

We added data on fruit growth period for the four peach cultivar studied were added in materiel and methods section as well as in figure as suggested by the reviewer 2. Please see line 129 – 133 page 6.

We added more information, about number of trees per treatment, the experiment design, the number of dripper and the flow of these drippers as asked by reviewer 1. Please see line 146 – 149, page 6.

We added the information as requested by the reviewer 1 about the shoot growth in line 175, page 8.

We added information about the number of trees per replicate and the frequency of measurement in line 181 – 183, page 8 as asked by the reviewer 1

We added information about the number of leaves per replication and measurement date of relative water content in line 190 – 192, page 8 as asked by the reviewer 1.

We corrected the abbreviation of (Pn) to (P_n) over all the manuscript.

We corrected the abbreviation of (Gs) to (g_s) over all the manuscript.

We added a definition of CO_2 In (Ci) in line 196, page 8 as suggested reviewer 1.

We added the yield and fruit number per tree for each treatment for the four cultivars studied in line 204 – 205, page 9.

We corrected the number of fruit samples in the revised version in line 207 – 208, page 9 as asked by the reviewer 1.

We added the reference for the analyses method of sugar and organic acids in line 223, page 9. As asked by the reviewer 1.

We re-wrote the section of statistical analysis in line 238 – 245, page 10 as suggested by reviewer 1.

Results

We added the total rainfall and total ET0 records in the revised version as suggested the reviewer 2. Please see revised manuscript line 250 – 258, page 11.

We added the detail of DOY corresponds to each date as asked by the reviewer 2. Please see line 261, page 11.

We added comparison between shoot growth respect to full irrigated trees in the revised version as suggested reviewer 2. Please see line 261 – 266, page 11.

We corrected the sentence in page 11, line 252 in revised version to "During 2016 and 2017, there was a slight decrease under FI strategy in early cultivars (from -0.53 MPa to -0.99 MPa)". Please see line 272 – 273, page 11 as suggested the reviewer 1.

We corrected the sentence line 265 page 11 as asked the reviewer 1. to "Flordestar had the highest water potential compared to other cultivars". Please see the revised version in line 276 – 278, page 12

We corrected and more explained the information exposed in table 1 in the revised version as recommended the reviewer 1. Please see line 287 – 297, page 12.

We added an explication of the figure 5 A and B in the results section as asked by the reviewer 1. Please see revised version line 303 – 305, page 13.

We corrected and well explained the result of Tr variation in the revised version as asked by the reviewer 1 in line 308 – 312, page 13.

We changed (Figure 4) to (Table 1), in the revised version in line 313, page 13 as asked by the reviewer 1.

We described the values of the both season studied in the revised version as asked by the reviewer 1.

We added the yield and fruit number for each cultivar, as suggested by the reviewers. Please see line 320 – 331, page 14.

We corrected the units of average firmness in the revised version. We add also, the data on average firmness for 2017 crop season in line 339 – 340, page 14 as asked by the reviewer 1.

We corrected the description of vitamin C in the revised version in line 362 – 364, page 15 as asked by the reviewer 1.

We re-write the paragraph that describe the of sugar content in the revised version in line 365 – 372, page 15 as recommended by the reviewer 1.

We re-write the description of organic acids variation as asked by the reviewer 1. Please see line from 377 – 385, page 16.

Discussion

Discussion section was revised according to the suggestion of the referee. We tried to improve and to get more in depth into our findings in the revised version.

We added an explication for the variation of shoot growth under water deficit for the cultivars studied as asked by the reviewer 1. Please see line 395 – 404, page 17.

We deleted the sentence ‘‘ Furthermore, the results obtained in this study were more expressed in 2017 season which can be explained (Figure 1) by the less amount of precipitation during this year. Consequently, the effect of the water deficit was more remarkable’’ in the corrected version because it was misplaced.

The reference of ''Scholander et al., 1965'' in line 383, page 15 is replaced by others more adequate in the revised version in line 409, page 17 as asked the reviewer 1.

The sentences in line 386 – 388, page 15 were re-written as asked the reviewer 1. Please see line 413 – 417, page 17.

The sentence in line 390, page 15 was corrected and revised in line 419, page 17 as asked by the reviewer 1.

We replaced the reference of ''Jiménez et al. (2013)'' by other more adequate. Please see the revised version in line 421, page 17.

We deleted the reference of ''Iannucci et al., 2002'' as recommended by the reviewer 1.

We corrected the reference in line 405 page 16 to ''Rahmati et al. 2015a'' as asked by the reviewer 1. Please see revised manuscript in line 434, page 18.

We deleted the sentence in line 435 – 437, page 17 in the revised version.

We added the fruit yield and fruit number. Please see line 457 – 460, page 19.

We explained the decrease in fruit size under water deficit in the revised version as suggested by reviewer 1. Please see line 462 – 465, page 19.

We got more in depth into our results and explained well the variation of firmness under deficit irrigation. Please see line 466 – 469, page 19.

We deleted the sentence in page 17, line 442 – 445 to avoid confusing.

We deleted the sentence in page 18, line 449 – 451, as suggested the reviewer 1.

We added an explanation for the increase of maturity index and consumer acceptance as requested by the reviewer 1, please see line 476 – 479, page 20.

We added detail about the concentration of sugar in peel and flesh tissues. Please see line 481 – 486, page 20.

We added an explanation for the '' decline in the use of this two components in glycolysis'' as requested by the reviewer 1. Please see line 493 – 495, page 20 and 21.

We had re-written the sentence ‘’ In this study, organic acid contents were negatively correlated with deficit irrigation in Early May Crest, Rubirich and O’Henry cultivars in flesh from fruits subjected to all treatments’’ as suggested by the reviewer 1. Please see line 497 – 498, page 21.

We added an explication in the revised version to explain the different behaviour of Flordastar cultivar as suggested reviewer 1. Please see the revised manuscript line 500 – 503, page 21.

We deleted the sentence presented in line 474, page 18 to avoid any confusion.

Conclusions

We re-wrote this section in the revised version as asked by the reviewer 1.

We removed the part in line 477 – 480, page 19 as asked by the reviewer 1.

We deleted also, the sentence in line 485 – 485, as asked by the reviewer 1.

We added information about yield and fruit number in the revised version.

We re-written the sentence in line 489 – 490, page 19 as asked by the reviewer 1.

References

References were checked as requested by the referees.

The DOI in page 20, line 505 was deleted in the revised version.

We deleted the reference ‘’Alcobendas, R., Mirás-Avalos, J.M., Alarcón, J.J., Nicolás, E., 2013. Effects of irrigation and fruit position on size, colour, firmness and sugar contents of fruits in a mid-late maturing peach cultivar. Sci. Hortic. 164, 340–347. https://doi.org/10.1016/j.scienta.2013.09.048’’ form the revised version.

We deleted the reference ‘’Etienne, A., Génard, M., Lobit, P., Bugaud, C., 2013. What controls fleshy fruit acidity ? A review of malate and citrate accumulation in fruit cells. J. Exp. Bot. 13. https://doi.org/10.1093/jxb/ert035’’ form the revised version.

We deleted the reference ’’ Falagán, N., Artés, F., Gómez, P.A., Artés-Hernández, F., Conejero, W., Aguayo, E., 2016. Deficit irrigation strategies enhance health-promoting compounds through the intensification of specific enzymes in early peaches. J. Sci. Food Agric. 96, 1803–1813. https://doi.org/10.1002/jsfa.7290'' form the revised version.

We deleted the reference '' Iannucci, A., Russo, M., Arena, L., Di Fonzo, N., Martiniello, P., 2002. Water deficit effects on osmotic adjustment and solute accumulation in leaves of annual clovers. Eur. J. Agron. 16, 111–122. https://doi.org/10.1016/S1161-0301(01)00121-6'' form the revised version.

We deleted the reference '' Jiménez, S., Dridi, J., Gutiérrez, D., Moret, D., Irigoyen, J.J., Moreno, M.A., Gogorcena, Y., 2013. Physiological, biochemical and molecular responses in four Prunus rootstocks submitted to drought stress. Tree Physiol. 33, 1061–1075. https://doi.org/10.1093/treephys/tpt074 '' form the revised version.

We deleted the reference '' Mpelasoka, B.S., Hossein Behboudian, M., 2002. Production of aroma volatiles in response to deficit irrigation and to crop load in relation to fruit maturity for "Braeburn" apple. Postharvest Biol. Technol. 24, 1–11. https://doi.org/10.1016/S0925-5214(01)00110-7 '' form the revised version.

We deleted the reference '' Naor, A., Peres, M., Greenblat, Y., Gal, Y., Ben Arie, R., 2004. Effects of pre-harvest irrigation regime and crop level on yield, fruit size distribution and fruit quality of field-grown "Black Amber" Japanese plum. J. Hortic. Sci. Biotechnol. 79, 281–288. https://doi.org/10.1080/14620316.2004.11511761 '' form the revised version.

We added the reference '' Borsani, J., Budde, C.O., Porrini, L., Lauxmann, M.A., Lombardo, V. nica A., Murray, R., Andreo, C.S., Dricovich, M.F., Lara, M. V, 2009. Carbon metabolism of peach fruit after harvest : changes in enzymes involved in organic acid and sugar level modifications. J. Exp. Bot. 60, 1823–1837. https://doi.org/10.1093/jxb/erp055 '' in the revised version

We added the reference "Chinnici, F., Spinabelli, U., Riponi, C., Amati, A., 2005. Optimization of the determination of organic acids and sugars in fruit juices by ion-exclusion liquid chromatography 18, 121–130. https://doi.org/10.1016/j.jfca.2004.01.005" in the revised version.

We added the reference '' De la Rosa, J.M., Domingo, R., Gómez-Montiel, J., Pérez-Pastor, A., 2015. Implementing deficit irrigation scheduling through plant water stress indicators in early nectarine trees. Agric. Water Manag. 152, 207–216. https://doi.org/10.1016/j.agwat.2015.01.018'' in the revised version.

We added the reference ''Domingo, R., Ruiz-Sainchez, M.C., Sfinchez-Blanco, M.., Torrecillas, A., 1996. Water relations , growth and yield of Fino lemon trees under regulated deficit irrigation. Irrig. Sci. 115–123'' in the revised version.

We added the reference ''Girona, J., Gelly, M., Mata, M., Arbone, A., Rufat, J., Marsal, J., 2005. Peach tree response to single and combined deficit irrigation regimes in deep soils. Agric. Water Manag. 72, 97–108. https://doi.org/10.1016/j.agwat.2004.09.011'' in the revised version.

We added the reference ''Jones, H.G., 2004. Irrigation scheduling : advantages and pitfalls of plant-based methods. J. Exp. Bot. 55, 2427–2436. https://doi.org/10.1093/jxb/erh213'' in the revised version.

We added the reference ''Kobashi, K., Gemma, H., Iwahori, S., 2000. Abscisic Acid Content and Sugar Metabolism of Peaches Grown under Water Stress. J. Am. Soc. Hortic. Sci. 125, 425–428'' in the revised version.

We added the reference '' Montevecchi, G., Vasile Simone, G., Mellano, M.G., Masino, F., Antonelli, A., 2013. Original article Fruit sensory characterization of four Pescabivona , white-fleshed peach [Prunus persica (L .) Batsch] , landraces and correlation with physical and chemical parameters. Fruits 68, 195–207. https://doi.org/10.1051/fruits/2013067'' in the revised version.

We added the reference '' Saidani, F., Giménez, R., Christophe, A., Chalot, G., Jesus, A. betran, Gogorcena, Y., 2017. Phenolic, sugar and acid profiles and the antioxidant composition in the peel and pulp of peach fruits. J. Food Compos. Anal. 62, 126–133. https://doi.org/10.1016/j.jfca.2017.04.015'' in the revised version.

We added the reference '' Silva, M.D.A., Moura, C., Labate, C.A., Guidetti-gonzalez, S., Borges, J.D.S., Ferreira, L.C., 2012. Chapter 6 Breeding for Water Use Efficiency, in: Fritsche-Neto, R., Borém, A. (Eds.), Plant Breeding for Abiotic Stress Tolerance. Springer-Verlag Berlin Heidelberg, p. VIII, 176. https://doi.org/10.1007/978-3-642-30553-5" in the revised version.

Highlight

We added the meaning of the abbreviations in the first highlight as asked by reviewer 1. Please see the highlight section

We agree the comment of the reviewer 1 and the sentence ‘’O’Henry cultivar was the most adaptable to water deficit in semi-arid region’’ was deleted from the revised manuscript.

The manuscript was revised by an English native speaker as suggested the reviewer 1 and 2.

======Responses to reviewers' comments=====

We have inserted and colored in red the requested modifications in the manuscript.

Reviewer 1:

==========

Specific comments to authors:

Figure 1: Remove "(mm)" from the legend.

We removed ''(mm)'' from the legend, as asked by reviewer 1.

In the tables, please, check the significance letters. Since you are showing too much information on each table, it is difficult to gather the statistical differences. In fact, looking at the standard deviation values, sometimes these statistical differences are unclear (for instance Pn among cultivars in the SDI and CDI treatments).

We checked the significance letters in the tables. We had to compare between cultivars and between treatments. So we had chosen (a, b, c, d) to indicate significant differences between the four cultivars for each treatment and (A, B, C) to indicate significance between irrigation treatment. These significance letters was classed according to the importance of the results (a > b > c > d), and these results were analysed with Duncan test.

Table 1: Change the title to "Gas exchange parameters during fruit expansion and harvest for four peach cultivars subjected to three irrigation treatments during two consecutive seasons (2016 and 2017)".

We changed the title of table 1 to: '' Gas exchange parameters during fruit expansion and harvest for four peach cultivars subjected to three irrigation treatments during two consecutive seasons (2016 and 2017)'' as asked by reviewer 1

Table 2: Change the title to "Peach fruit quality traits for four peach cultivars subjected to three irrigation treatments during two consecutive seasons (2016 and 2017)".

We changed the title of table 2 to: ‘’Peach fruit quality traits for four peach cultivars subjected to three irrigation treatments during two consecutive seasons (2016 and 2017)’’ as asked by reviewer 1

Table 3: Change the title to “Sugar contents (g 100 g^{-1} dry weight) in peel and flesh of peach fruits from four cultivars subjected to three irrigation treatments during two consecutive seasons (2016 and 2017)”. Besides, this table is confusing because there are too many comparisons within it.

We changed the title of table 3 to: ‘’Sugar contents (g 100 g^{-1} dry weight) in peel and flesh of peach fruits from four cultivars subjected to three irrigation treatments during two consecutive seasons (2016 and 2017)’’ as asked by reviewer 1

Table 4: Change the title to “Organic acid contents (g 100 g-1 dry weight) in peel and flesh of peach fruits from four cultivars subjected to three irrigation treatments during two consecutive seasons (2016 and 2017)”. Besides, this table is confusing because there are too many comparisons within it. Moreover, you used “Tr” and “tr” for abbreviate “traces”; please, be consistent and use only one form of the abbreviation.

We changed the title of table 4 to: ‘’Organic acid contents (g 100 g^{-1} dry weight) in peel and flesh of peach fruits from four cultivars subjected to three irrigation treatments during two consecutive seasons (2016 and 2017)’’ as asked by reviewer 1.
We corrected the notation of the ‘’tr’’ over the table.

Comments in the manuscript

Abstract

Comment 1: Page 2, line 41-43: Why do you show these results in numbers and not other results from your study?

We chose to show these values as an example that reflects the increase of water use efficiency. In fact such result, under water deficit, reflects an important response mechanism below drought. Under water deficit condition, instantaneous water use efficiency (WUE) has a high correlation with net photosynthesis, transpiration and stomatal conductance. However, as asked, we added other results in number. Please see line 43 – 44, page 2.

Comments 2: Page 2, line 48: Página: 3
Not true according to what you just said in the abstract. In fact, you said that CDI increased sugar concentrations and reduced acidity in fruits, so it altered fruit quality parameters.

We agree to the comment of reviewer 1, and we corrected the sentence ‘’ since it can save water without altering fruit quality parameters’’ by ‘’since it can save water and improve fruit quality parameters’’. Please see line 47, page 2.

Introduction

Comments 3: Page 3, line 52: I feel that this introduction does not reflect the state of the art within the subject of the manuscript. I suggest authors to re-write the fourth paragraph, extending the information that it contains. I recommend to divide this paragraph into several ones, with additional information.

We re-wrote the fourth paragraph of the introduction and divided it into three paragraphs. We added supplementary information as asked by the reviewer 1.

Comments 4: Page 4, line 86-88: ‘’Deficit irrigation can be used for saving water, maintaining or increasing the yield and improving water use efficiency and fruit quality (Du et al., 2017).” This sentence is not well placed here.

The sentence was removed to the fifth paragraph in line 85, page 4.

Comment 5: Page 4, line 96: What do you mean by cyclic stress? Many works exist about the use of deficit irrigation over a number of seasons, which can be considered a way to obtain a water stress in a cyclic manner

A cyclic stress is a water deficit that consists to refill the soil when water content decrease in the soil and the crop being in stress and had difficult to extract water. In our study, the kinetics of imposition consists to irrigate the soil up to field capacity when its water content fell to 50% of the field capacity.

Comment 6: Page 4, line 97-99: "Despite, this type of stress has been applied to other species such as *Laurus nobilis L.* (Maatallah et al., 2010) and *Vitis vinifera* (Gómez-del-Campo et al., 2007)*."* So what? Authors must be more clear about what has been made up to date and the results and conclusions obtained in previous studies.

We added more details in the revised version in line 97 – 102 and page 4 and 5.

Comment 7: Page 4, line 102-104: "The effects of the regime irrigation on plant shoot growth, water status, gas exchange, and fruit quality parameters were evaluated over two consecutive growing seasons." What are the hypothesis of this study? Would early or late-ripening cultivars respond differently to the two deficit irrigation strategies? Which ones would be more affected?

As asked by the Reviewer in the comment 7, the hypothesis of this study was to suppose that late-ripening cultivars will be more affected by water deficit. Furthermore, we assumed that sustained water deficit will alter the physiology and the fruit quality more than cyclic water deficit.

Materials and methods

Comment 8: Page 5, line 108: This section requires further information in order to fully describe the experiment that has been carried out. For instance, why yield or number of fruits per tree have not been assessed? Maybe crop load was different in the four cultivars studied, and this altered your results and conclusions.

We added further important information as asked by the reviewer 1, such as the yield and fruit number for each treatment for the four cultivars studied. Please see line 204 – 205, page 9.

Comment 9: Page 5, line 110: "peach orchard "Página: 4 Please, include the surface of the orchard.

We added the surface of the experimental plot as asked by the reviewer 1 in line 123, page 5.

Comment 10: Page 5, line 114: The soil was a silty clay-loam. Página: 5 More data on soil characteristics must be provided. Rooting depth ? Soil water storage capacity ? pH ? etc.

We added more data about soil and rooting depth in the revised version in line 117 – 124 page 5.

Comment 11: Page 5, line 118-119: " The irrigation water was pumped from drip irrigation with two pipes per row. "Página: 5
Move to the description of the irrigation treatments.

We moved to the irrigation treatment section, in line 148, page 6.

Comment 12: Page 6, line 132: "irrigation treatments "Página: 5
How many trees per treatment ? How was the experiment lad out ? Were there trees used as guards or borders ? How many drippers per tree ? What was the flow of these drippers ? In fact a brief description of the irrigation system should be provided : did you use counters to check the volume of water applied ?

We added the requested information, as asked Reviewer 1: ''Eighteen trees per irrigation treatment were used for each cultivar. The experimental plot was set up as a Criss-cross plot in a randomized complete block design with three blocks. Each block is divided in to two rows. Irrigation was carried out using a drip irrigation system with two lateral pipes per row and four emitters per tree. The flow was 4 L h^{-1}. Yes, we had use counters to check the volume of water applied'' in line 146 – 149, page 6.

Comment 13: Page 6, line 146-148: "CDI was a moderate stress treatment that included a cyclic soil re-irrigation up to field capacity whenever the soil moisture decreased to 50%." Página: 5
This should be further explained. When was it applied ? How did you calculate the irrigation dose to re-fill the soil ?

For CDI treatment we irrigated at 100% of filed capacity whenever the soil water stock decreases to 50% of field capacity.

CDI was applied during all the irrigation period. We calculate the water stock at the field capacity in the root zone in every 10 cm, up to root depth (0-120cm).

The water stock at the field capacity was 258.3 mm. Therefore, when the soil water stock reaches 50% of field capacity (129.2 mm), we started the irrigation. The dose to re-fill the soil was (d= 258.3 – 129.2).

Comment 14: Page 6, line 151: “to the manual Watermark moisture meter readings every 4 days.” Página: 5
Unclear. Was this made in all treatments?
We had used the tensiometric probes for trees under FI and CDI treatment.

The tensiometric probes was installed a three depths (40, 60, and 80 cm). After installation the tensiometers were left 4 days to acclimate with the soil. In the same time, Monitoring is also ensured by the gravimetric method. Daily readings were doing specially during the periods of high evaporation level.

These informations were explained in material and methods section, line 167 – 171, page 7.

Comment 15: Page 7, line 152: “The follow-up was coupled by the gravimetric method” Página: 6
What do you mean?

In addition to tensiometer reading, for each depth, we measured the soil water content by the gravimetric method. So, we determined two calibration curves (before and after irrigation) to convert the measured tension (kPa) into water content. Soil water content was determined in a soil profile from 0–1.20 m taken in 20 cm, oven dried at 105-110°C to constant weight, and then quantify soil water content of the peach root zone.

Comment 16: Page 7 line 156: “twelve shoots” Página: 6
Per tree? Per replication? Per treatment?

Twelve shoots per treatment. Four shoots were chosen per tree, in the four sides. We added the informations requested in line 175, page 8.

Comment 17: Page 7, line 157: “at random spacing “Página: 6
What do you mean?

Since this description is not precise, we decide to replace it by this sentence: “For each tree, shoots were chosen in the four sides and in the same level”. One shoots from each compass direction was chosen. See line 175, page 8.

Comment 18: Page 7, line 159: “four tagged shoots in each tree “Página: 6 So how could be selected at random spacing ?

We added this information to the manuscript as asked Reviewer 1 ‘’Shoots from previous year were chosen in the four sides and in the same level’’ in line 175, page 8.

Comment 19: Page 7, line 164-166: Remov, but indicate on how many trees per replication you measured predawn leaf water potential. Moreover, what was the frequency of these measurements?

Predawn leaf water potential was measured in four leaves from each tree. Three trees per replicate were chosen for each treatment. And these measurements were made every week. These informations were added in line 181 – 183, page 8.

Comment 20: Page 7, line 171-173: “The saturation was achieved by covering the leaves with water and leaving them in the dark at a temperature of 4 °C during 24 h, whereas DW was determined by drying the leaf in an oven at 80 °C for 48 h. “ How many leaves per replication and measurement date ?

Twelve leaves were taken in replication and the measurement was achieved once every two weeks. These informations were added in line 190 – 192, page 8.

Comment 21: Page 7, line 175: Please, correct all over the manuscript.

We corrected the abbreviation over all the manuscript.

Comment 22: Page 7, line 176: Please, correct all over the manuscript.

We corrected the abbreviation over all the manuscript.

Comment 23: Page 8, line 177: “(CO_2 Out” and “CO_2 In) “Página: 7 What do you mean?

CO_2 Out: the molar fractions of CO_2 in the atmosphere.

Ci or CO_2 In: molar fraction of CO_2 in the intercellular spaces.

Comment 24: Page 8, line 183: “Sample processing and fruit quality parameters“ Did you determine yield per tree and number of fruits per tree? This would be very interesting in order to see the performance of the four cultivars to the different irrigation treatments.

We added the yield and fruit number per tree for each treatment for the four cultivars studied in line 204 – 205, page 9.

Comment 25: Page 8, line 186: "10 fruits per cultivar" Only 40 fuits in total for the whole experiment ? This seems to be not representative. How were these fruits selected? Maybe, there is a mistake and you collected 10 fruits per cultivar and irrigation treatment, which is still a low number but more adequate for a study of these characteristics. If not, there is a strong bias on sampling because 10 fruits is less than 10% of the whole crop load carried by peach trees at commercial loading.

We agree with your comment and we corrected this mistake in the revised version in line 207– 208, page 9.

Comment 26: Page 9, line 206-213: "The obtained extracts were analyzed in a HPLC system (Hewlett-Packard series 1100) equipped with a Supelcogel C-610H column (300 × 7.8 mm i.d.), connected to a guard Supelcogel TM carbohydrate pre-column (50 × 4.6 mm), and with a stationary phase of sulfonated polystyrene divinilbenzene. The isocratic separation of sugars and organic acids was performed at 30 °C, using a mobile phase of 0.1% phosphoric acid pumped into the column with a flow rate of 0.5 mL min^{-1}. The quantification of sugars was carried out with a refractive index detector (RID), and the organic acids were quantified using an Ultra-Violet detector (UV) at a wavelength of 210 nm." Please, indicate a reference for this method.

As asked by the Reviewer 1, we added the reference in line 223, page 9.

Comment 27: Page 9, line 217: "Statistical analysis" This sub-section should be revised and re-written again in order to clarify the statistical methods used. In fact, it seems that you analyzed statistically fruit compositional traits but not physiological aspects. Be careful with what you are stating here in order to avoid any confusion.

We analysed both physiological aspects and fruit quality traits. Duncan multiple comparison test was used to (i) discriminate among mean values obtained with the three irrigation treatments applied on each cultivar and to (ii) compare the four cultivars studied.

For shoot growth, leaf water potential and relative water content, we analysed differences among the three irrigation treatments.

For gas exchange parameters and fruit quality traits, we analysed differences among irrigation treatments and among cultivars. In addition, Student-t test was used to compare peel and flesh. We re-wrote the section of statistical analysis in line 238 – 245, page 10.

Comment 28: Page 9, line 220: "among means". Among treatments you mean?

It was the difference among treatments and cultivars. This was corrected in the revised version.

Comment 29: Page 9, line 220-221:"Duncan test was used to compare means between cultivars and ripening dates" Why ripening dates? Did you harvest the same cultivar on different dates?

We agree with your comment and we corrected the mistake in line 240, page 10. For each cultivar, we picked the fruit at one date (commercial stage). Duncan test was used to compare means between cultivars and between irrigation treatments.

Comment 30: Page 9, line 222: "All analyses were carried out in triplicate" Do you mean the statistical analyses?

Yes, all analyses were carried out in triplicate.

Results

Comment 31: Page 11, line 252:" (-0.53 MPa and -0.99 MPa)" For which cultivar ?

We corrected in revised version in line 272 – 273, page 11 "During 2016 and 2017, there was a slight decrease under FI strategy in early cultivars".

Comment 32: Page 11, line 265: "high water potential (-2MPa)" This is not high. In fact, for an early-maturing cultivar, is very low. I mean very negative and likely indicating moderate to severe water stress

We corrected this comment in revised version in line 276 – 278, page 12 "Flordestar had the highest water potential compared to other cultivars".

Comment 33: Page 11, line 268-271: "The average values of Pn for FI varied from 9.43 to 11.41 µmol $m^{-2}s^{-1}$ and while for SDI it was only between 4.91 and 7.36 µmol $m^{-2}s^{-1}$ in all the cultivars studied during fruit growth. Furthermore, Pn values in CDI were significantly higher than SDI." Explain better. In the table you have two dates and here you do not mention this fact. Moreover, in the table you present a huge amount of information, but here you only scratched the surface of your data.

This was corrected and more explained it in the revised version. Please see line 287 – 297, page 12.

Comment 34: Page 12, line 283-284: "No significant differences were detected in Tr values among the cultivars studied (Table 1)" Not true in the harvest stage according to Table 1.

This was corrected and well explained in the revised version in line 308 – 312, page 13.

Comment 35: Page 12, line 285: "(Figure 4)" This figure shows RWC not WUE. It should be Table 1.

This was corrected in the revised version in line 313, page 13.

Comment 36: Page 12, line 292: "Fruit quality traits " It is not clear how these data are described in the text since authors sometimes commented values for a given year but, some other times, they referred to both seasons studied.

In the revised version we described the values of the both season studied.

Comment 37: Page 13, line 302-303: "The average firmness in FI treatment varied from 4.16 to 6.48 kg 0.5 cm^{-2} in the four cultivars". This is only for 2016. Check the units, in the table is kg per cm2, while here is kg per 0.5 cm^2.

The unit used for firmness is kg cm^{-2}. It was corrected in the revised version and data on average firmness for 2017 crop season were added in line 339 – 340, page 14.

Comment 38: Page 13, line 322-323: "Fruits from CDI were the richest in vitamin C (7.13 mg $100g^{-1}$ in O'Henry fruit during 2017)." Página: 10

According to Table 2, this is not true for all cultivars, especially in 2017.

We agree the comment and the sentence was corrected in the revised version in line 362 – 364, page 15.

Comment 39: Page 14, line 327-332: "There was a significant difference among the four cultivars in the amounts of sucrose, glucose, and fructose. Furthermore, these amounts varied significantly between peel and flesh tissues. O'Henry fruits had the highest concentrations of total sugars (64.16 and 59.67 g100 g^{-1} DW in FI during 2016 and 2017, respectively). These results showed that SDI and CDI strategies improved significantly the sugar content in both tissues (peel and flesh)." Here you mixed factors and the text is confusing. Please, improve writing.

The sentences were corrected in the revised version in line 365 – 372, page 15 and 16.

Comment 40: Page 14, line 339-341: "while for citric and succinic acids the reduction was not significant ($p > 0.05$). Furthermore, SDI and CDI strategies had drop the total organic acids contents in flesh parts of all cultivars, except for Flordastar fruits." Not true according to table 4. Please, check your results in order to avoid these inconsistencies.
We agree the comment and the sentences were corrected in the revised version. Please see line from 377 – 386, page 16.

Discussion

Comment 41: Page 14, line 366: Página: 11
This section is extremely weak. In fact, it is a repetition of results with the addition of statements indicating the agreement or the lack of agreement among the results observed in the current study and those from other authors. What is new here? It is nice that your results agree with those from previous studies but your discussion should get more in depth into your findings.

Discussion section was revised according to the suggestion of the referee. We tried to improve and to get more in depth into our findings in the revised version.

Comment 42: Page 14, line373-376: ''The effect of CDI varied among cultivars; it exerted the same effect as SDI for early cultivars (Flordatar and Early May Crest) that have a short cycle of fruit development. Whereas, for Rubrish and O'Henry cultivars, the vegetative growth was significantly higher in CDI regime than that exposed to SDI.'' Why may this different effect be caused ? Duration of CDI ? Maybe because of the different atmospheric demands on the times in which the growing cycle of each cultivar occurs?

We added an explication of this part in the revised version in line 395 – 404, page 16.

Comment 43: Page 15, line 379-381: ''Furthermore, the results obtained in this study were more expressed in 2017 season which can be explained (Figure 1) by the less amount of precipitation during this year. Consequently, the effect of the water deficit was more remarkable'' Why? Irrigation was higher, I presume.

This sentence was deleted in the corrected version because it was misplaced. The lack of precipitation during 2017 season increased the effect of water deficit in the tree physiology because the precipitation refill the soil and thus decrease the intensity of the water stress for the trees. Irrigation rates are calculated according to the needs of the trees and the moisture content in the soil.

Comment 44: Page 15, line 383: ‘’(Scholander et al., 1965)’’ This is not the right citation here. In fact, this is the study that proposed the method; consequently, when it was published, the method was not worldwide accepted as the most accurate.

This reference is replaced by others more adequate. This was corrected in the revised version in line 409, page 17.

Comment 45 : Page 15, line 386-388: ‘’These results are consistent with Intrigliolo and Castel (2006) in plum and Rahmati et al. (2015a) in peach trees which showed a significant decrease in predawn water potential under severe stress treatment’’ All right, but this is widely known.

We re-write this sentence in the revised version. Please see line 412 – 417, page 17.

Comment 46: Page 15, line 390: ‘’engendered’’ What do you mean?

We corrected the word ‘’engendered’’ by ‘’showed’’. Please see revised in line 419, page 17

Comment 47: Page 15, line 393: ‘’those reported by Jiménez et al (2013)’’ These guys studied rootstocks and not cultivars. Please, check the reference

We agree with the comment as asked by the reviewer 1 and the reference is replaced by other more adequate. This was corrected in the revised version in line 421, page 18.

Comment 48: Page 15, line 397: ‘’low Ψ_b’’ Very negative ?

We corrected the sentence as follows “O’Henry cultivar, maintained the higher RWC (66%) and a very negative Ψb (-2.84 MPa) under SDI treatment during 2017 season”. Please see line 425 – 426, page 18.

Comment 49: Page 15, line 397: (Iannucci et al., 2002): Nice, but this citation does not refer to trees

We agree with the comment as asked by the reviewer 1 and the reference was deleted.

Comment 50: Page 15, line 398-399: "O'Henry cultivar, in the present study, where RWC was higher than 66% and the Ψb was (-2.84 MPa) under SDI treatment during 2017 season" Would these results be caused by the fact that the growing cycle of this cultivar spans for a longer period ?

These results would be caused by the higher crop yield and by to the longer growing cycle period. This was corrected in the revised version in line 426 – 427, page 18.

Comment 51: Page 15, line 400: ''the cultivars were able to tolerate the water stress conditions'' But this is in contradiction with what you just commented about O'Henry cultivar.

We agree with the comment as asked by the reviewer 1 and the sentence was corrected in the revised manuscript in line 428 – 430, page 18.

Comment 52: Page 16, line 405 "Rahmati et al (2015)" a or b ?

We corrected the refrence in the revised maniscript in line 434, page 18.

Comment 53: Page 16, line 414-419: "The positive correlation of gs and Pn presented in Figure 5 (coefficient of correlation, r = 0.91) confirm that gs governs Pn, and the limitation of gs induces a decrease in the photosynthetic assimilation. In addition, the significant correlation (r = 0.89) between Pn and the intercellular CO_2 concentration (Ci) might indicate the presence of stomatal limitations in our study (Figure 5)" This figure was not explained in the results section

We added an explication of this part in the results section. Please see revised version line 303 – 305, page 13.

Comment 54: Page 17, line 428: "which represents the main obstacle in arid and semi-arid regions" What? A good efficiency in water use is an obstacle in arid and semi-arid regions? Please, check this sentence.

This sentence was misplaced and we deleted it in the revised version. Please see line 455, page 19.

Comment 55: Page 17, line 433: "blocks the cells" What do you mean?

The word “blocks” was a mistake and we corrected it by “affected cell expansion”. Please see line 462, page 19.

Comment 56: Page 17, line 435: “Rahmati et al. (2015)” a or b ?

We corrected the reference in the revised version. Please see line 461, page 19.

Comment 57: Page 17, line 435-437: “mentioned that a low leaf stomatal conductance reduced the peach fruit weight and size at harvest. Fruits obtained from SDI were more affected by the water stress and had a smaller size compared to fruits obtained from CDI” So what if they mention this ? Very well, what is new ?

We deleted these sentences in the revised version.

Comment 58: Page 17, line 436-337: “Fruits obtained from SDI were more affected by the water stress and had a smaller size compared to fruits obtained from CDI” These are results and not discussion

We corrected the sentence in the revised version. Please see line 463 – 465, page 19.

Comment 59: Page 17, line 440-441: “This has been proven by many authors, such as Alcobendas et al. (2013) for peach, Mpelasoka and Hossein Behboudian (2002) for apple and Naor et al. (2004) for plums” All right, so what is new in your study?

This was corrected in the revised version and we got more in depth into our results. Please see line 466 – 469, page 19.

Comment 60: Page 17, line 442-444: “restriction of division and dilation of pulp cells, as well as an increase in the density of the flesh cell and the thickness of the palisade tissue (Zhou et al., 2017)” You did not observe this.

We agree with the comment as asked by the reviewer 1 and the sentence was deleted from the revised manuscript.

Comment 61: Page 17, line 445: ‘’Conversely, Crisosto et al. (1994) found no significant difference in fruits firmness under regular deficit irrigation in peach.” All right, so what ?

This was deleted in the revised version.

Comment 62: Page 18, line 449-451: "Ascorbic acid and Dehydroascorbic Acid (DHA: oxidized form) are the major forms of vitamin C. Falagán et al. (2016) showed an increase in DHA in peach fruits exposed to water deficiency" So what ? You did not measure DHA or ascorbic acid

We agree with the comment as asked by the reviewer 1 and the sentence was deleted from the revised manuscript.

Comment 63: Page 18, line 465: "As a consequence, there was a significant increase in the maturity index (SSC/TA) which may increase consumer acceptance" Why ? Provide an explanation.

We added an explanation as requested by reviewer1, please see line 476 – 479, page 20 and 21.

Comment 64: Page 18, line 464-465: "This is a result in a decline in the use of this two components in glycolysis (Maatallah et al., 2015)" Unclear meaning

An explanation was added as requested, please see line 493 – 495, page 20.

Comment 65: Page 18, line 469-471: "In this study, organic acid contents were negatively correlated with deficit irrigation in Early May Crest, Rubirich and O'Henry cultivars in flesh from fruits subjected to all treatments" This sentence does not make sense.

We agree with the comment as asked by the reviewer 1 and the sentence was re-written. Please see line 500 – 501, page 21.

Comment 66: Page 18, line 471: "While, it was not the case for Flordastar" Why Flordastar behaved differently from the other cultivars ?

An explication was added in the revised version. It could be genotype specific manner. The exact mechanism by which deficit irrigation influences the organic acid concentration in the fruit during its growth and maturation is not well investigated. Please see the revised manuscript line 500 – 503, page 21.

Comment 67: Page 18, line 471-473: "These results are in agreement with those described by Ripoll et al. (2014) in many species (notably peach, clementine, mandarin, pear)": These authors found also that water deficit reduced organic acid contents in fruits or, as the case of Flordastar, they found the contrary?

These authors found also that water deficit reduced organic acid content in fruits. However, other authors found no significant effect of water deficit in the organic acid content as the case of Flordastar. This was corrected in the revised version. Please see line 503 – 505, page 21.

Comment 68: Page 18, line 474: ''However, Etienne et al. (2013) showed that in nectarines this correlation was positive'' So what ?

To avoid any confusion, we deleted this sentence.

Conclusions

Comment 69: Page 19, line 476: Well, the first part looks like a summary and then there are several statements that are hypothetical. This section must be re-written.

We re-write this section in the revised version. Please see line 511 – 521, page 21 and 22.

Comment 70: Page 19, line 477-480: This looks like a summary. I would remove it.

We removed this part in the revised version.

Comment 71: Page 19, line 484-485: You did not make any test on consumers, so you cannot conclude this.

We agree with the comment as asked by the reviewer 1 and the sentence was deleted.

Comment 72: Page 19, line 487-488: Not true since no indication on yield has been given

We added information about yield and fruit number. This was corrected in the revised version. Please see line 320 – 331, page 13 and 14.

Comment 73: Page 19, line 489-490: Too hypothetical from a two-year study.

We agree with the comment as asked by the reviewer 1 and the sentence was re-written.

Comment 74: Page 20, line 495: I suggest the authors to check their reference list according to the journal guidelines for authors.

References were checked as requested, please see reference section

Comment 75: Page 20, line 505: This is not the correct DOI.

We agree with the comment as asked by the reviewer and we deleted the DOI in the revised version. Please see line 527, page 22.

Highlight

Comment 76: I suggest to define the meaning of the abbreviations in the first highlight.

The meaning of the abbreviations were added in the first highlight as asked by reviewer 1, please see the highlight section

Comment 77: This is not true. You did not consider yield or number of fruits per tree, you cannot say that this cultivar is the most adapted to water deficit.

We agree with the comment as asked by the reviewer 1 and the sentence was deleted from the revised manuscript.

Reviewer 2:
==========

The authors refer to 'Fruit growth cycle', 'fruit growing', … but each cultivar has a different fruit growth period (duration in days), and no mention is made in the text of the manuscript. Please indicate in M&M and in the Figures.

Data on fruit growth period for the four peach cultivar studied were added in materiel and methods section as well as in figure as requested by reviewer 2. Please see line 129 – 133 page 6.

Cyclic deficit irrigation must be better described, how the irrigation was managed,…

We added the description of cyclic water deficit in the revised version as asked by the reviewer 2. Please see line 162 – 164, page 7.

Specific comments to authors:

Abstract

L-37: soil moisture dropped to 50% of what? How it was measured? Please indicate the value of field capacity of the soil?

Soil moisture dropped to 50% of field capacity.

We calculate the water stock at the field capacity in the root zone in every 10 cm, up to root depth (0-120cm).

We found that water stock at the field capacity was 258.3 mm. Therefore, when the water stock reaches 50% of field capacity (129.2 mm), we start the irrigation.

The irrigation dose (mm) = 258.3 - 129.2

The field capacity of the soil varied between 19.2 and 23.5 %.

Materials and Methods

L-103: Size of the plot and of the area of each cultivar (numbers of trees) of each cultivar

The experimental plot had an area of 1ha. We studied four cultivars; in each cultivar we had 72 trees.

L-110: Dates of harvest for the three groups of cultivars. More details of tree size

Flordastar and Early Maycrest were harvested from the second to the fourth week of May. Rubirich, a mid-season cultivar, was harvested during the fourth week of June. Finally, O'Henry the late cultivar was harvested in the third week of August. The following table summarises the harvest dates for each cultivars during 2016 and 2017 seasons.

Cultivars	**Harvest date 2016**	**Harvest date 2017**
Flordastar	16/05/2016	17/05/2017
Early Maycrest	25/05/2016	29/05/2017
Rubirich	16/06/2016	19/06/2017
O'Henry	15/08/2016	13/08/2017

The four cultivars studied are in their full maturing size which was about 3.5 m.

L-112: drip irrigation: two pipes per row located at ??, how many drippers per tree?, distances? Flow (L per h)?

Detail on irrigation treatments were added in material and method section as asked by the reviewer 2. Please see line 146 – 149, page 6.

L-125: Design of the experiment, how the treatments were distributed?

The experimental plot had an area of 1ha and was set up as a criss-cross plot in a randomized complete block design with three blocks. Each block is divided in to two rows with 24 peach trees from each cultivar in each block. Three irrigation type was carried in each row (three trees for each treatment) while three trees were used as borders. Six trees per irrigation treatment were used for each cultivar in each block. We added those informations in the material and methods section. Please see line 117 – 124, page 5.

L-132: Were the Kc adjusted for each cultivars?

The coefficient (K_c) varied with fruit phenology stage of each cultivar. For early cultivars (Flordastar and Early Maycrest), the phenological stage periods were very close. However, for mid- season cultivar (Rubirich) and late cultivar (O'Henry) it was adjusted for each cultivar.

L-137: SDI….50% of the FI during the fruit cycle or during the whole irrigation season?

For both treatments (sustained and cyclic deficit irrigation), the deficit irrigation was applied for the whole irrigation season.

L-139: tensiometers for CDI irrigation only? How many tensiometers? Do you irrigate trees by ETc (as indicated in L-128) or tensiometric readings? Please clarify

We used the tensiometric probes for trees under FI and CDI treatment. The tensiometric probes was installed a three depths (40, 60, and 80 cm).

For CDI trees, we refill the soil at 100% field capacity, when the soil water stock decreases to 50% of field capacity. The tensiometers with the gravimetric method are used to control the soil water stock. We added those informations in the revised manuscript. Please see line 165 – 171, page 7.

L-154-156: can be omitted. Well know technique. How many leaves were measured?

The part from L-154-156 was omitted in the revised manuscript. We tested four leaves from three different trees (n=12). Please see line 181 – 183, page 8.

L-173: how many picks were made at harvest?

We made one pick at the commercial ripening stage; we had already studied the ripening date of those peach cultivars and the work is under consideration in another journal.

Results

L-214-223: Rewrite: "…temperature increased during the fruit growing (of which cultivar?) Delete fruit growing. Rainfall was 44 mm in April and 2 mm in August (do not said rainfall decreased or dropped). Indicate the total annual rainfall and ET0 records

We corrected the sentence in the revised version. Please see revised manuscript line 250 – 258, page 11.

Figure 1: Monthly average air temperature, but monthly total rainfall and ET0 (the units in the legend should be: mm month^{-1})

This was corrected in the revised version. Please see figure 1.

L-227: To facilitate the reader, please add the DOY that corresponds to each date (…end of July (197 DOY)

We added the detail as asked by the reviewer 2, please see line 261, page 11.

L-233: respectively, instead of successively

This was corrected in the revised version.

Shoot growth: Please make comparison of shoot growth respect to full irrigated trees

We added this comparison in the revised version. Please see line 261 – 266, page 11.

L-240: I should write: Flordastar maintained higher predawn leaf water potentials (>-2 MPa)

This was corrected in the revised version. Please see line 277 – 278, page 12.

Gas exchange: Do the authors compare the same date on Table 1? Again, the question is that fruit expansion period and harvest occurs differently in the four cultivars. How they are compared?

The four cultivars studied have different dates of fruit expansion and harvest. In fact, in the table we put the values of gas exchange corresponding to the date of fruits expansion and the harvest date of each cultivar. The purpose of these measures was to study the effect of the water stress on the tree behaviour during those periods for each cultivar.

L-257-258: gs decrease under SDI from 32 to 46? Please explain. Also in CDI ranges in which cultivars?

To avoid confusion, this sentence was deleted in the revised manuscript. Please see line 298 – 302, page 13.

Fruit yield: I should be interesting to have data on total yield (kg and number of fruits per tree). Why they are not included in the manuscript?

We added the yield (kg $tree^{-1}$) and fruit number (fruit $tree^{-1}$) for each treatment for the four cultivars studied. This was corrected in the revised version. Please see line 320 – 331, page 14.

Discussion

When discussing the own results the authors should use the level of water deficits in terms of leaf water potential values i.e. L-386: fruits from SDI trees had smaller fruits size than CDI because water stress were more severe (Figure 3). Also when compared with other authors 'results, the water deficit degree must be referred.

We agree with the comment as asked by the reviewer 2 and the details were added in the revised version.

Revision by a native speaker must clarify the text: L-332 the results were more expressed?

The difference between the two water regimes (cyclic and sustained) was more remarkable during 2017, which may be due to the effect of the climatic conditions (less amounts of precipitation during 2017).

The manuscript was revised by an English native speaker.

Conclusions

L-430: I should write: '… study, two deficit irrigation strategies were compared in four cultivars of different date of maturing…….concluded that cyclic deficit irrigation (CDI) is most advisable than sustained deficit irrigation (SDI).

This sentence was deleted as suggested by other reviewers.

Figures 2, 3 and 4: must indicate when the harvest occurs for each cultivar (for example with an arrow). Also, the X axis DOY should be the same in the three figures. It is no clear which DOY correspond to the tick (the DOY is in the middle of two ticks, and it must coincide with the tick).

This was corrected in the revised version. We chose the same DOY for the three figures. And the harvest date for each cultivar was indicated. Please see figures 2, 3 and 4.

Legend to figures: should write '…exposed to full irrigation (FI, sustained deficit irrigation (SDI) and cyclic deficit irrigation, instead of '…in comparison to full irrigation (FI)'. Also, the abbreviation for irrigation treatments can be omitted (repeated).

This was corrected in the revised version. Please see figure captions page 29 and 30.

Figure 5: legend inside the figure do not corresponds to SDI and CDI but COWD, CYWD? Is r value for linear regression? Please, draw it.

Legends inside the figures were corrected as suggested; please see Figure 5A and 5B

Reviewer 3:

==========

Introduction

It is very nicely written with some typos.

Line 52: del 'is'

We corrected those typos in the revised version. Please see line 52, page 3.

Line 55: area

We deleted this sentence in the revised version. Please see line 54 – 55, page 3.

Line 56 del ‘were’

We deleted this sentence in the revised version. Please see line 54 – 55, page 3.

Line 60 affects

This word was corrected in the revised version. Please see line 60, page 3.

Material and methods

In statistical analysis, it will be nice to mention the experimental design along with number of replications; experimental unit. Though, the sample size (n) is mentioned below the tables or figures.

We added the experimental design, which was the Criss-cross model, and the number of replications in the Material and methods section. This was corrected in the revised version. Please see line 127 – 128, page 5, and line 150, page 6.

If possible, kindly mention the fruit number per tree or fruit yield/ tree; or if there any nearby fruit number was fixed on the trees after thinning. The discussion has to take the number of fruits per tree or yield in account as it has a major role in fruit quality especially in peach.

We added the yield (kg $tree^{-1}$) and fruit number (fruit $tree^{-1}$) for each treatment applied to the four cultivars studied. And data were discussed please see line 457 – 460 page 19.

Results and discussion

The results are nicely presented and discussed.

In Figure 2. EMC (2016) its ‘shoot growth’.

We corrected the figure 2 in the revised version. Please see figure 2 EMC (2016).

Uniform formatting required in figures and vertical axis of the figures.

We checked and corrected the figures as suggested by the reviewer 3. Please see figures.

Double check the references. Though it seems all the citations have been included in the references.

References checked throughout the manuscript; please see manuscript.

Physiological responses and fruit quality of four peach cultivars under sustained and cyclic deficit irrigation in west center of Tunisia

Monia GUIZANI[1,2*], Samia DABBOU[3], Samira MAATALLAH[4,5], Giuseppe MONTEVECCHI[6], Hichem HAJLAOUI[4,5], Mourad REZIG[8], Ahmed Noureddine HELAL[2,7], Soumaya KILANI-JAZIRI[1,2]

[1]Unit of Bioactive and Natural Substances and Biotechnology UR17ES49, Faculty of Dentistry University of Monastir, Avicenne Street, 5019 Monastir, Tunisia.

[2]Department of Pharmaceutical Sciences A, Faculty of Pharmacy of Monastir University of Monastir, Avicenne Street, 5019 Monastir, Tunisia.

[3]Faculty of Dentistry, University of Monastir, Avicenne Street, 5019 Monastir, Tunisia

[4]Institution of Research and Higher Education Agriculture (IRESA), Regional Center for Agricultural Research, 9100, Sidi Bouzid, Tunisia

[5]Laboratory of Research Non-Conventional Water Valuation (LR VENC), INRGREF, Hedi EL Karray Street, El Menzah IV, 1004 Tunis, Tunisia

[6]BIOGEST - SITEIA Interdepartmental Centre, University of Modena and Reggio Emilia, Piazzale Europa 1, 42124 Reggio Emilia, Italy

[7]Laboratory of Bioressources: Integrative Biology and Valorization at Higher Institute of Biotechnology of Monastir, Tunisia

[8]Laboratory of Rural Engineering, National Institute of Research of Rural Engineering, Waters and Forests of Tunis, INRGREF, Hedi EL Karray Street, El Menzah IV, 1004 Tunis,Tunisia.

* Corresponding author: Monia Guizani

guizanimonia2018@gmail.com;guizanimonia@ymail.com

Abstract

In arid and semi-arid regions, the research and application of new irrigation techniques that economize water without altering tree performance and fruit quality is a challenge. The aim of this study was to investigate the effect of two different deficit irrigation strategies on tree physiology and fruit quality of four *Prunus persica* cultivars: two early-ripening cultivars (Flordastar and Early Maycrest), a mid-season cultivar (Rubirich), and a late-ripening cultivar (O'Henry). During two consecutive seasons (2016 and 2017), three different irrigation treatments were established: i) Full Irrigation (FI; 100% ET_c), ii) Sustained Deficit Irrigation (SDI; 50% ET_c) and iii) Cyclic Deficit Irrigation (CDI; trees irrigated at 100 % field capacity whenever the soil moisture dropped to 50% field capacity). Tree water status, gas exchange, yield, fruit pomology and the concentrations of the main sugars and organic acids were determined. Deficit irrigation decreased net photosynthesis rate, stomatal conductance and transpiration rate while it improved instantaneous water use efficiency (WUEins). In O'Henry cultivar, WUEins increased from 3.21 μ mol $mmol^{-1}$ in FI to 7.04 μmol $mmol^{-1}$ in CDI during harvest. Deficit irrigation significantly reduced shoot growth in the four cultivars. Furthermore, SDI decreased the yield significantly (from 41 to 26.3 kg in O'Henry cultivar during 2016), fruit size and weight while CDI increased soluble solids and sugar contents and decreased titratable acidity. The total sugar content increased significantly under deficit irrigation in all cultivars studied. In conclusion, CDI seems to be the best strategy in semi-arid regions, since it can save water and improve fruit quality parameters.

Keywords: *Prunus persica*; Shoot growth; Tree water status; Sugar contents; Organic acids; Water use efficiency

1. Introduction

The peach (*Prunus persica* L. Batsch) tree is originated from the Middle East (Persia or China), although its area of cultivation spreaded to all regions with a temperate climate (Chavez et al., 2014). In Tunisia, peach has been cultivated for a long time and the surface devoted to this crop doubled during the last two decades. The substantial raise in the production is the result of the introduction of new early- and late-ripening cultivars, particularly in the north and west-central of Tunisia. In this way, the extensive range of cultivars is able to provide these fruits for 4 to 5 months, from April to September (Gifruits, 2018).

In arid and semi-arid areas, low annual precipitation and high evaporation rates affect the production of fruit trees, which require efficient water supply. This is the case of southern and central Tunisia (Ghrab et al., 2008). Environmental variables like temperature, solar radiation, photoperiod, precipitation, and soil profile affect the growing environment and result in a wide variation in peach fruit quality at harvest (Lopresti et al., 2014).

The water scarcity for irrigation, especially in semi-arid zones, requires the application of deficit irrigation strategies. Regardless the type of irrigation scheduling used, it is necessary to develop and implement techniques that optimize agricultural water use without affecting crop yields (Fereres and Soriano, 2007). Among these strategies, Sustained-deficit irrigation (SDI) is a continuous water deficit, based on uniform water restriction throughout the entire season, whereas cyclic deficit irrigation (CDI) is to re-water soil to field capacity when its water content fell to 50 % of field capacity.

The intensity and duration of the water deficit, as well as other weather conditions, can cause changes in plant behavior (Shao et al., 2008). Such conditions may induce responses at all levels of plant organization. It is well known that a reduction of the irrigation can be a useful tool to limit unwanted vegetative growth and to increase water productivity in orchards

(Fereres and Soriano, 2007; Ruiz-Sánchez et al., 2010). Drought stress affects most of the processes involving gas exchange, leaf water potential and accelerated senescence (Jiménez-García et al., 2013). It reduces stomatal conductance, transpiration and net photosynthesis rate. Stomatal closure is one of the first responses to water deficit that allows plants to limit respiration, but it also limits CO_2 absorption, resulting in a decrease in photosynthetic activity (Flexas and Medrano, 2002). The ratio between net CO_2 fixation (P_n) and transpiration (Tr) is defined as instantaneous WUE (WUEins) which is the most important component of drought adaptation (Silva et al., 2012)

Deficit irrigation can be used to maintain or optimize the yield and improves peach fruit quality (Du et al., 2017). Kobashi et al. (2000) showed that moderate stress in peaches improves fruit quality as result of an increase in the sugar content and a higher maturity index. Sugars mainly sucrose, the major sugar in peaches, and reducing sugars (glucose and fructose) influence the peach taste along with the main organic acids, malic and citric ones (Borsani et al., 2009). Early and late-maturing peach cultivars seem to respond differently to water deficit (Buendía et al., 2008; Girona et al., 2005). In early cultivars that had a short ripening time, an increase in the amounts of sugar in fruit was recorded which induced a higher maturity index (Buendía et al., 2008; Falagán et al., 2015). In late cultivars, higher amounts of sugars, total phenols and ascorbic acid were found (Thakur and Singh, 2012).

The effect of deficit irrigation on the physiology and the fruit quality of peach has been studied by other authors, although researches on the effect of cyclic stress on *Prunus persica* cultivars are scarce. However, this type of stress has been applied to other species such as *Laurus nobilis L.* (Maatallah et al., 2010). Those authors proved that cyclic deficit irrigation is a good strategy in water shortage that may influence the plants ability to cope with a subsequent episode of water scarcity. In addition, it had limited impact on the plants behavior. As well, Gómez-del-Campo et al. (2007) found that the application of cyclic periods of stress and re-watering in *Vitis vinifera,* induced an adaptation of the leaf area development to the available water, thereby improving water use efficiency.

In this context, the main objectives of the present study were; (1) to investigate the performance of four peach cultivars (with contrasting lengths of their growing cycle) grown in semi-arid climate (Centre west of Tunisia) when subjected to cyclic and sustained deficit irrigation; (2) to define which is the efficient irrigation strategy that saves water without affecting the physiology and the fruit quality of peach. The effects of the irrigation strategy on plant shoot growth, water status, gas exchange, yield and fruit quality parameters were evaluated over two consecutive growing seasons.

2. Materials and methods

2.1. Orchard description

The study was carried out in an experimental peach orchard located 3 km south west of Sidi Bouzid (Mid-Western Tunisia) (35° 01'21.9" N, 9° 26'31.3" E; 160 m above sea level) during two consecutive seasons: 2016 and 2017. The region is characterized by a typical Mediterranean climate with low rainfall and high temperatures during the summer season. The soil was a sandy loam-clay, with an average rooting depth of 1.20 m and total assimilable phosphorus (P_2O_5) of 15 ppm. Calcium carbonate ($CaCO_3$) and organic matter contents was 12.5% and 0.48 %, respectively. The soil sample showed a pH of 7.8 and a salinity of 1.8 g kg^{-1}. The electrical conductivity (EC) of the irrigation water varied between 1.33 and 3.18 dS m^{-1}. The value of the measured field water capacity was between 19.8% and 23.5%, wilting point was about 7.90 % and saturation water content was approximately 28.5%. Bulk density was around 1.62 g cm^{-3}. The experimental plot had an area of 1 ha and was set up as a criss-cross plot randomized with three blocks. Each block is divided into two rows. The thirteen-year-old peach cultivars (*P. persica* L. Batsch), Flordastar, Early Maycrest, Rubirich and O'Henry, were grafted on the Guernem wild rootstock at a spacing of 4 m × 6 m. The four cultivars covered the whole peach season; they can be classified into two early cultivars (Flordastar and Early Maycrest), a mid-season one (Rubirich) and a late cultivar (O'Henry). Fruit growth period for early cultivars was approximately from mid-February to the third week of May (from 45 DOY to 142 DOY), for the mid-season cultivar it was from the second week of March to the third week of June (from 74 DOY to 173 DOY). Concerning, the fruit growing period for the late cultivar, it was ranging from the end of February to the mid-August (from 59 DOY to 228 DOY). During the two experimental seasons, all cultivars were similarly fertilized. Soluble fertilizers (potassium sulphate, magnesium sulphate, potash and nitric acid) were applied with the drip irrigation system throughout the irrigation season. Irrigation season started in late February or early March and finished by late September or early October, according to the seasonal meteorological trend.

2.2. Weather conditions

Daily meteorological data was collected from an automatic weather station (Pessl instruments, GesmbHWeiz, Austria). The station was located in the experimental plot at 20 m from the peach orchard. Every 30 min, this station stored data on air temperature, air relative humidity, wind speed and direction, solar radiation, and precipitation. The daily meteorological data was used to estimate daily values of reference evapotranspiration (ET_0) computed using the FAO Penman–Monteith approach (Allen et al., 1998).

2.3. Irrigation treatments

Eighteen trees per irrigation treatment were used for each cultivar. Three irrigations types were carried in each row (three trees for each treatment) while three trees were used as borders. Irrigation was carried out using a drip irrigation system with two lateral pipes per row and four emitters per tree. The flow was $4Lh^{-1}$. Three different irrigation treatments were considered in this study: i) the control is Full Irrigation (FI); ii) Sustained Deficit Irrigation (SDI), and; iii) Cyclic Deficit Irrigation (CDI).

In FI, trees were irrigated at 100% of crop evapotranspiration (ET_c). The irrigations amounts were calculated to replace ET_c (net of the effective rainfall) by the following formula:

$ET_c = ET_0 \times K_c$

K_c, a crop coefficient adapted to peaches, was modified according to the stage of fruit development (Ayars et al., 2003): initial K_c was 0.5 during Stage I; in the mid-season K_c was 0.9 during Stage II and III; and in the late season K_c was 0.5 after harvest. These crop coefficients corresponded to those usually recommended to fruit growers in the area by agricultural extension services.

The SDI treatment consisted of an irrigation at 50% ET_c in order to apply a water deficit uniformly over the whole fruit development cycle and to reduce the irrigation application to 50% of the FI (100% ETc) during the fruit cycle. CDI was a deficit irrigation treatment, consisted to re-irrigating at 100% field capacity whenever the soil water content decreased to 50% of field capacity.

Soil water potential was monitored with tensiometric probes, (Watermark WM-S-15) at three depths (40, 60, and 80 cm) within the root zone (40 cm apart from the tree trunk) and irrigation was applied according to the manual Watermark moisture meter readings. The tensiometric probes were installed in trees under FI and CDI treatments. In addition to tensiometric probes, gravimetric soil moisture content was measured with soil profile from 0–1.20 m taken in 20 cm, oven dried at 105 – 110 °C to constant weight, then quantify soil water content of the peach root zone.

2.4. Shoot growth

During the two consecutive years, shoot growth was assessed by measuring the shoot extension at different time intervals. At the beginning of the vegetative growth, twelve shoots from the previous year were selected from the four sides and in the same level in each tree to monitor the growth of new shoots. Measurements were carried out every 15 days during the growth season. Shoot growth was determined on three trees per treatment by measuring four tagged shoots in each tree (n = 12).

2.5. Tree water status

Predawn leaf water potential (ψ_b) was measured using a pressure chamber (PMS Instruments, Corvallis, OR, USA), shortly before sunrise (Scholander et al., 1965). Four leaves were taken from each tree and three trees were chosen for each treatment (n=12). These measurements were made weekly.

The relative water content (RWC) was determined by the method described by Kramer (1980) and calculated using the following formula:

$$RWC = (FW - DW) \times 100/(FW_{sat} - DW)$$

Where FW represents the fresh weight of leaves, DW is the dry weight of leaves, and FW_{sat} is the fresh weight of leaves at saturation. The saturation was achieved by covering the leaves with water and leaving them in the dark at a temperature of 4 °C during 24 h, whereas DW was determined by drying the leaf in an oven at 80 °C for 48 h. Four leaves were taken from one tree and three different trees were chosen for each treatment (n=12). RWC was measured every two weeks.

2.6. Gas exchange parameters

The rate of photosynthetic assimilation (P_n, µmol CO_2 m^{-2} s^{-1}), the stomatal conductance (g_s, mmol H_2O m^{-2} s^{-1}), the transpiration rate (Tr, mmol H_2O $m^{-2}s^{-1}$), the instantaneous water use efficiency (WUEins = P_n/Tr), and “Ci’’ (molar fraction of CO_2 in the intercellular spaces) were measured on mature leaves with a portable gas-exchange analyzer (LCpro+ ADC Ltd. BioScientific, Hoddensdon, UK). These gas exchanges parameters were measured under saturating sunlight of the day. The measurements were performed on three leaves per tree, and three trees per cultivar per treatment at each measurement date.

2.7. Sample processing and fruit quality parameters

Hand thinning was applied in both years (2016 and 2017). Harvest was based on our previous study on the fruit ripening. For each cultivar, fruits were harvested at their corresponding commercial ripening stage. Each tree was harvested individually. The total number of fruits was weighed and counted in three trees per replicate for each treatment. Immediately after harvest, fruit diameter, weight, firmness, juice content, soluble solid content (SSC), titratable acidity (TA), and vitamin C contents were determined on 10 fruits per tree considering three trees per replicate for each treatment and for each cultivar. For biochemical analyses, the fruits were frozen and ground in liquid nitrogen and then stored at −80 °C until analysis.

The width (mm) and length (mm) of each fruit were measured using a caliper (Mitutoyo, UK), while the fresh weight was determined using a precision balance (AXIS-AGN 100 C, Poland). The flesh firmness was measured on a partially peeled fruit using a penetrometer (FT 327, Italy). To determine the SSC of the juice, a digital refractometer (Atago-Palette PR 101; Atago Co., Tokyo, Japan) was used and results were expressed in °Brix. The determination of titratable acidity was achieved as described by Dabbou et al. (2016), in two-fold water diluted peach juice by the neutralization of the free acids with a solution of 0.1 N NaOH added dropwise until pH 8.2 (checking through a pH-meter). The results were expressed as g malic acid 100 ml^{-1}, the most abundant organic acid in peaches (Montevecchi et al., 2012).The ratio SSC/TA was also calculated. The vitamin C content was determined by iodometric titration of ascorbic acid (Nweze et al., 2015).

2.8. Determination of soluble sugars and organic acids

Extraction and quantification of soluble sugar and organic acids were determined as described by Chinnici et al. (2005) with minor modification. Aqueous extracts were prepared from 1 g of freeze-dried samples suspended in 10 mL of deionized water and subjected to homogenization, centrifugation at 15000 g for 15 min at 4 °C and, finally, filtration through a cellulose nitrate membrane filter (0.45 µm pore size). The obtained extracts were analyzed in a HPLC system (PU 4180, Jasco Europe Srl, Cremella, LC) equipped with a Rezex™ RCM-Monosaccharide Ca+2 (8%), LC Column 300 x 7.8 mm, Ea column. The isocratic separation of sugars and organic acids was performed at 30 °C, using a mobile phase of 0.1% phosphoric acid pumped into the column with a flow rate of 0.5 mL min^{-1}. The quantification of sugars was carried out with a refractive index detector (RI 4030) and the organic acids were quantified using an UV/Vis detector (UV4070, Jasco) at a wave length of 210 nm. The identification of the analytes was performed by comparing the retention times of the peaks with pure reference standards. Sugar and organic acid standards were supplied by Supelco analysis (Bellefonte, PA, USA). Quantification was carried out through the external standard calibration method.

2.9. Statistical analysis

Statistical analyses were performed using SPSS software (release 17.0 for Windows, SPSS, Chicago, IL, USA). The analysis of variance (ANOVA) was employed. Duncan test was used to compare means between cultivars for each irrigation treatment and to compare the three irrigation treatments in each cultivar. Student-t test was used to compare among the two different tissues (peel and flesh). The values were represented as the mean ± the standard deviation. Additionally, relationships among variables were assessed through Pearson's "r" coefficient. Statistically significant differences between groups were considered when $p < 0.05$.

3. Results

3.1. Meteorological conditions and evapotranspiration

The temperature increased during the fruit growth period from 14 and 16 °C in February to 30 and 35 °C in August in 2016 and 2017, respectively. Total annual rainfall of 250 mm during 2016 and 235 mm during 2017 concentrated mainly from autumn to spring. Total rainfall was low during fruit development, 44 mm in April 2016 and 2 mm during the summer (August). In 2017, total rainfall was lower than the previous year and it dropped down from 24 mm to 1 mm from April to August. The total evapotranspiration (ET_0) recorded was 1450.36 and 1329.68 mm during 2016 and 2017, respectively. The conditions of high temperatures and low summer rainfalls resulted in a high evaporative demand (Fig. 1), which reached its maximum (205.53 mm month^{-1}) and (197.47 mm month^{-1}) in July 2016 and 2017, respectively.

3.2. Shoot growth

The shoot growth of the four peach cultivars studied is represented in Fig. 2. Shoot growth was stopped form mid (196 DOY) to the end (211 DOY) of July in all cultivars studied. Shoot growth decreased under water deficit treatment. This parameter was the most affected by SDI in the O'Henry cultivar, with a reduction of 53.74% and 52.61 % during 2016 and 2017, respectively, compared to FI. Significant reductions were also observed in Flordastar, Early Maycrest and Rubirich. In the last cultivar this decrease was 48.27% and 44.54% during 2016 and 2017 respectively, under SDI compared to FI. In addition, no significant differences were found between SDI and CDI for the early cultivars (Flordastar and Early Maycrest). However, for Rubirich and O'Henry, shoot growth in trees subjected to CDI was significantly higher than that in trees under SDI.

3.3. Tree water status

The evolution of Ψ_b showed a decreasing trend over the growing season in all treatments (Fig. 3). During 2016 and 2017, there was a slight decrease under FI strategy in early cultivars (from -0.46 MPa to -0.99 MPa). While for O'Henry and Rubirich cultivars, it varied between

-0.48 and -1.01 MPa during 2016 and 2017. Ψ_b dropped in trees under SDI and reached a minimum in O'Henry cultivar (-2.90 MPa). The effect of CDI on Ψ_b was moderate in comparison with that of SDI. Flordastar cultivar maintained higher predawn leaf water potential (approximately -2MPa) during 2016 and 2017 seasons compared to the other cultivars.

The relative water content (RWC) in leaves (Fig. 4) showed a decreasing trend over the growing season in all cultivars and treatments. In FI, the RWC for Rubirich and O'Henry ranged from 80% to 85.33% whereas, for Flordasatr and Early Maycrest it was between 77.66% and 83.67 %. In all cultivars, compared to the control values, SDI presented a significant decrease of RWC which dropped to 62%. However, CDI generated a slight decrease significantly higher than SDI and it was around 71% for all cultivars during 2016 and 2017.

3.4. Gas exchange parameters

Photosynthesis rates differed significantly among irrigation treatments for all cultivars studied (Table 1). Under FI treatment, during the fruit expansion period, O'Henry cultivar had the higher P_n values (11.37 and 11.28 μmol $m^{-2}s^{-1}$ during 2016 and 2017 seasons, respectively) while the lowest P_n was found in Rubirich cultivar during 2017 (9.08 μmol $m^{-2}s^{-1}$) and in Flordastar cultivar during 2016 (9.33 μmol $m^{-2}s^{-1}$). Over the fruit harvest period, O'Henry and Early Maycrest cultivars had higher P_n compared to Flordastar and Rubirich cultivars. Water deficit induced a significant decrease of P_n during the two periods for all cultivars. Furthermore, P_n values in CDI were significantly higher than that obtained under SDI treatment. For instance, during the fruit expansion period, P_n ranged from 6.13 to 7.63 μmol $m^{-2}s^{-1}$ under SDI and between 7.78 to 8.91 μmol m^{-2} s^{-1} under CDI for Flordastar and O'Henry cultivars respectively, during 2016.

Stomatal conductance exhibited the same variation pattern as P_n (Table 1). Under FI conditions, the four peach cultivars studied had a high g_s that reached 94.05 mmol $m^{-2}s^{-1}$ in O'Henry cultivar during fruit expansion in 2017 season. The lack of water led to a significant decrease of g_s in all cultivars studied. In addition, g_s presented a severe decrease under SDI with respect to FI. Under CDI, g_s was significantly higher than that in SDI trees.

Correlation between P_n and g_s (fig. 5A) and P_n and Ci (Fig. 5B) were studied. Results showed a positive correlations between P_n and g_s (r = 0.91) as well as, between P_n and intercellular CO_2 (r = 0.89).

Transpiration rate clearly decreased with water deficit (Table 1). The SDI treatment exerted a depressive effect on Tr which dropped to 1.04 mmol $m^{-2}s^{-1}$ in Flordastar during fruit expansion in 2016, for instance. The values of Tr under CDI treatment were significantly higher than those obtained under SDI during 2016 except for O'Henry cultivar during fruit expansion period and for Flordastar and O'Henry cultivars during harvest periods (Table 1). However, there was no significant difference among deficit irrigation treatments in 2017 during the two periods studied.

The irrigation strategy affected WUEins (Table 1). WUEins in stressed trees (under CDI and SDI treatment) was significantly higher than WUEins under FI trees. The application of water stress affected differently the WUE in the four cultivars. For the early cultivars (Flordastar and Early Maycrest), the maximum WUEins was obtained under the SDI treatment at the fruit expansion stage, while for Rubirich and O'Henry, the highest WUEins was recorded in CDI treatment at fruit harvest (5.45 and 7.04 µ mol $mmol^{-1}$, respectively during 2016 season).

3.5. Fruit quality traits

O'Henry cultivar had the highest yield (41 and 44.05 kg $tree^{-1}$, during 2016 and 2017 respectively) while Early Maycrest had the lowest one for both years (30.33 and 30.56 kg $tree^{-1}$ during 2016 and 2017, respectively). SDI had a depressive effect on fruit yield during

2016 and 2017 seasons (Fig. 6A) contrary to CDI. This effect was not observed for Flordastar cultivar that showed a slight decrease under CDI treatment.

Flordastar cultivar had the highest number of fruit (270 fruits tree^{-1}) during 2016, followed by Rubirich, O'Henry and Early Maycrest cultivar (262.66; 227; 212, respectively fruits tree^{-1}) under FI treatment. However, Rubirich and Flordastar showed the highest number (276.33 and 260 fruits trees^{-1}, respectively) and Early Maycrest the lowest one (218 fruits tree $^{-1}$) under SDI during 2016 season. During 2017, there was no significant variation between cultivars as shown in Fig. 6B. Irrigation treatments did not affect the number of fruits during 2016 and 2017 seasons in all the cultivars studied (Fig. 6B).

There was a significant difference among cultivars and treatments ($P < 0.05$) for fruit size and weight (Table 2). Under FI, fruits from O'Henry were the largest (72.45 mm and 71.09 mm for 2016 and 2017 seasons, respectively) and the heaviest (172.07 g in 2016 and 195.55 g in 2017 season), followed by Rubirich cultivar while Flordastar and Early Maycrest cultivars produced the smallest fruits. The SDI regime generated a significant decrease in fruits weight, length, and diameter; conversely to CDI which did not have a significant effect compared to FI during both seasons studied except for the size of Flordastar fruit during 2017.

The average firmness in FI treatment varied from 4.18 to 6.48 kg cm^{-2} in the four cultivars during 2016 and from 3.86 to 5.52 kg cm^{-2} during 2017 seasons. O'Henry fruits had the greatest firmness, followed by Rubirich and Early Maycrest, whereas, Flordastar fruits showed the lowest firmness during 2016. However, Early Maycrest had the lowest firmness during 2017. For all cultivars, SDI significantly increased fruits firmness, for instance, O'Henry fruits firmness reached approximately 7.6 kg cm^{-2} during both seasons (Table 2). On the other hand, CDI caused a slight increase in fruit firmness but lower than that obtained under SDI.

Statistical differences were found for the soluble solid content (SSC) among cultivars and irrigation treatments. Under FI treatment, O'Henry fruits presented the highest values of SSC (15.18 and 13.98 °Brix during 2016 and 2017 seasons, respectively). In contrast, fruits from Rubirich had the lowest SSC (10.50 and 11.88 °Brix during 2016 and 2017, respectively). The SDI and CDI treatments increased the values of SSC. In the 2017 season, fruit subjected to SDI had higher SSC compared to fruits from CDI treatment, while in 2016 season there was no significant difference (Table 2).

The four cultivars differed in TA (Table 2). Flordastar had the highest TA (2.07 and 2.02% during 2016 and 2017 seasons, respectively), while Early Maycrest showed he lowest values (1.13 and 1.19 % during 2016 and 2017 seasons, respectively). In most cultivars, deficit irrigation reduced TA. According to these results, the SSC/TA ratio was significantly higher in fruit under SDI and CDI compared to fruits from the FI treatment.

Vitamin C exhibited the highest concentration in O'Henry fruits (5.86 and 5.83 mg100g^{-1} in 2016 and 2017 seasons, respectively) while Flordastar fruits had the lowest concentration (2.83 mg 100g^{-1}) under FI (Table 2). Generally, the SDI and CDI treatments significantly increased the level of vitamin C in peach fruits. For all cultivars, fruit from trees under CDI treatment had the higher vitamin C content during the both crop season. However, it was not the case for Rubirich cultivar during 2017 season (Table 2).

Sucrose was the main sugar found in the peaches (Table 3). In the both seasons studied, sucrose content ranged from 26.17 to 38.53 g 100 g^{-1} DW in flesh and from 15.59 to 33.39 g 100 g^{-1} DW in peels under FI treatment. In all cultivars studied, there was a significant difference in the amounts of all main soluble sugars. O'Henry fruits had the highest concentrations of total sugars (64.16 and 59.67 g100 g^{-1} DW in flesh under FI during 2016 and 2017 seasons, respectively). Deficit irrigation increased sugar content significantly. In fact, SDI and CDI treatments improved the sugar content in both tissues (peel and flesh) as shown in Table 3.

Malic acid was the main organic acid in peach fruits, followed by citric and succinic acids, while fumaric acid was present as traces (Table 4). Flesh part had significantly higher concentrations of organic acids than peels. Under FI treatment, Flordastar fruits had the highest total organic acid contents (8.78 and 10.19 g 100 g^{-1} DW in the flesh during 2016 and 2017, respectively). While, O'Henry fruits showed the lowest values (5.62 and 8.58 g 100 g^{-1} DW in 2016 and 2017 seasons, respectively). The deficit irrigation regimes (SDI and CDI) affected the amount of organic acid in flesh and peel tissues during both crops seasons. This decrease was not statistically significant in peel tissue. SDI and CDI treatments decreased malic and citric acids in the most cultivars (Table 4). However, this reduction was low in succinic and fumaric acids for both tissues. Furthermore, under SDI treatment, there was a significant decrease of total organic acid contents in flesh tissue for all cultivars during 2017 season. This variation was not significant for Flordastar and Rubirich flesh in 2016 season. Concerning CDI strategy, total organic acids dropped significantly in flesh tissue in all cultivars, except for Flordastar fruits (Table 4).

4. Discussion

4.1 Effect of water deficit on tree physiology of four *Prunus persica* cultivars

Results from shoot growth showed that vegetative growth (Fig. 2) was very sensitive to water deficit. In fact, SDI and CDI significantly reduced the shoot growth in all cultivars. These findings have been widely documented in peach trees (Li et al., 1989; Rahmati et al., 2015a; Mirás-Avalos et al., 2016). The effect of CDI varied among cultivars; it exerted the same effect as SDI for early cultivars (Flordatar and Early Maycrest) that have a short cycle of fruit development. This may be explained by the competition between vegetative and fruit growth since the goal of the fruit tree is to divert carbohydrates into fruit growth. According to De la Rosa et al. (2015) fruit growth tends to dominate over vegetative growth in early cultivars. In addition, Ruiz-Sánchez et al. (2010) indicated that if vegetative and fruit growth processes overlap, the vegetative growth will be the more affected. Whereas, for late and mid-season cultivars (Rubirich and O'Henry), vegetative growth was more effected under SDI treatment. This may be attributed to many factors such as duration of the stress exposure period, duration of growth cycle that varies from one cultivar to another and climatic conditions. Vegetative growth under CDI was significantly higher than that measured under SDI, this effect can be explained by the re-watering period. In the same way, Abrisqueta et al. (2010) indicated that shoot growth in continuous deficit irrigation was more affected by water stress than shoot growth in regulated deficit irrigation strategy.

Predawn leaf water potential (Ψ_b), is recognized worldwide as one of the most accurate indicators of the state of plant water as a result of the balance in the soil - plant - atmosphere reached during the night (Domingo et al., 1996; Jones, 2004). The FI treatment showed decreasing tendency of Ψ_b along the season but their values were always maintained less negative than -1MPa (Fig. 3). Ψ_b was significantly decreased by water deficit where the maximum reduction was recorded under SDI treatment. These results are consistent with Rahmati et al.(2015a) in peach and Intrigliolo and Castel (2006) in plum. O'Henry cultivar had the highest baseline water potential, indeed, this behavior is explained by the combined effect of water deficit and crop load (Ruiz-Sánchez et al., 2010). The fruit development of this cultivar was occurred during the hottest months (July and August), and it had the highest fruit yield as well. The slight increase of Ψ_b in the four cultivars studied during 2017 season could be explained by the lack of precipitation in comparison to 2016 season. The RWC of leaves (Fig. 4) showed a slight decrease under all treatments applied and in all cultivars studied. This reduction can be explained by the increase of temperature and evaporative demand, especially in July and August (Fig. 1). These results confirm those reported by Pourghayoumi et al. (2017) in pomegranate cultivars. The effect of CDI was moderate and the plant could maintain a high leaf water content, in agreement with the results published by Fathi et al. (2017) on almond trees and by Wahbi et al. (2005) on olive trees. Furthermore, in the present study, O'Henry cultivar, maintained the higher RWC (66%) and a very negative Ψb (-2.84 MPa) under SDI treatment during 2017 season. This behavior could be explained by the higher crop yield, and by the longer growing cycle period (harvest date in mid-August). According to the parameters followed, the four cultivars studied were able to better perform under CDI than SDI treatment. In fact, they maintained predawn water potential around -1.5 MPa and 71% of RWC. This allows to explain the conservation of a good quality of fruit under CDI in comparison with SDI.

In all cultivars, under FI treatment, the values of P_n and g_s reached a maximum of 11.37 µmol m^{-2} s^{-1} and 94.05 mmol m^{-2} s^{-1}, respectively, during the study period. These results are in agreement with previous work on peach trees (Rahmati et al., 2015a). During fruits expansion P_n and g_s values were higher than those found during harvest in most of the cultivars studied. The increase of P_n and g_s during the fruit enlargement was proven by Zhao et al. (2015) in pear and Palmer et al. (1997) in apple trees. P_n, g_s and Tr decreased significantly under deficit irrigation treatments (CDI and SDI). The decline of these parameters have already been described by others authors in fruit trees subjected to water stress (Rahmati et al., 2015a; Zhou et al., 2017). The reduction in P_n was probably due to stomatal closure when the leaf water potential fell to a given threshold (Centritto et al., 2002). Furthermore, the reduction in g_s under water deficit condition is related to the plant's ability to withstand drought conditions. The positive correlation of g_s and P_n (coefficient of correlation r = 0.91) presented in Fig. 5 confirm that g_s governs P_n, and the limitation of g_s induces a decrease in the photosynthetic assimilation. In addition, the significant correlation (r = 0.89) between P_n and

Ci might indicate the presence of stomatal limitations in our study (Fig. 5). Similar results were found in sweet orange trees grown under water deficit (Pérez-Pérez et al., 2008). The observation of a concomitant decrease in Ci at a decrease of P_n during a constraint suggests that stomatal closure is involved in the inhibition of leaf photosynthesis. WUEins was extensively used in genotype selection and evaluation for the improvement of water use efficiency (Polley, 2002). For the FI treatment, the low WUEins values are due to high transpiration by the leaves. While, for SDI and CDI treatments, the increase of WUEins can be explained by the decline on Tr. A high ratio of P_n/Tr was recorded in O'Henry and Early Maycrest face to deficit irrigation strategy. This indicated a good efficiency in the use of water resource in these two cultivars.

4.2 Fruit quality parameters

Fruit number was not affected by irrigation treatment in 2016 and 2017 crop seasons. Water deficit did not affect flowering and fruit set in 2016 and 2017. The reduction in crop yield in SDI treatment resulted mainly from the reduction of fruit size and weight. These results were consistent with those reported by Rahmati et al. (2015b). The decrease of fruit size and weight under SDI is in agreement with previous works (Lopez et al., 2011; Rahmati et al., 2015b). Water stress considerably affected cell expansion. This reduction is mainly due to a reduction in turgor pressure (Shao et al., 2008). Furthermore, fruits from SDI trees had smaller size than CDI because water stress was more severe (Fig. 3) and net photosynthetic assimilation was lower (Table 1).

In addition to the reduction of fruit size in all cultivars studied, SDI treatment increased also the firmness of peach fruits. Indeed, according to Lopez et al. (2011) fruit firmness is affected by fruit size and this may be due to the higher cellular density. This may explain the higher firmness under SDI compared to FI and CDI. Moreover, in all cultivars, water deficit induced an increase in vitamin C content (Table 2). These results are in accordance with previous works carried out on peaches (Zhou et al., 2017) and on table grapes (Du et al., 2008). Furthermore, for soluble solid content (mainly represented by sugars) in the fruit, our results are in accordance with the works of Crisosto et al. (1994) and Lopez et al. (2011), which found a significant increase of SSC under deficit irrigation. Simultaneously, a decline in titratable acidity was noticed. As a consequence, there was a significant increase in the maturity index (SSC/TA) which may increase consumer's acceptance. In fact, peaches with high SSC generally have higher retail value (Parker et al., 1991; Montevecchi et al., 2013). Fruit acidity can also influence the consumer's acceptance of peaches. The acceptance is higher for fruit with lower acidity values. That is obtained under SDI and CDI. These results are in agreement with previous studies (Faci et al., 2014; Mirás-Avalos et al., 2016).

The main sugars identified, in our study, were sucrose with higher concentration, followed by fructose and glucose in both peel and flesh tissues which is in agreement with previous study of Saidani et al. (2017). For Flordastar, Early Maycrest and O'Henry cultivars, flesh tissue had significantly higher concentration of total sugar content compared to peel tissue. These results are in accordance with Saidani et al. (2017). However it was not the case for Rubirich under SDI and CDI during 2016 and 2017 seasons. In addition, the main sugars identified were significantly higher in the fruit subjected to water deficit treatments (Table 3). These results confirm what was found in previous works on peaches and nectarines (Thakur and Singh, 2012; Rahmati et al., 2015b). The higher amount of sucrose and total sugars in fruits subjected to deficit irrigation treatments is probably related to a higher amount of SSC and also to the reduction in fruit size (Stefanelli et al., 2010). Our work showed an increase in glucose and fructose contents under CDI and SDI treatments which is explained by the decrease in energy cost for fruit growth under drought condition. It could result, in turn, in a decline in the utilization of glucose and fructose through glycolysis pathway, thus explaining the increase in their contents (Maatallah et al., 2015; Rahmati et al., 2015b). Peach's flavor is highly dependent on sugar concentration, as well as on the titratable acidity (Cantín et al., 2009). Besides to soluble sugars, organic acids (primarily malic and citric acids) are among the major osmotic compounds that accumulate in fleshy fruits (Ripoll et al., 2014). In addition, the concentration of the total organic acids identified was higher in flesh tissue than in peel tissue (Saidani et al., 2017). The deficit irrigation treatments affected the fruit's organic acid content in a genotype-specific manner. For Early Maycrest, Rubirich and O'Henry cultivars, there was a significant decrease of organic acids under SDI and CDI. However, it was not the case for Flordastar. The decrease of organic acid contents is in agreement with the results described by Ripoll et al. (2014) in many species (notably peach, clementine, mandarin, pear). The decrease in levels of total organic acids in the fruit may be due to the decreased levels of malic and citric acid (Table 4) which is in accordance with the work of Thakur and Singh (2012). Furthermore, water deficit can affect organic acid concentration in fruit through a simple dehydration effect (Thakur and Singh, 2012).

5. Conclusions

Cyclic deficit irrigation (CDI) is more advisable than sustained deficit irrigation (SDI) for a better management of irrigation water without affecting tree functions. Trees under CDI treatment used water efficiently compared to the fully irrigated treatment, showing significant possibilities of saving water. Moreover, CDI improved the quality of fruits by increasing the maturity index, vitamin C and sugar contents in both peel and flesh. SDI treatment decreased trees yield in all cultivars studied. However, CDI treatment had no significant effect on fruit yield in the most cultivars compared to that under FI treatment.

Among the four cultivars studied, O'Henry cultivar was proven to have the best yield and fruit quality under deficit irrigation mostly under CDI. However, Early Maycrest cultivar showed better water use efficiency. The findings gathered from this study will help farmers to improve water management in regions with low water availability.

References

Abrisqueta, I., Tapia, L.M., Conejero, W., Sanchez-Toribio, M.I., Abrisqueta, J.M., Vera, J., Ruiz-Sanchez, M.C., 2010. Response of early-peach [*Prunus persica* (L.)] trees to deficit irrigation. Spanish J. Agric. Res. 8, 30–39. https://doi.org/10.5424/sjar/201008S2-1345

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., Ab, W., 1998. Crop evapotranspiration — guidelines for computing crop water requirements. FAO Irrig. Drain. Pap. 56. Food Agric. Organ. Rome. 1–15.

Ayars, J.E., Johnson, R.S., Phene, C.J., Trout, T.J., Clark, D.A., Mead, R.M., 2003. Water use by drip-irrigated late-season peaches. Irrig. Sci. 22, 187–194. https://doi.org/10.1007/s00271-003-0084-4

Borsani, J., Budde, C.O., Porrini, L., Lauxmann, M.A., Lombardo, V. nica A., Murray, R., Andreo, C.S., Dricovich, M.F., Lara, M. V, 2009. Carbon metabolism of peach fruit after harvest: changes in enzymes involved in organic acid and sugar level modifications. J. Exp. Bot. 60, 1823–1837. https://doi.org/10.1093/jxb/erp055

Buendía, B., Allende, A., Nicolás, E., Alarcón, J.J., Gil, M.I., 2008. Effect of regulated deficit irrigation and crop load on the antioxidant compounds of peaches. J. Agric. Food Chem. 56, 3601–3608. https://doi.org/10.1021/jf800190f

Cantín, C.M., Gogorcena, Y., Moreno, M.Á., 2009. Analysis of phenotypic variation of sugar profile in different peach and nectarine [*Prunus persica* (L.) Batsch] breeding progenies. J. Sci. Food Agric. 89, 1909–1917. https://doi.org/10.1002/jsfa.3672

Centritto, M., Lucas, M.E., Jarvis, P.G., 2002. Gas exchange, biomass, whole-plant water-use efficiency and water uptake of peach (*Prunus persica*) seedlings in response to elevated carbon dioxide concentration and water availability. Tree Physiol. 22, 699–706. https://doi.org/10.1093/treephys/22.10.699

Chavez, D.J., Beckman, T.G., Werner, D.J., Chaparro, J.X., 2014. Genetic diversity in peach *Prunus persica* (L.) Batsch at the University of Florida: past, present and future. Tree Genet. Genomes 10, 1399–1417. https://doi.org/10.1007/s11295-014-0769-2

Chinnici, F., Spinabelli, U., Riponi, C., Amati, A., 2005. Optimization of the determination of organic acids and sugars in fruit juices by ion-exclusion liquid chromatography 18, 121–130. https://doi.org/10.1016/j.jfca.2004.01.005

Crisosto, C.H., Johnson, R.S., Luza, J.G., Crisosto, G.M., 1994. Irrigation regimes affect fruit soluble solids concentration and rate of water loss of 'O'Henry' peaches. HortScience 29, 1169–1171.

Dabbou, S., Lussiana, C., Maatallah, S., Gasco, L., Hajlaoui, H., Flamini, G., 2016. Changes in biochemical compounds in fl esh and peel from *Prunus persica* fruits grown in Tunisia during two maturation stages. Plant Physiol. Biochem. 100, 1–11. https://doi.org/10.1016/j.plaphy.2015.12.015

De la Rosa, J.M., Domingo, R., Gómez-Montiel, J., Pérez-Pastor, A., 2015. Implementing deficit irrigation scheduling through plant water stress indicators in early nectarine trees. Agric. Water Manag. 152, 207–216. https://doi.org/10.1016/j.agwat.2015.01.018

Domingo, R., Ruiz-Sainchez, M.C., Sfinchez-Blanco, M.., Torrecillas, A., 1996. Water relations , growth and yield of Fino lemon trees under regulated deficit irrigation. Irrig. Sci. 16, 115–123.

Du, S., Kang, S., Li, F., Du, T., 2017. Water use efficiency is improved by alternate partial root-zone irrigation of apple in arid northwest China. Agric. Water Manag. 179, 184–192. https://doi.org/10.1016/j.agwat.2016.05.011

Du, T., Kang, S., Zhang, J., Li, F., Yan, B., 2008. Water use efficiency and fruit quality of

table grape under alternate partial root-zone drip irrigation. Agric. Water Manag. 95, 659–668. https://doi.org/10.1016/j.agwat.2008.01.017
Faci, J.M., Medina, E.T., Martínez-Cob, A., Alonso, J.M., 2014. Fruit yield and quality response of a late season peach orchard to different irrigation regimes in a semi-arid environment. Agric. Water Manag. https://doi.org/10.1016/j.agwat.2014.07.004
Falagán, N., Artés, F., Artés-Hernández, F., Gómez, P.A., Pérez-Pastor, A., Aguayo, E., 2015. Comparative study on postharvest performance of nectarines grown under regulated deficit irrigation. Postharvest Biol. Technol. 110, 24–32. https://doi.org/10.1016/j.postharvbio.2015.07.011
Fathi, H., Imani, A., Amiri, M.E., Hajilou, J., Nikbakht, J., 2017. Response of Almond Genotypes / Cultivars G rafted on GN15 'Garnem' Rootstock in Deficit-Irrigation Stress Conditions. J. Nuts 8, 123–135.
Fereres, E., Soriano, M.A., 2007. Deficit irrigation for reducing agricultural water use. J. Exp. Bot. 58, 147–159.
Flexas, J., Medrano, H., 2002. Drought-inhibition of photosynthesis in C3plants: Stomatal and non-stomatal limitations revisited. Ann. Bot. 89, 183–189. https://doi.org/10.1093/aob/mcf027
Ghrab M., Gargouri K., B.M.M., 2008. Long-term effect of dry conditions and drought on fruit trees yield in dryland areas of Tunisia. López-Francos A. (ed.). Drought Manag. Sci. Technol. Innov.80, 107-112.
Gifruits, 2018. Groupement Interprofessionnel des Fruits [WWW Document]. Pech. [WWW Doc. Group. interprofessionnel des fruits. URL http://gifruits.com (accessed 4.10.18).
Girona, J., Gelly, M., Mata, M., Arbone, A., Rufat, J., Marsal, J., 2005. Peach tree response to single and combined deficit irrigation regimes in deep soils. Agric. Water Manag. 72, 97–108. https://doi.org/10.1016/j.agwat.2004.09.011

Gómez-del-Campo, M., Baeza, P., Ruiz, C., Sotés, V., Lissarrague, J.R., 2007. Effect of previous water conditions on vine response to rewatering. Vitis - J. Grapevine Res. 46, 51–55.

Intrigliolo, D.S., Castel, J.R., 2006. Performance of various water stress indicators for prediction of fruit size response to deficit irrigation in plum. Agric. Water Manag. 83, 173–180. https://doi.org/10.1016/j.agwat.2005.12.005

Jiménez-García, S.N., Vázquez-Cruz, M.A., Guevara-González, R.G., Torres-Pacheco, I., Cruz-Hernández, A., Feregrino-Pérez, A.., 2013. Current approaches for enhanced expression of secondary metabolites as bioactive compounds in plants for agronomic and human health purposes - A review. Polish J. Food Nutr. Sci. 63, 67–78. https://doi.org/10.2478/v10222-012-0072-6

Jones, H.G., 2004. Irrigation scheduling: advantages and pitfalls of plant-based methods. J. Exp. Bot. 55, 2427–2436. https://doi.org/10.1093/jxb/erh213

Kobashi, K., Gemma, H., Iwahori, S., 2000. Abscisic acid content and sugar metabolism of peaches grown under water stress. J. Am. Soc. Hortic. Sci. 125, 425–428.

Kramer, P.J., 1980. Drought, stress and the origin of adaptations. John Wiley and Sons, Inc.

Li, S., Huguet, J., Schoch, P.G., Orlando, P., 1989. Response of peach tree growth and cropping to soil water deficit at various phenological stages of fruit development. J. Hortic. Sci. 64, 541–552. https://doi.org/10.1080/14620316.1989.11515989

Lopez, G., Hossein Behboudian, M., Echeverria, G., Girona, J., Marsal, J., 2011. Instrumental and sensory evaluation of fruit quality for “Ryan’s Sun” peach grown under deficit irrigation. Hort Technol. 21, 712–719.

Lopresti, J., Goodwin, I., Mcglasson, B., Holford, P., Golding, J., 2014. Variability in size and soluble solids concentration in peaches and nectarines. Hortic. Rev. 42, 253–312. https://doi.org/10.1002/9781118916827.ch05

Maatallah, S., Ghanem, M.E., Albouchi, A., Bizid, E., Lutts, S., 2010. A greenhouse investigation of responses to different water stress regimes of Laurus nobilis trees from two climatic regions. J. Arid Environ. 74, 327–337. https://doi.org/10.1016/j.jaridenv.2009.09.008

Maatallah, S., Guizani, M., Hjlaoui, H., Boughattas, N.E.H., Lopez-Lauri, F., Ennajeh, M., 2015. Improvement of fruit quality by moderate water deficit in three plum cultivars (*Prunus salicina* L.) cultivated in a semi-arid region. Fruits 70, 325–332. https://doi.org/10.1051/fruits/2015023

Mirás-Avalos, J.M., Pérez-Sarmiento, F., Alcobendas, R., Alarcón, J.J., Mounzer, O., Nicolás, E., 2016. Using midday stem water potential for scheduling deficit irrigation in mid–late maturing peach trees under Mediterranean conditions. Irrig. Sci. 34, 161–173. https://doi.org/10.1007/s00271-016-0493-9

Montevecchi, G., Vasile Simone, G., Masino, F., Bignami, C., Antonelli, A., 2012. Physical and chemical characterization of Pescabivona , a Sicilian white flesh peach cultivar [*Prunus persica* (L .) Batsch]. Food Res. Int. 45, 123–131. https://doi.org/10.1016/j.foodres.2011.10.019

Montevecchi, G., Vasile Simone, G., Mellano, M.G., Masino, F., Antonelli, A., 2013. Original article Fruit sensory characterization of four Pescabivona , white-fleshed peach [*Prunus persica* (L .) Batsch] , landraces and correlation with physical and chemical parameters. Fruits 68, 195–207. https://doi.org/10.1051/fruits/2013067

Nweze, C.C., Abdulganiyu, M.G., Erhabor, O.G., 2015. Comparative analysis of vitamin C in fresh fruits juice of *Malus domestica*, *Citrus sinensi*, Ananas comosus and Citrullus lanatus by iodometric titration. Int. J. Sci. Environ. Technol. 4, 17–22.

Palmer, J.W., Giulani, R., Adams, H.M., 1997. Efect of crop load on fruiting and leaf phosynthesis of “Braeburn”/M26 apple trees. Tree Physiol. 17, 741–746.

Parker, D.D., Zilberman, P.D., Moulton, K., 1991. How quality relates to price in California fresh peaches. Calif. Agric. 45, 14–16.

Pérez-Pérez, J.G., Romero, P., Navarro, J.M., Botía, P., 2008. Response of sweet orange cv "Lane late" to deficit-irrigation strategy in two rootstocks. II: Flowering, fruit growth, yield and fruit quality. Irrig. Sci. 26, 519–529. https://doi.org/10.1007/s00271-008-0113-4

Polley, H.W., 2002. Implications of atmospheric and climatic change for crop yield and water use efficiency. Crop Sci. 42, 131–140. https://doi.org/10.2135/cropsci2002.1310

Pourghayoumi, M., Rahemi, M., Bakhshi, D., Aaalami, A., Kamgar-Haghighi, A.A., 2017. Responses of pomegranate cultivars to severe water stress and recovery: changes on antioxidant enzyme activities, gene expression patterns and water stress responsive metabolites. Physiol. Mol. Biol. Plants 23, 321–330. https://doi.org/10.1007/s12298-017-0435-x

Rahmati, M., Davarynejad, G.H., Génard, M., Bannayan, M., Azizi, M., Vercambre, G., 2015a. Peach water relations, gas exchange, growth and shoot mortality under water deficit in semi-arid weather conditions. PLoS One 10, 1–19. https://doi.org/10.1371/journal.pone.0120246

Rahmati, M., Vercambre, G., Davarynejad, G., Bannayan, M., Azizi, M., Génard, M., 2015b. Water scarcity conditions affect peach fruit size and polyphenol contents more severely than other fruit quality traits. J. Sci. Food Agric. 95, 1055–1065. https://doi.org/10.1002/jsfa.6797

Ripoll, J., Urban, L., Staudt, M., Lopez-Lauri, F., Bidel, L.P.R., Bertin, N., 2014. Water shortage and quality of fleshy fruits-making the most of the unavoidable. J. Exp. Bot. 65, 4097–4117. https://doi.org/10.1093/jxb/eru197

Ruiz-Sánchez, M.C., Domingo, R., Castel, J.R., 2010. Deficit irrigation in fruit trees and vines in Spain. Spanish J. Agric. Res. 8, 5. https://doi.org/10.5424/sjar/201008S2-1343

Saidani, F., Giménez, R., Christophe, A., Chalot, G., Jesus, A. betran, Gogorcena, Y., 2017. Phenolic, sugar and acid profiles and the antioxidant composition in the peel and pulp of peach fruits. J. Food Compos. Anal. 62, 126–133. https://doi.org/10.1016/j.jfca.2017.04.015

Scholander, P.F., Hammel, H.T., Bradstreet, E.D., Hemmingsen, E.A., 1965. Sap Pressure in Vascular Plants: Negative hydrostatic pressure can be measured in plants. Science. 148, 339–346. https://doi.org/10.1126/science.148.3668.339

Shao, H.B., Chu, L.Y., Jaleel, C.A., Zhao, C.X., 2008. Water-deficit stress-induced anatomical changes in higher plants. Comptes Rendus - Biol. 331, 215–225. https://doi.org/10.1016/j.crvi.2008.01.002

Silva, M.D.A., Moura, C., Labate, C.A., Guidetti-gonzalez, S., Borges, J.D.S., Ferreira, L.C., 2012. Chapter 6 Breeding for Water Use Efficiency, in: Fritsche-Neto, R., Borém, A. (Eds.), Plant Breeding for Abiotic Stress Tolerance. Springer-Verlag Berlin Heidelberg, p. VIII, 176. https://doi.org/10.1007/978-3-642-30553-5

Stefanelli, D., Goodwin, I., Jones, R., 2010. Minimal nitrogen and water use in horticulture: Effects on quality and content of selected nutrients. Food Res. Int. 43, 1833–1843. https://doi.org/10.1016/j.foodres.2010.04.022

Thakur, A., Singh, Z., 2012. Responses of "Spring Bright" and "Summer Bright" nectarines to deficit irrigation: Fruit growth and concentration of sugars and organic acids. Sci. Hortic. 135, 112–119. https://doi.org/10.1016/j.scienta.2011.12.013

Wahbi, S., Wakrim, R., Aganchich, B., Tahi, H., Serraj, R., 2005. Effects of partial rootzone drying (PRD) on adult olive tree (Olea europaea) in field conditions under arid climate: I. Physiological and agronomic responses. Agric. Ecosyst. Environ. 106, 289–301. https://doi.org/10.1016/j.agee.2004.10.015

Zhao, Z., Wang, W., Wu, Y., Xu, M., Huang, X., Ma, Y., Ren, D., 2015. Leaf physiological responses of mature pear trees to regulated deficit irrigation in field conditions under desert climate. Sci. Hortic. 187, 122–130. https://doi.org/10.1016/j.scienta.2015.03.009

Zhou, H. mi, Zhang, F. cang, Roger, K., Wu, L.F., Gong, D.Z., Zhao, N., Yin, D.X., Xiang, Y.Z., Li, Z.J., 2017. Peach yield and fruit quality is maintained under mild deficit irrigation in semi-arid China. J. Integr. Agric. 16, 1173–1183. https://doi.org/10.1016/S2095-3119(16)61571-X

Figures captions

Fig. 1. Monthly average air temperature (T °C), evapotranspiration (ET_0 mm month^{-1}) and rainfall (mm month^{-1}) at the experimental site during the studied period (2016 and 2017)

Fig. 2. Shoot growth of four peach cultivars grown in the center of Tunisia and subjected to full irrigation (FI), sustained deficit irrigation (SDI) and cyclic deficit irrigation (CDI). Values are the means of twelve samples (n = 12) ± standard deviation. Letters (a, b, c) indicate significant differences ($p < 0.05$) between the three irrigation treatments.
FS: Flordastar, EMC: Early Maycrest, RUB: Rubirich, OH: O'Henry. FI: Full irrigation, SDI sustained deficit irrigation, CDI Cyclic deficit irrigation, DOY: day of the year

Fig. 3. Leaf water potential (ψb) of four peach cultivars grown in the center of Tunisia and subjected to full irrigation (FI), sustained deficit irrigation (SDI) and cyclic deficit irrigation (CDI). Values are the means of twelve samples (n = 12) ± standard deviation. Letters (a, b, c) indicate significant differences ($p < 0.05$) between the three irrigation treatments.
FS: Flordastar, EMC: Early Maycrest, RUB: Rubirich, OH: O'Henry, FI: Full irrigation, SDI: sustained deficit irrigation, CDI: Cyclic deficit irrigation, DOY: day of year

Fig. 4. Relative water content (RWC) in leaves of four peach cultivars grown in the center of Tunisia and subjected to full irrigation (FI), sustained deficit irrigation (SDI) and cyclic deficit irrigation (CDI). Values are the means of twelve samples (n = 12) ± standard deviation.

Letters (a, b, c) indicate significant differences ($p < 0.05$) between the three irrigation treatments.

FS: Flordastar, EMC: Early Maycrest, RUB: Rubirich, OH: O'Henry. FI: Full irrigation, SDI: sustained deficit irrigation, CDI: Cyclic deficit irrigation, DOY: day of year

Fig. 5. Correlation between P_n and g_s (A) and P_n and Ci (B) in four peach cultivars grown in the center of Tunisia and subjected to full irrigation (FI),sustained deficit irrigation (SDI) and cyclic deficit irrigation (CDI)

FI: Full irrigation, SDI: sustained deficit irrigation, CDI: Cyclic deficit irrigation, P_n: net photosynthesis rate, g_s: stomatal conductance, Ci: intercellular CO_2 concentration

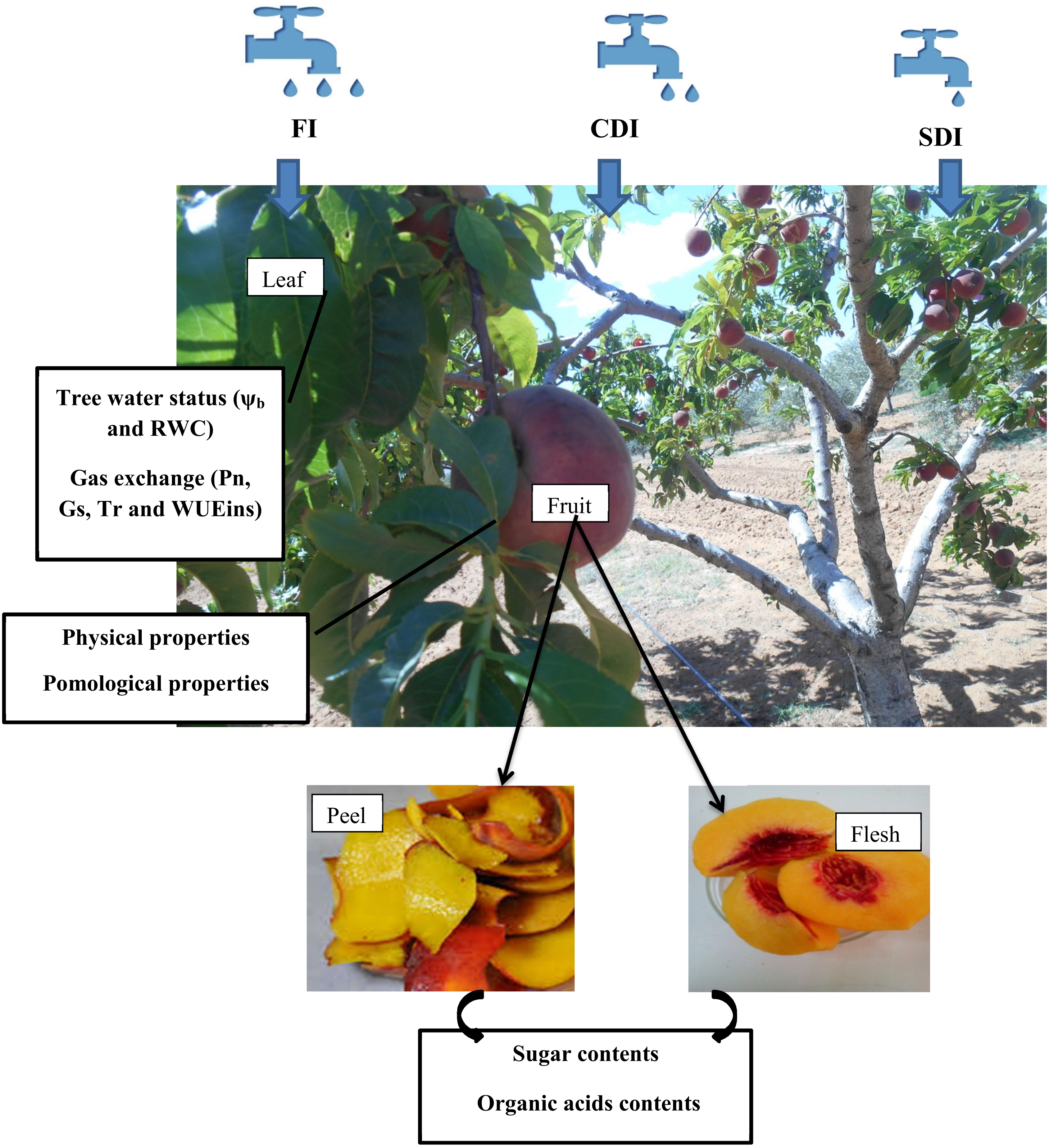
Fig. 6. Crop yield (A) and fruit number (B) in the trees of four peach cultivars grown in the center of Tunisia and subjected to full irrigation (FI), sustained deficit irrigation (SDI) and cyclic deficit irrigation (CDI). Values are the means of three trees ($n = 3$) ± standard deviation. Letters (a, b, c, d) and (A, B, C) indicate significant differences ($p < 0.05$) between the four cultivars and the three irrigation treatments respectively.

FS: Flordastar, EMC: Early Maycrest, RUB: Rubirich, OH: O'Henry. FI: Full irrigation, SDI: sustained deficit irrigation, CDI: Cyclic deficit irrigation

Highlights

- Cyclic (CDI) and Sustained (SDI) deficit irrigation increased fruit sugar content.
- CDI did not alter yield in most of the cultivars
- CDI improved sensory quality without altering fruit size and weight.
- CDI and SDI reduced vegetative growth.
- SDI affected tree physiology parameters more than CDI.

Physiological responses and fruit quality of four peach cultivars face to sustained and cyclic deficit irrigation in west center of Tunisia



Physiological responses and fruit quality of four peach cultivars under sustained and cyclic deficit irrigation in west center of Tunisia

Monia GUIZANI[1,2*], Samia DABBOU[3], Samira MAATALLAH[4,5], Giuseppe MONTEVECCHI[6], Hichem HAJLAOUI[4,5], Mourad REZIG[8], Ahmed Noureddine HELAL[2,7], Soumaya KILANI-JAZIRI[1,2]

[1]Unit of Bioactive and Natural Substances and Biotechnology UR17ES49, Faculty of Dentistry University of Monastir, Avicenne Street, 5019 Monastir, Tunisia.

[2]Department of Pharmaceutical Sciences A, Faculty of Pharmacy of Monastir University of Monastir, Avicenne Street, 5019 Monastir, Tunisia.

[3]Faculty of Dentistry, University of Monastir, Avicenne Street, 5019 Monastir, Tunisia

[4]Institution of Research and Higher Education Agriculture (IRESA), Regional Center for Agricultural Research, 9100, Sidi Bouzid, Tunisia

[5]Laboratory of Research Non-Conventional Water Valuation (LR VENC), INRGREF, Hedi EL Karray Street, El Menzah IV, 1004 Tunis, Tunisia

[6]BIOGEST - SITEIA Interdepartmental Centre, University of Modena and Reggio Emilia, Piazzale Europa 1, 42124 Reggio Emilia, Italy

[7]Laboratory of Bioressources: Integrative Biology and Valorization at Higher Institute of Biotechnology of Monastir, Tunisia

[8]Laboratory of Rural Engineering, National Institute of Research of Rural Engineering, Waters and Forests of Tunis, INRGREF, Hedi EL Karray Street, El Menzah IV, 1004 Tunis,Tunisia.

* Corresponding author: Monia Guizani

guizanimonia2018@gmail.com;guizanimonia@ymail.com

Abstract

In arid and semi-arid regions, the research and application of new irrigation techniques that economize water without altering tree performance and fruit quality is a challenge. The aim of this study was to investigate the effect of two different deficit irrigation strategies on tree physiology and fruit quality of four *Prunus persica* cultivars: two early-ripening cultivars (Flordastar and Early Maycrest), a mid-season cultivar (Rubirich), and a late-ripening cultivar (O'Henry). During two consecutive seasons (2016 and 2017), three different irrigation treatments were established: i) Full Irrigation (FI; 100% ET_c), ii) Sustained Deficit Irrigation (SDI; 50% ET_c) and iii) Cyclic Deficit Irrigation (CDI; trees irrigated at 100 % field capacity whenever the soil moisture dropped to 50% field capacity). Tree water status, gas exchange, yield, fruit pomology and the concentrations of the main sugars and organic acids were determined. Deficit irrigation decreased net photosynthesis rate, stomatal conductance and transpiration rate while it improved instantaneous water use efficiency (WUEins). In O'Henry cultivar, WUEins increased from 3.21 μ mol $mmol^{-1}$ in FI to 7.04 μmol $mmol^{-1}$ in CDI during harvest. Deficit irrigation significantly reduced shoot growth in the four cultivars. Furthermore, SDI decreased the yield significantly (from 41 to 26.3 kg in O'Henry cultivar during 2016), fruit size and weight while CDI increased soluble solids and sugar contents and decreased titratable acidity. The total sugar content increased significantly under deficit irrigation in all cultivars studied. In conclusion, CDI seems to be the best strategy in semi-arid regions, since it can save water and improve fruit quality parameters.

Keywords: *Prunus persica*; Shoot growth; Tree water status; Sugar contents; Organic acids; Water use efficiency

1. Introduction

The peach (*Prunus persica* L. Batsch) tree is originated from the Middle East (Persia or China), although its area of cultivation spreaded to all regions with a temperate climate (Chavez et al., 2014). In Tunisia, peach has been cultivated for a long time and the surface devoted to this crop doubled during the last two decades. The substantial raise in the production is the result of the introduction of new early- and late-ripening cultivars, particularly in the north and west-central of Tunisia. In this way, the extensive range of cultivars is able to provide these fruits for 4 to 5 months, from April to September (Gifruits, 2018).

In arid and semi-arid areas, low annual precipitation and high evaporation rates affect the production of fruit trees, which require efficient water supply. This is the case of southern and central Tunisia (Ghrab et al., 2008). Environmental variables like temperature, solar radiation, photoperiod, precipitation, and soil profile affect the growing environment and result in a wide variation in peach fruit quality at harvest (Lopresti et al., 2014).

The water scarcity for irrigation, especially in semi-arid zones, requires the application of deficit irrigation strategies. Regardless the type of irrigation scheduling used, it is necessary to develop and implement techniques that optimize agricultural water use without affecting crop yields (Fereres and Soriano, 2007). Among these strategies, Sustained-deficit irrigation (SDI) is a continuous water deficit, based on uniform water restriction throughout the entire season, whereas cyclic deficit irrigation (CDI) is to re-water soil to field capacity when its water content fell to 50 % of field capacity.

The intensity and duration of the water deficit, as well as other weather conditions, can cause changes in plant behavior (Shao et al., 2008). Such conditions may induce responses at all levels of plant organization. It is well known that a reduction of the irrigation can be a useful tool to limit unwanted vegetative growth and to increase water productivity in orchards

(Fereres and Soriano, 2007; Ruiz-Sánchez et al., 2010). Drought stress affects most of the processes involving gas exchange, leaf water potential and accelerated senescence (Jiménez-García et al., 2013). It reduces stomatal conductance, transpiration and net photosynthesis rate. Stomatal closure is one of the first responses to water deficit that allows plants to limit respiration, but it also limits CO_2 absorption, resulting in a decrease in photosynthetic activity (Flexas and Medrano, 2002). The ratio between net CO_2 fixation (P_n) and transpiration (Tr) is defined as instantaneous WUE (WUEins) which is the most important component of drought adaptation (Silva et al., 2012)

Deficit irrigation can be used to maintain or optimize the yield and improves peach fruit quality (Du et al., 2017). Kobashi et al. (2000) showed that moderate stress in peaches improves fruit quality as result of an increase in the sugar content and a higher maturity index. Sugars mainly sucrose, the major sugar in peaches, and reducing sugars (glucose and fructose) influence the peach taste along with the main organic acids, malic and citric ones (Borsani et al., 2009). Early and late-maturing peach cultivars seem to respond differently to water deficit (Buendía et al., 2008; Girona et al., 2005). In early cultivars that had a short ripening time, an increase in the amounts of sugar in fruit was recorded which induced a higher maturity index (Buendía et al., 2008; Falagán et al., 2015). In late cultivars, higher amounts of sugars, total phenols and ascorbic acid were found (Thakur and Singh, 2012).

The effect of deficit irrigation on the physiology and the fruit quality of peach has been studied by other authors, although researches on the effect of cyclic stress on *Prunus persica* cultivars are scarce. However, this type of stress has been applied to other species such as *Laurus nobilis L.* (Maatallah et al., 2010). Those authors proved that cyclic deficit irrigation is a good strategy in water shortage that may influence the plants ability to cope with a subsequent episode of water scarcity. In addition, it had limited impact on the plants behavior. As well, Gómez-del-Campo et al. (2007) found that the application of cyclic periods of stress and re-watering in *Vitis vinifera,* induced an adaptation of the leaf area development to the available water, thereby improving water use efficiency.

In this context, the main objectives of the present study were; (1) to investigate the performance of four peach cultivars (with contrasting lengths of their growing cycle) grown in semi-arid climate (Centre west of Tunisia) when subjected to cyclic and sustained deficit irrigation; (2) to define which is the efficient irrigation strategy that saves water without affecting the physiology and the fruit quality of peach. The effects of the irrigation strategy on plant shoot growth, water status, gas exchange, yield and fruit quality parameters were evaluated over two consecutive growing seasons.

2. Materials and methods

2.1. Orchard description

The study was carried out in an experimental peach orchard located 3 km south west of Sidi Bouzid (Mid-Western Tunisia) (35° 01'21.9" N, 9° 26'31.3" E; 160 m above sea level) during two consecutive seasons: 2016 and 2017. The region is characterized by a typical Mediterranean climate with low rainfall and high temperatures during the summer season. The soil was a sandy loam-clay, with an average rooting depth of 1.20 m and total assimilable phosphorus (P_2O_5) of 15 ppm. Calcium carbonate ($CaCO_3$) and organic matter contents was 12.5% and 0.48 %, respectively. The soil sample showed a pH of 7.8 and a salinity of 1.8 g kg^{-1}. The electrical conductivity (EC) of the irrigation water varied between 1.33 and 3.18 dS m^{-1}. The value of the measured field water capacity was between 19.8% and 23.5%, wilting point was about 7.90 % and saturation water content was approximately 28.5%. Bulk density was around 1.62 g cm^{-3}. The experimental plot had an area of 1 ha and was set up as a criss-cross plot randomized with three blocks. Each block is divided into two rows. The thirteen-year-old peach cultivars (*P. persica* L. Batsch), Flordastar, Early Maycrest, Rubirich and O’Henry, were grafted on the Guernem wild rootstock at a spacing of 4 m × 6 m. The four cultivars covered the whole peach season; they can be classified into two early cultivars (Flordastar and Early Maycrest), a mid-season one (Rubirich) and a late cultivar (O’Henry). Fruit growth period for early cultivars was approximately from mid-February to the third week of May (from 45 DOY to 142 DOY), for the mid-season cultivar it was from the second week of March to the third week of June (from 74 DOY to 173 DOY). Concerning, the fruit growing period for the late cultivar, it was ranging from the end of February to the mid-August (from 59 DOY to 228 DOY). During the two experimental seasons, all cultivars were similarly fertilized. Soluble fertilizers (potassium sulphate, magnesium sulphate, potash and nitric acid) were applied with the drip irrigation system throughout the irrigation season. Irrigation season started in late February or early March and finished by late September or early October, according to the seasonal meteorological trend.

2.2. Weather conditions

Daily meteorological data was collected from an automatic weather station (Pessl instruments, GesmbHWeiz, Austria). The station was located in the experimental plot at 20 m from the peach orchard. Every 30 min, this station stored data on air temperature, air relative humidity, wind speed and direction, solar radiation, and precipitation. The daily meteorological data was used to estimate daily values of reference evapotranspiration (ET_0) computed using the FAO Penman–Monteith approach (Allen et al., 1998).

2.3. Irrigation treatments

Eighteen trees per irrigation treatment were used for each cultivar. Three irrigations types were carried in each row (three trees for each treatment) while three trees were used as borders. Irrigation was carried out using a drip irrigation system with two lateral pipes per row and four emitters per tree. The flow was $4Lh^{-1}$. Three different irrigation treatments were considered in this study: i) the control is Full Irrigation (FI); ii) Sustained Deficit Irrigation (SDI), and; iii) Cyclic Deficit Irrigation (CDI).

In FI, trees were irrigated at 100% of crop evapotranspiration (ET_c). The irrigations amounts were calculated to replace ET_c (net of the effective rainfall) by the following formula:

$ET_c = ET_0 \times K_c$

K_c, a crop coefficient adapted to peaches, was modified according to the stage of fruit development (Ayars et al., 2003): initial K_c was 0.5 during Stage I; in the mid-season K_c was 0.9 during Stage II and III; and in the late season K_c was 0.5 after harvest. These crop coefficients corresponded to those usually recommended to fruit growers in the area by agricultural extension services.

The SDI treatment consisted of an irrigation at 50% ET_c in order to apply a water deficit uniformly over the whole fruit development cycle and to reduce the irrigation application to 50% of the FI (100% ETc) during the fruit cycle. CDI was a deficit irrigation treatment, consisted to re-irrigating at 100% field capacity whenever the soil water content decreased to 50% of field capacity.

Soil water potential was monitored with tensiometric probes, (Watermark WM-S-15) at three depths (40, 60, and 80 cm) within the root zone (40 cm apart from the tree trunk) and irrigation was applied according to the manual Watermark moisture meter readings. The tensiometric probes were installed in trees under FI and CDI treatments. In addition to tensiometric probes, gravimetric soil moisture content was measured with soil profile from 0–1.20 m taken in 20 cm, oven dried at 105 – 110 °C to constant weight, then quantify soil water content of the peach root zone.

2.4. Shoot growth

During the two consecutive years, shoot growth was assessed by measuring the shoot extension at different time intervals. At the beginning of the vegetative growth, twelve shoots from the previous year were selected from the four sides and in the same level in each tree to monitor the growth of new shoots. Measurements were carried out every 15 days during the growth season. Shoot growth was determined on three trees per treatment by measuring four tagged shoots in each tree (n = 12).

2.5. Tree water status

Predawn leaf water potential (ψ_b) was measured using a pressure chamber (PMS Instruments, Corvallis, OR, USA), shortly before sunrise (Scholander et al., 1965). Four leaves were taken from each tree and three trees were chosen for each treatment (n=12). These measurements were made weekly.

The relative water content (RWC) was determined by the method described by Kramer (1980) and calculated using the following formula:

$RWC = (FW - DW) \times 100/(FW_{sat} - DW)$

Where FW represents the fresh weight of leaves, DW is the dry weight of leaves, and FW_{sat} is the fresh weight of leaves at saturation. The saturation was achieved by covering the leaves with water and leaving them in the dark at a temperature of 4 °C during 24 h, whereas DW was determined by drying the leaf in an oven at 80 °C for 48 h. Four leaves were taken from one tree and three different trees were chosen for each treatment (n=12). RWC was measured every two weeks.

2.6. Gas exchange parameters

The rate of photosynthetic assimilation (P_n, µmol CO_2 m^{-2} s^{-1}), the stomatal conductance (g_s, mmol H_2O m^{-2} s^{-1}), the transpiration rate (Tr, mmol H_2O $m^{-2}s^{-1}$), the instantaneous water use efficiency (WUEins = P_n/Tr), and "Ci'' (molar fraction of CO_2 in the intercellular spaces) were measured on mature leaves with a portable gas-exchange analyzer (LCpro+ ADC Ltd. BioScientific, Hoddensdon, UK). These gas exchanges parameters were measured under saturating sunlight of the day. The measurements were performed on three leaves per tree, and three trees per cultivar per treatment at each measurement date.

2.7. Sample processing and fruit quality parameters

Hand thinning was applied in both years (2016 and 2017). Harvest was based on our previous study on the fruit ripening. For each cultivar, fruits were harvested at their corresponding commercial ripening stage. Each tree was harvested individually. The total number of fruits was weighed and counted in three trees per replicate for each treatment. Immediately after harvest, fruit diameter, weight, firmness, juice content, soluble solid content (SSC), titratable acidity (TA), and vitamin C contents were determined on 10 fruits per tree considering three trees per replicate for each treatment and for each cultivar. For biochemical analyses, the fruits were frozen and ground in liquid nitrogen and then stored at −80 °C until analysis.

The width (mm) and length (mm) of each fruit were measured using a caliper (Mitutoyo, UK), while the fresh weight was determined using a precision balance (AXIS-AGN 100 C, Poland). The flesh firmness was measured on a partially peeled fruit using a penetrometer (FT 327, Italy). To determine the SSC of the juice, a digital refractometer (Atago-Palette PR 101; Atago Co., Tokyo, Japan) was used and results were expressed in °Brix. The determination of titratable acidity was achieved as described by Dabbou et al. (2016), in two-fold water diluted peach juice by the neutralization of the free acids with a solution of 0.1 N NaOH added dropwise until pH 8.2 (checking through a pH-meter). The results were expressed as g malic acid 100 ml^{-1}, the most abundant organic acid in peaches (Montevecchi et al., 2012).The ratio SSC/TA was also calculated. The vitamin C content was determined by iodometric titration of ascorbic acid (Nweze et al., 2015).

2.8. Determination of soluble sugars and organic acids

Extraction and quantification of soluble sugar and organic acids were determined as described by Chinnici et al. (2005) with minor modification. Aqueous extracts were prepared from 1 g of freeze-dried samples suspended in 10 mL of deionized water and subjected to homogenization, centrifugation at 15000 g for 15 min at 4 °C and, finally, filtration through a cellulose nitrate membrane filter (0.45 µm pore size). The obtained extracts were analyzed in a HPLC system (PU 4180, Jasco Europe Srl, Cremella, LC) equipped with a Rezex™ RCM-Monosaccharide Ca+2 (8%), LC Column 300 x 7.8 mm, Ea column. The isocratic separation of sugars and organic acids was performed at 30 °C, using a mobile phase of 0.1% phosphoric acid pumped into the column with a flow rate of 0.5 mL min^{-1}. The quantification of sugars was carried out with a refractive index detector (RI 4030) and the organic acids were quantified using an UV/Vis detector (UV4070, Jasco) at a wave length of 210 nm. The identification of the analytes was performed by comparing the retention times of the peaks with pure reference standards. Sugar and organic acid standards were supplied by Supelco analysis (Bellefonte, PA, USA). Quantification was carried out through the external standard calibration method.

2.9. Statistical analysis

Statistical analyses were performed using SPSS software (release 17.0 for Windows, SPSS, Chicago, IL, USA). The analysis of variance (ANOVA) was employed. Duncan test was used to compare means between cultivars for each irrigation treatment and to compare the three irrigation treatments in each cultivar. Student-t test was used to compare among the two different tissues (peel and flesh). The values were represented as the mean ± the standard deviation. Additionally, relationships among variables were assessed through Pearson's "r" coefficient. Statistically significant differences between groups were considered when $p < 0.05$.

3. Results

3.1. Meteorological conditions and evapotranspiration

The temperature increased during the fruit growth period from 14 and 16 °C in February to 30 and 35 °C in August in 2016 and 2017, respectively. Total annual rainfall of 250 mm during 2016 and 235 mm during 2017 concentrated mainly from autumn to spring. Total rainfall was low during fruit development, 44 mm in April 2016 and 2 mm during the summer (August). In 2017, total rainfall was lower than the previous year and it dropped down from 24 mm to 1 mm from April to August. The total evapotranspiration (ET_0) recorded was 1450.36 and 1329.68 mm during 2016 and 2017, respectively. The conditions of high temperatures and low summer rainfalls resulted in a high evaporative demand (Fig. 1), which reached its maximum (205.53 mm $month^{-1}$) and (197.47 mm $month^{-1}$) in July 2016 and 2017, respectively.

3.2. Shoot growth

The shoot growth of the four peach cultivars studied is represented in Fig. 2. Shoot growth was stopped form mid (196 DOY) to the end (211 DOY) of July in all cultivars studied. Shoot growth decreased under water deficit treatment. This parameter was the most affected by SDI in the O'Henry cultivar, with a reduction of 53.74% and 52.61 % during 2016 and 2017, respectively, compared to FI. Significant reductions were also observed in Flordastar, Early Maycrest and Rubirich. In the last cultivar this decrease was 48.27% and 44.54% during 2016 and 2017 respectively, under SDI compared to FI. In addition, no significant differences were found between SDI and CDI for the early cultivars (Flordastar and Early Maycrest). However, for Rubirich and O'Henry, shoot growth in trees subjected to CDI was significantly higher than that in trees under SDI.

3.3. Tree water status

The evolution of Ψ_b showed a decreasing trend over the growing season in all treatments (Fig. 3). During 2016 and 2017, there was a slight decrease under FI strategy in early cultivars (from -0.46 MPa to -0.99 MPa). While for O'Henry and Rubirich cultivars, it varied between

-0.48 and -1.01 MPa during 2016 and 2017. Ψ_b dropped in trees under SDI and reached a minimum in O'Henry cultivar (-2.90 MPa). The effect of CDI on Ψ_b was moderate in comparison with that of SDI. Flordastar cultivar maintained higher predawn leaf water potential (approximately -2MPa) during 2016 and 2017 seasons compared to the other cultivars.

The relative water content (RWC) in leaves (Fig. 4) showed a decreasing trend over the growing season in all cultivars and treatments. In FI, the RWC for Rubirich and O'Henry ranged from 80% to 85.33% whereas, for Flordasatr and Early Maycrest it was between 77.66% and 83.67 %. In all cultivars, compared to the control values, SDI presented a significant decrease of RWC which dropped to 62%. However, CDI generated a slight decrease significantly higher than SDI and it was around 71% for all cultivars during 2016 and 2017.

3.4. Gas exchange parameters

Photosynthesis rates differed significantly among irrigation treatments for all cultivars studied (Table 1). Under FI treatment, during the fruit expansion period, O'Henry cultivar had the higher P_n values (11.37 and 11.28 µmol $m^{-2}s^{-1}$ during 2016 and 2017 seasons, respectively) while the lowest P_n was found in Rubirich cultivar during 2017 (9.08 µmol $m^{-2}s^{-1}$) and in Flordastar cultivar during 2016 (9.33 µmol $m^{-2}s^{-1}$). Over the fruit harvest period, O'Henry and Early Maycrest cultivars had higher P_n compared to Flordastar and Rubirich cultivars. Water deficit induced a significant decrease of P_n during the two periods for all cultivars. Furthermore, P_n values in CDI were significantly higher than that obtained under SDI treatment. For instance, during the fruit expansion period, P_n ranged from 6.13 to 7.63 µmol $m^{-2}s^{-1}$ under SDI and between 7.78 to 8.91 µmol m^{-2} s^{-1} under CDI for Flordastar and O'Henry cultivars respectively, during 2016.

Stomatal conductance exhibited the same variation pattern as P_n (Table 1). Under FI conditions, the four peach cultivars studied had a high g_s that reached 94.05 mmol $m^{-2}s^{-1}$ in O'Henry cultivar during fruit expansion in 2017 season. The lack of water led to a significant decrease of g_s in all cultivars studied. In addition, g_s presented a severe decrease under SDI with respect to FI. Under CDI, g_s was significantly higher than that in SDI trees.

Correlation between P_n and g_s (fig. 5A) and P_n and Ci (Fig. 5B) were studied. Results showed a positive correlations between P_n and g_s ($r = 0.91$) as well as, between P_n and intercellular CO_2 ($r = 0.89$).

Transpiration rate clearly decreased with water deficit (Table 1). The SDI treatment exerted a depressive effect on Tr which dropped to 1.04 mmol $m^{-2}s^{-1}$ in Flordastar during fruit expansion in 2016, for instance. The values of Tr under CDI treatment were significantly higher than those obtained under SDI during 2016 except for O'Henry cultivar during fruit expansion period and for Flordastar and O'Henry cultivars during harvest periods (Table 1). However, there was no significant difference among deficit irrigation treatments in 2017 during the two periods studied.

The irrigation strategy affected WUEins (Table 1). WUEins in stressed trees (under CDI and SDI treatment) was significantly higher than WUEins under FI trees. The application of water stress affected differently the WUE in the four cultivars. For the early cultivars (Flordastar and Early Maycrest), the maximum WUEins was obtained under the SDI treatment at the fruit expansion stage, while for Rubirich and O'Henry, the highest WUEins was recorded in CDI treatment at fruit harvest (5.45 and 7.04 μ mol $mmol^{-1}$, respectively during 2016 season).

3.5. Fruit quality traits

O'Henry cultivar had the highest yield (41 and 44.05 kg $tree^{-1}$, during 2016 and 2017 respectively) while Early Maycrest had the lowest one for both years (30.33 and 30.56 kg $tree^{-1}$ during 2016 and 2017, respectively). SDI had a depressive effect on fruit yield during

2016 and 2017 seasons (Fig. 6A) contrary to CDI. This effect was not observed for Flordastar cultivar that showed a slight decrease under CDI treatment.

Flordastar cultivar had the highest number of fruit (270 fruits tree^{-1}) during 2016, followed by Rubirich, O'Henry and Early Maycrest cultivar (262.66; 227; 212, respectively fruits tree^{-1}) under FI treatment. However, Rubirich and Flordastar showed the highest number (276.33 and 260 fruits trees^{-1}, respectively) and Early Maycrest the lowest one (218 fruits tree $^{-1}$) under SDI during 2016 season. During 2017, there was no significant variation between cultivars as shown in Fig. 6B. Irrigation treatments did not affect the number of fruits during 2016 and 2017 seasons in all the cultivars studied (Fig. 6B).

There was a significant difference among cultivars and treatments ($P < 0.05$) for fruit size and weight (Table 2). Under FI, fruits from O'Henry were the largest (72.45 mm and 71.09 mm for 2016 and 2017 seasons, respectively) and the heaviest (172.07 g in 2016 and 195.55 g in 2017 season), followed by Rubirich cultivar while Flordastar and Early Maycrest cultivars produced the smallest fruits. The SDI regime generated a significant decrease in fruits weight, length, and diameter; conversely to CDI which did not have a significant effect compared to FI during both seasons studied except for the size of Flordastar fruit during 2017.

The average firmness in FI treatment varied from 4.18 to 6.48 kg cm^{-2} in the four cultivars during 2016 and from 3.86 to 5.52 kg cm^{-2} during 2017 seasons. O'Henry fruits had the greatest firmness, followed by Rubirich and Early Maycrest, whereas, Flordastar fruits showed the lowest firmness during 2016. However, Early Maycrest had the lowest firmness during 2017. For all cultivars, SDI significantly increased fruits firmness, for instance, O'Henry fruits firmness reached approximately 7.6 kg cm^{-2} during both seasons (Table 2). On the other hand, CDI caused a slight increase in fruit firmness but lower than that obtained under SDI.

Statistical differences were found for the soluble solid content (SSC) among cultivars and irrigation treatments. Under FI treatment, O'Henry fruits presented the highest values of SSC (15.18 and 13.98 °Brix during 2016 and 2017 seasons, respectively). In contrast, fruits from Rubirich had the lowest SSC (10.50 and 11.88 °Brix during 2016 and 2017, respectively). The SDI and CDI treatments increased the values of SSC. In the 2017 season, fruit subjected to SDI had higher SSC compared to fruits from CDI treatment, while in 2016 season there was no significant difference (Table 2).

The four cultivars differed in TA (Table 2). Flordastar had the highest TA (2.07 and 2.02% during 2016 and 2017 seasons, respectively), while Early Maycrest showed he lowest values (1.13 and 1.19 % during 2016 and 2017 seasons, respectively). In most cultivars, deficit irrigation reduced TA. According to these results, the SSC/TA ratio was significantly higher in fruit under SDI and CDI compared to fruits from the FI treatment.

Vitamin C exhibited the highest concentration in O'Henry fruits (5.86 and 5.83 mg100g^{-1} in 2016 and 2017 seasons, respectively) while Flordastar fruits had the lowest concentration (2.83 mg 100g^{-1}) under FI (Table 2). Generally, the SDI and CDI treatments significantly increased the level of vitamin C in peach fruits. For all cultivars, fruit from trees under CDI treatment had the higher vitamin C content during the both crop season. However, it was not the case for Rubirich cultivar during 2017 season (Table 2).

Sucrose was the main sugar found in the peaches (Table 3). In the both seasons studied, sucrose content ranged from 26.17 to 38.53 g 100 g^{-1} DW in flesh and from 15.59 to 33.39 g 100 g^{-1} DW in peels under FI treatment. In all cultivars studied, there was a significant difference in the amounts of all main soluble sugars. O'Henry fruits had the highest concentrations of total sugars (64.16 and 59.67 g100 g^{-1} DW in flesh under FI during 2016 and 2017 seasons, respectively). Deficit irrigation increased sugar content significantly. In fact, SDI and CDI treatments improved the sugar content in both tissues (peel and flesh) as shown in Table 3.

Malic acid was the main organic acid in peach fruits, followed by citric and succinic acids, while fumaric acid was present as traces (Table 4). Flesh part had significantly higher concentrations of organic acids than peels. Under FI treatment, Flordastar fruits had the highest total organic acid contents (8.78 and 10.19 g 100 g^{-1} DW in the flesh during 2016 and 2017, respectively). While, O'Henry fruits showed the lowest values (5.62 and 8.58 g 100 g^{-1} DW in 2016 and 2017 seasons, respectively). The deficit irrigation regimes (SDI and CDI) affected the amount of organic acid in flesh and peel tissues during both crops seasons. This decrease was not statistically significant in peel tissue. SDI and CDI treatments decreased malic and citric acids in the most cultivars (Table 4). However, this reduction was low in succinic and fumaric acids for both tissues. Furthermore, under SDI treatment, there was a significant decrease of total organic acid contents in flesh tissue for all cultivars during 2017 season. This variation was not significant for Flordastar and Rubirich flesh in 2016 season. Concerning CDI strategy, total organic acids dropped significantly in flesh tissue in all cultivars, except for Flordastar fruits (Table 4).

4. Discussion

4.1 Effect of water deficit on tree physiology of four *Prunus persica* cultivars

Results from shoot growth showed that vegetative growth (Fig. 2) was very sensitive to water deficit. In fact, SDI and CDI significantly reduced the shoot growth in all cultivars. These findings have been widely documented in peach trees (Li et al., 1989; Rahmati et al., 2015a; Mirás-Avalos et al., 2016). The effect of CDI varied among cultivars; it exerted the same effect as SDI for early cultivars (Flordatar and Early Maycrest) that have a short cycle of fruit development. This may be explained by the competition between vegetative and fruit growth since the goal of the fruit tree is to divert carbohydrates into fruit growth. According to De la Rosa et al. (2015) fruit growth tends to dominate over vegetative growth in early cultivars. In addition, Ruiz-Sánchez et al. (2010) indicated that if vegetative and fruit growth processes overlap, the vegetative growth will be the more affected. Whereas, for late and mid-season cultivars (Rubirich and O'Henry), vegetative growth was more effected under SDI treatment. This may be attributed to many factors such as duration of the stress exposure period, duration of growth cycle that varies from one cultivar to another and climatic conditions. Vegetative growth under CDI was significantly higher than that measured under SDI, this effect can be explained by the re-watering period. In the same way, Abrisqueta et al. (2010) indicated that shoot growth in continuous deficit irrigation was more affected by water stress than shoot growth in regulated deficit irrigation strategy.

Predawn leaf water potential (Ψ_b), is recognized worldwide as one of the most accurate indicators of the state of plant water as a result of the balance in the soil - plant - atmosphere reached during the night (Domingo et al., 1996; Jones, 2004). The FI treatment showed decreasing tendency of Ψ_b along the season but their values were always maintained less negative than -1MPa (Fig. 3). Ψ_b was significantly decreased by water deficit where the maximum reduction was recorded under SDI treatment. These results are consistent with Rahmati et al.(2015a) in peach and Intrigliolo and Castel (2006) in plum. O'Henry cultivar had the highest baseline water potential, indeed, this behavior is explained by the combined effect of water deficit and crop load (Ruiz-Sánchez et al., 2010). The fruit development of this cultivar was occurred during the hottest months (July and August), and it had the highest fruit yield as well. The slight increase of Ψ_b in the four cultivars studied during 2017 season could be explained by the lack of precipitation in comparison to 2016 season. The RWC of leaves (Fig. 4) showed a slight decrease under all treatments applied and in all cultivars studied. This reduction can be explained by the increase of temperature and evaporative demand, especially in July and August (Fig. 1). These results confirm those reported by Pourghayoumi et al. (2017) in pomegranate cultivars. The effect of CDI was moderate and the plant could maintain a high leaf water content, in agreement with the results published by Fathi et al. (2017) on almond trees and by Wahbi et al. (2005) on olive trees. Furthermore, in the present study, O'Henry cultivar, maintained the higher RWC (66%) and a very negative Ψb (-2.84 MPa) under SDI treatment during 2017 season. This behavior could be explained by the higher crop yield, and by the longer growing cycle period (harvest date in mid-August). According to the parameters followed, the four cultivars studied were able to better perform under CDI than SDI treatment. In fact, they maintained predawn water potential around -1.5 MPa and 71% of RWC. This allows to explain the conservation of a good quality of fruit under CDI in comparison with SDI.

In all cultivars, under FI treatment, the values of P_n and g_s reached a maximum of 11.37 μmol m^{-2} s^{-1} and 94.05 mmol m^{-2} s^{-1}, respectively, during the study period. These results are in agreement with previous work on peach trees (Rahmati et al., 2015a). During fruits expansion P_n and g_s values were higher than those found during harvest in most of the cultivars studied. The increase of P_n and g_s during the fruit enlargement was proven by Zhao et al. (2015) in pear and Palmer et al. (1997) in apple trees. P_n, g_s and Tr decreased significantly under deficit irrigation treatments (CDI and SDI). The decline of these parameters have already been described by others authors in fruit trees subjected to water stress (Rahmati et al., 2015a; Zhou et al., 2017). The reduction in P_n was probably due to stomatal closure when the leaf water potential fell to a given threshold (Centritto et al., 2002). Furthermore, the reduction in g_s under water deficit condition is related to the plant's ability to withstand drought conditions. The positive correlation of g_s and P_n (coefficient of correlation r = 0.91) presented in Fig. 5 confirm that g_s governs P_n, and the limitation of g_s induces a decrease in the photosynthetic assimilation. In addition, the significant correlation (r = 0.89) between P_n and

Ci might indicate the presence of stomatal limitations in our study (Fig. 5). Similar results were found in sweet orange trees grown under water deficit (Pérez-Pérez et al., 2008). The observation of a concomitant decrease in Ci at a decrease of P_n during a constraint suggests that stomatal closure is involved in the inhibition of leaf photosynthesis. WUEins was extensively used in genotype selection and evaluation for the improvement of water use efficiency (Polley, 2002). For the FI treatment, the low WUEins values are due to high transpiration by the leaves. While, for SDI and CDI treatments, the increase of WUEins can be explained by the decline on Tr. A high ratio of P_n/Tr was recorded in O'Henry and Early Maycrest face to deficit irrigation strategy. This indicated a good efficiency in the use of water resource in these two cultivars.

4.2 Fruit quality parameters

Fruit number was not affected by irrigation treatment in 2016 and 2017 crop seasons. Water deficit did not affect flowering and fruit set in 2016 and 2017. The reduction in crop yield in SDI treatment resulted mainly from the reduction of fruit size and weight. These results were consistent with those reported by Rahmati et al. (2015b). The decrease of fruit size and weight under SDI is in agreement with previous works (Lopez et al., 2011; Rahmati et al., 2015b). Water stress considerably affected cell expansion. This reduction is mainly due to a reduction in turgor pressure (Shao et al., 2008). Furthermore, fruits from SDI trees had smaller size than CDI because water stress was more severe (Fig. 3) and net photosynthetic assimilation was lower (Table 1).

In addition to the reduction of fruit size in all cultivars studied, SDI treatment increased also the firmness of peach fruits. Indeed, according to Lopez et al. (2011) fruit firmness is affected by fruit size and this may be due to the higher cellular density. This may explain the higher firmness under SDI compared to FI and CDI. Moreover, in all cultivars, water deficit induced an increase in vitamin C content (Table 2). These results are in accordance with previous works carried out on peaches (Zhou et al., 2017) and on table grapes (Du et al., 2008). Furthermore, for soluble solid content (mainly represented by sugars) in the fruit, our results are in accordance with the works of Crisosto et al. (1994) and Lopez et al. (2011), which found a significant increase of SSC under deficit irrigation. Simultaneously, a decline in titratable acidity was noticed. As a consequence, there was a significant increase in the maturity index (SSC/TA) which may increase consumer's acceptance. In fact, peaches with high SSC generally have higher retail value (Parker et al., 1991; Montevecchi et al., 2013). Fruit acidity can also influence the consumer's acceptance of peaches. The acceptance is higher for fruit with lower acidity values. That is obtained under SDI and CDI. These results are in agreement with previous studies (Faci et al., 2014; Mirás-Avalos et al., 2016).

The main sugars identified, in our study, were sucrose with higher concentration, followed by fructose and glucose in both peel and flesh tissues which is in agreement with previous study of Saidani et al. (2017). For Flordastar, Early Maycrest and O'Henry cultivars, flesh tissue had significantly higher concentration of total sugar content compared to peel tissue. These results are in accordance with Saidani et al. (2017). However it was not the case for Rubirich under SDI and CDI during 2016 and 2017 seasons. In addition, the main sugars identified were significantly higher in the fruit subjected to water deficit treatments (Table 3). These results confirm what was found in previous works on peaches and nectarines (Thakur and Singh, 2012; Rahmati et al., 2015b). The higher amount of sucrose and total sugars in fruits subjected to deficit irrigation treatments is probably related to a higher amount of SSC and also to the reduction in fruit size (Stefanelli et al., 2010). Our work showed an increase in glucose and fructose contents under CDI and SDI treatments which is explained by the decrease in energy cost for fruit growth under drought condition. It could result, in turn, in a decline in the utilization of glucose and fructose through glycolysis pathway, thus explaining the increase in their contents (Maatallah et al., 2015; Rahmati et al., 2015b). Peach's flavor is highly dependent on sugar concentration, as well as on the titratable acidity (Cantín et al., 2009). Besides to soluble sugars, organic acids (primarily malic and citric acids) are among the major osmotic compounds that accumulate in fleshy fruits (Ripoll et al., 2014). In addition, the concentration of the total organic acids identified was higher in flesh tissue than in peel tissue (Saidani et al., 2017). The deficit irrigation treatments affected the fruit's organic acid content in a genotype-specific manner. For Early Maycrest, Rubirich and O'Henry cultivars, there was a significant decrease of organic acids under SDI and CDI. However, it was not the case for Flordastar. The decrease of organic acid contents is in agreement with the results described by Ripoll et al. (2014) in many species (notably peach, clementine, mandarin, pear). The decrease in levels of total organic acids in the fruit may be due to the decreased levels of malic and citric acid (Table 4) which is in accordance with the work of Thakur and Singh (2012). Furthermore, water deficit can affect organic acid concentration in fruit through a simple dehydration effect (Thakur and Singh, 2012).

5. Conclusions

Cyclic deficit irrigation (CDI) is more advisable than sustained deficit irrigation (SDI) for a better management of irrigation water without affecting tree functions. Trees under CDI treatment used water efficiently compared to the fully irrigated treatment, showing significant possibilities of saving water. Moreover, CDI improved the quality of fruits by increasing the maturity index, vitamin C and sugar contents in both peel and flesh. SDI treatment decreased trees yield in all cultivars studied. However, CDI treatment had no significant effect on fruit yield in the most cultivars compared to that under FI treatment.

Among the four cultivars studied, O'Henry cultivar was proven to have the best yield and fruit quality under deficit irrigation mostly under CDI. However, Early Maycrest cultivar showed better water use efficiency. The findings gathered from this study will help farmers to improve water management in regions with low water availability.

References

Abrisqueta, I., Tapia, L.M., Conejero, W., Sanchez-Toribio, M.I., Abrisqueta, J.M., Vera, J., Ruiz-Sanchez, M.C., 2010. Response of early-peach [*Prunus persica* (L.)] trees to deficit irrigation. Spanish J. Agric. Res. 8, 30–39. https://doi.org/10.5424/sjar/201008S2-1345

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., Ab, W., 1998. Crop evapotranspiration — guidelines for computing crop water requirements. FAO Irrig. Drain. Pap. 56. Food Agric. Organ. Rome. 1–15.

Ayars, J.E., Johnson, R.S., Phene, C.J., Trout, T.J., Clark, D.A., Mead, R.M., 2003. Water use by drip-irrigated late-season peaches. Irrig. Sci. 22, 187–194. https://doi.org/10.1007/s00271-003-0084-4

Borsani, J., Budde, C.O., Porrini, L., Lauxmann, M.A., Lombardo, V. nica A., Murray, R., Andreo, C.S., Dricovich, M.F., Lara, M. V, 2009. Carbon metabolism of peach fruit after harvest: changes in enzymes involved in organic acid and sugar level modifications. J. Exp. Bot. 60, 1823–1837. https://doi.org/10.1093/jxb/erp055

Buendía, B., Allende, A., Nicolás, E., Alarcón, J.J., Gil, M.I., 2008. Effect of regulated deficit irrigation and crop load on the antioxidant compounds of peaches. J. Agric. Food Chem. 56, 3601–3608. https://doi.org/10.1021/jf800190f

Cantín, C.M., Gogorcena, Y., Moreno, M.Á., 2009. Analysis of phenotypic variation of sugar profile in different peach and nectarine [*Prunus persica* (L.) Batsch] breeding progenies. J. Sci. Food Agric. 89, 1909–1917. https://doi.org/10.1002/jsfa.3672

Centritto, M., Lucas, M.E., Jarvis, P.G., 2002. Gas exchange, biomass, whole-plant water-use efficiency and water uptake of peach (*Prunus persica*) seedlings in response to elevated carbon dioxide concentration and water availability. Tree Physiol. 22, 699–706. https://doi.org/10.1093/treephys/22.10.699

Chavez, D.J., Beckman, T.G., Werner, D.J., Chaparro, J.X., 2014. Genetic diversity in peach *Prunus persica* (L.) Batsch at the University of Florida: past, present and future. Tree Genet. Genomes 10, 1399–1417. https://doi.org/10.1007/s11295-014-0769-2

Chinnici, F., Spinabelli, U., Riponi, C., Amati, A., 2005. Optimization of the determination of organic acids and sugars in fruit juices by ion-exclusion liquid chromatography 18, 121–130. https://doi.org/10.1016/j.jfca.2004.01.005

Crisosto, C.H., Johnson, R.S., Luza, J.G., Crisosto, G.M., 1994. Irrigation regimes affect fruit soluble solids concentration and rate of water loss of ‘O’Henry’ peaches. HortScience 29, 1169–1171.

Dabbou, S., Lussiana, C., Maatallah, S., Gasco, L., Hajlaoui, H., Flamini, G., 2016. Changes in biochemical compounds in fl esh and peel from *Prunus persica* fruits grown in Tunisia during two maturation stages. Plant Physiol. Biochem. 100, 1–11. https://doi.org/10.1016/j.plaphy.2015.12.015

De la Rosa, J.M., Domingo, R., Gómez-Montiel, J., Pérez-Pastor, A., 2015. Implementing deficit irrigation scheduling through plant water stress indicators in early nectarine trees. Agric. Water Manag. 152, 207–216. https://doi.org/10.1016/j.agwat.2015.01.018

Domingo, R., Ruiz-Sainchez, M.C., Sfinchez-Blanco, M.., Torrecillas, A., 1996. Water relations , growth and yield of Fino lemon trees under regulated deficit irrigation. Irrig. Sci. 16, 115–123.

Du, S., Kang, S., Li, F., Du, T., 2017. Water use efficiency is improved by alternate partial root-zone irrigation of apple in arid northwest China. Agric. Water Manag. 179, 184–192. https://doi.org/10.1016/j.agwat.2016.05.011

Du, T., Kang, S., Zhang, J., Li, F., Yan, B., 2008. Water use efficiency and fruit quality of

table grape under alternate partial root-zone drip irrigation. Agric. Water Manag. 95, 659–668. https://doi.org/10.1016/j.agwat.2008.01.017
Faci, J.M., Medina, E.T., Martínez-Cob, A., Alonso, J.M., 2014. Fruit yield and quality response of a late season peach orchard to different irrigation regimes in a semi-arid environment. Agric. Water Manag. https://doi.org/10.1016/j.agwat.2014.07.004
Falagán, N., Artés, F., Artés-Hernández, F., Gómez, P.A., Pérez-Pastor, A., Aguayo, E., 2015. Comparative study on postharvest performance of nectarines grown under regulated deficit irrigation. Postharvest Biol. Technol. 110, 24–32. https://doi.org/10.1016/j.postharvbio.2015.07.011
Fathi, H., Imani, A., Amiri, M.E., Hajilou, J., Nikbakht, J., 2017. Response of Almond Genotypes / Cultivars G rafted on GN15 ‘Garnem’ Rootstock in Deficit-Irrigation Stress Conditions. J. Nuts 8, 123–135.
Fereres, E., Soriano, M.A., 2007. Deficit irrigation for reducing agricultural water use. J. Exp. Bot. 58, 147–159.
Flexas, J., Medrano, H., 2002. Drought-inhibition of photosynthesis in C3plants: Stomatal and non-stomatal limitations revisited. Ann. Bot. 89, 183–189. https://doi.org/10.1093/aob/mcf027
Ghrab M., Gargouri K., B.M.M., 2008. Long-term effect of dry conditions and drought on fruit trees yield in dryland areas of Tunisia. López-Francos A. (ed.). Drought Manag. Sci. Technol. Innov.80, 107-112.
Gifruits, 2018. Groupement Interprofessionnel des Fruits [WWW Document]. Pech. [WWW Doc. Group. interprofessionnel des fruits. URL http://gifruits.com (accessed 4.10.18).
Girona, J., Gelly, M., Mata, M., Arbone, A., Rufat, J., Marsal, J., 2005. Peach tree response to single and combined deficit irrigation regimes in deep soils. Agric. Water Manag. 72, 97–108. https://doi.org/10.1016/j.agwat.2004.09.011

Gómez-del-Campo, M., Baeza, P., Ruiz, C., Sotés, V., Lissarrague, J.R., 2007. Effect of previous water conditions on vine response to rewatering. Vitis - J. Grapevine Res. 46, 51–55.

Intrigliolo, D.S., Castel, J.R., 2006. Performance of various water stress indicators for prediction of fruit size response to deficit irrigation in plum. Agric. Water Manag. 83, 173–180. https://doi.org/10.1016/j.agwat.2005.12.005

Jiménez-García, S.N., Vázquez-Cruz, M.A., Guevara-González, R.G., Torres-Pacheco, I., Cruz-Hernández, A., Feregrino-Pérez, A.., 2013. Current approaches for enhanced expression of secondary metabolites as bioactive compounds in plants for agronomic and human health purposes - A review. Polish J. Food Nutr. Sci. 63, 67–78. https://doi.org/10.2478/v10222-012-0072-6

Jones, H.G., 2004. Irrigation scheduling: advantages and pitfalls of plant-based methods. J. Exp. Bot. 55, 2427–2436. https://doi.org/10.1093/jxb/erh213

Kobashi, K., Gemma, H., Iwahori, S., 2000. Abscisic acid content and sugar metabolism of peaches grown under water stress. J. Am. Soc. Hortic. Sci. 125, 425–428.

Kramer, P.J., 1980. Drought, stress and the origin of adaptations. John Wiley and Sons, Inc.

Li, S., Huguet, J., Schoch, P.G., Orlando, P., 1989. Response of peach tree growth and cropping to soil water deficit at various phenological stages of fruit development. J. Hortic. Sci. 64, 541–552. https://doi.org/10.1080/14620316.1989.11515989

Lopez, G., Hossein Behboudian, M., Echeverria, G., Girona, J., Marsal, J., 2011. Instrumental and sensory evaluation of fruit quality for “Ryan’s Sun” peach grown under deficit irrigation. Hort Technol. 21, 712–719.

Lopresti, J., Goodwin, I., Mcglasson, B., Holford, P., Golding, J., 2014. Variability in size and soluble solids concentration in peaches and nectarines. Hortic. Rev. 42, 253–312. https://doi.org/10.1002/9781118916827.ch05

Maatallah, S., Ghanem, M.E., Albouchi, A., Bizid, E., Lutts, S., 2010. A greenhouse investigation of responses to different water stress regimes of Laurus nobilis trees from two climatic regions. J. Arid Environ. 74, 327–337. https://doi.org/10.1016/j.jaridenv.2009.09.008

Maatallah, S., Guizani, M., Hjlaoui, H., Boughattas, N.E.H., Lopez-Lauri, F., Ennajeh, M., 2015. Improvement of fruit quality by moderate water deficit in three plum cultivars (*Prunus salicina* L.) cultivated in a semi-arid region. Fruits 70, 325–332. https://doi.org/10.1051/fruits/2015023

Mirás-Avalos, J.M., Pérez-Sarmiento, F., Alcobendas, R., Alarcón, J.J., Mounzer, O., Nicolás, E., 2016. Using midday stem water potential for scheduling deficit irrigation in mid–late maturing peach trees under Mediterranean conditions. Irrig. Sci. 34, 161–173. https://doi.org/10.1007/s00271-016-0493-9

Montevecchi, G., Vasile Simone, G., Masino, F., Bignami, C., Antonelli, A., 2012. Physical and chemical characterization of Pescabivona , a Sicilian white flesh peach cultivar [*Prunus persica* (L .) Batsch]. Food Res. Int. 45, 123–131. https://doi.org/10.1016/j.foodres.2011.10.019

Montevecchi, G., Vasile Simone, G., Mellano, M.G., Masino, F., Antonelli, A., 2013. Original article Fruit sensory characterization of four Pescabivona , white-fleshed peach [*Prunus persica* (L .) Batsch] , landraces and correlation with physical and chemical parameters. Fruits 68, 195–207. https://doi.org/10.1051/fruits/2013067

Nweze, C.C., Abdulganiyu, M.G., Erhabor, O.G., 2015. Comparative analysis of vitamin C in fresh fruits juice of *Malus domestica*, *Citrus sinensi*, Ananas comosus and Citrullus lanatus by iodometric titration. Int. J. Sci. Environ. Technol. 4, 17–22.

Palmer, J.W., Giulani, R., Adams, H.M., 1997. Efect of crop load on fruiting and leaf phosynthesis of “Braeburn”/M26 apple trees. Tree Physiol. 17, 741–746.

Parker, D.D., Zilberman, P.D., Moulton, K., 1991. How quality relates to price in California fresh peaches. Calif. Agric. 45, 14–16.

Pérez-Pérez, J.G., Romero, P., Navarro, J.M., Botía, P., 2008. Response of sweet orange cv “Lane late” to deficit-irrigation strategy in two rootstocks. II: Flowering, fruit growth, yield and fruit quality. Irrig. Sci. 26, 519–529. https://doi.org/10.1007/s00271-008-0113-4

Polley, H.W., 2002. Implications of atmospheric and climatic change for crop yield and water use efficiency. Crop Sci. 42, 131–140. https://doi.org/10.2135/cropsci2002.1310

Pourghayoumi, M., Rahemi, M., Bakhshi, D., Aaalami, A., Kamgar-Haghighi, A.A., 2017. Responses of pomegranate cultivars to severe water stress and recovery: changes on antioxidant enzyme activities, gene expression patterns and water stress responsive metabolites. Physiol. Mol. Biol. Plants 23, 321–330. https://doi.org/10.1007/s12298-017-0435-x

Rahmati, M., Davarynejad, G.H., Génard, M., Bannayan, M., Azizi, M., Vercambre, G., 2015a. Peach water relations, gas exchange, growth and shoot mortality under water deficit in semi-arid weather conditions. PLoS One 10, 1–19. https://doi.org/10.1371/journal.pone.0120246

Rahmati, M., Vercambre, G., Davarynejad, G., Bannayan, M., Azizi, M., Génard, M., 2015b. Water scarcity conditions affect peach fruit size and polyphenol contents more severely than other fruit quality traits. J. Sci. Food Agric. 95, 1055–1065. https://doi.org/10.1002/jsfa.6797

Ripoll, J., Urban, L., Staudt, M., Lopez-Lauri, F., Bidel, L.P.R., Bertin, N., 2014. Water shortage and quality of fleshy fruits-making the most of the unavoidable. J. Exp. Bot. 65, 4097–4117. https://doi.org/10.1093/jxb/eru197

Ruiz-Sánchez, M.C., Domingo, R., Castel, J.R., 2010. Deficit irrigation in fruit trees and vines in Spain. Spanish J. Agric. Res. 8, 5. https://doi.org/10.5424/sjar/201008S2-1343

Saidani, F., Giménez, R., Christophe, A., Chalot, G., Jesus, A. betran, Gogorcena, Y., 2017. Phenolic, sugar and acid profiles and the antioxidant composition in the peel and pulp of peach fruits. J. Food Compos. Anal. 62, 126–133. https://doi.org/10.1016/j.jfca.2017.04.015

Scholander, P.F., Hammel, H.T., Bradstreet, E.D., Hemmingsen, E.A., 1965. Sap Pressure in Vascular Plants: Negative hydrostatic pressure can be measured in plants. Science. 148, 339–346. https://doi.org/10.1126/science.148.3668.339

Shao, H.B., Chu, L.Y., Jaleel, C.A., Zhao, C.X., 2008. Water-deficit stress-induced anatomical changes in higher plants. Comptes Rendus - Biol. 331, 215–225. https://doi.org/10.1016/j.crvi.2008.01.002

Silva, M.D.A., Moura, C., Labate, C.A., Guidetti-gonzalez, S., Borges, J.D.S., Ferreira, L.C., 2012. Chapter 6 Breeding for Water Use Efficiency, in: Fritsche-Neto, R., Borém, A. (Eds.), Plant Breeding for Abiotic Stress Tolerance. Springer-Verlag Berlin Heidelberg, p. VIII, 176. https://doi.org/10.1007/978-3-642-30553-5

Stefanelli, D., Goodwin, I., Jones, R., 2010. Minimal nitrogen and water use in horticulture: Effects on quality and content of selected nutrients. Food Res. Int. 43, 1833–1843. https://doi.org/10.1016/j.foodres.2010.04.022

Thakur, A., Singh, Z., 2012. Responses of “Spring Bright” and “Summer Bright” nectarines to deficit irrigation: Fruit growth and concentration of sugars and organic acids. Sci. Hortic. 135, 112–119. https://doi.org/10.1016/j.scienta.2011.12.013

Wahbi, S., Wakrim, R., Aganchich, B., Tahi, H., Serraj, R., 2005. Effects of partial rootzone drying (PRD) on adult olive tree (Olea europaea) in field conditions under arid climate: I. Physiological and agronomic responses. Agric. Ecosyst. Environ. 106, 289–301. https://doi.org/10.1016/j.agee.2004.10.015

Zhao, Z., Wang, W., Wu, Y., Xu, M., Huang, X., Ma, Y., Ren, D., 2015. Leaf physiological responses of mature pear trees to regulated deficit irrigation in field conditions under desert climate. Sci. Hortic. 187, 122–130. https://doi.org/10.1016/j.scienta.2015.03.009

Zhou, H. mi, Zhang, F. cang, Roger, K., Wu, L.F., Gong, D.Z., Zhao, N., Yin, D.X., Xiang, Y.Z., Li, Z.J., 2017. Peach yield and fruit quality is maintained under mild deficit irrigation in semi-arid China. J. Integr. Agric. 16, 1173–1183. https://doi.org/10.1016/S2095-3119(16)61571-X

Figures captions

Fig. 1. Monthly average air temperature (T °C), evapotranspiration (ET_0 mm month^{-1}) and rainfall (mm month^{-1}) at the experimental site during the studied period (2016 and 2017)

Fig. 2. Shoot growth of four peach cultivars grown in the center of Tunisia and subjected to full irrigation (FI), sustained deficit irrigation (SDI) and cyclic deficit irrigation (CDI). Values are the means of twelve samples (n = 12) ± standard deviation. Letters (a, b, c) indicate significant differences ($p < 0.05$) between the three irrigation treatments.
FS: Flordastar, EMC: Early Maycrest, RUB: Rubirich, OH: O'Henry. FI: Full irrigation, SDI sustained deficit irrigation, CDI Cyclic deficit irrigation, DOY: day of the year

Fig. 3. Leaf water potential (ψb) of four peach cultivars grown in the center of Tunisia and subjected to full irrigation (FI), sustained deficit irrigation (SDI) and cyclic deficit irrigation (CDI). Values are the means of twelve samples (n = 12) ± standard deviation. Letters (a, b, c) indicate significant differences ($p < 0.05$) between the three irrigation treatments.
FS: Flordastar, EMC: Early Maycrest, RUB: Rubirich, OH: O'Henry, FI: Full irrigation, SDI: sustained deficit irrigation, CDI: Cyclic deficit irrigation, DOY: day of year

Fig. 4. Relative water content (RWC) in leaves of four peach cultivars grown in the center of Tunisia and subjected to full irrigation (FI), sustained deficit irrigation (SDI) and cyclic deficit irrigation (CDI). Values are the means of twelve samples (n = 12) ± standard deviation.

Letters (a, b, c) indicate significant differences ($p < 0.05$) between the three irrigation treatments.

FS: Flordastar, EMC: Early Maycrest, RUB: Rubirich, OH: O'Henry. FI: Full irrigation, SDI: sustained deficit irrigation, CDI: Cyclic deficit irrigation, DOY: day of year

Fig. 5. Correlation between P_n and g_s (A) and P_n and Ci (B) in four peach cultivars grown in the center of Tunisia and subjected to full irrigation (FI),sustained deficit irrigation (SDI) and cyclic deficit irrigation (CDI)

FI: Full irrigation, SDI: sustained deficit irrigation, CDI: Cyclic deficit irrigation, P_n: net photosynthesis rate, g_s: stomatal conductance, Ci: intercellular CO_2 concentration

Fig. 6. Crop yield (A) and fruit number (B) in the trees of four peach cultivars grown in the center of Tunisia and subjected to full irrigation (FI), sustained deficit irrigation (SDI) and cyclic deficit irrigation (CDI). Values are the means of three trees ($n = 3$) ± standard deviation. Letters (a, b, c, d) and (A, B, C) indicate significant differences ($p < 0.05$) between the four cultivars and the three irrigation treatments respectively.

FS: Flordastar, EMC: Early Maycrest, RUB: Rubirich, OH: O'Henry. FI: Full irrigation, SDI: sustained deficit irrigation, CDI: Cyclic deficit irrigation

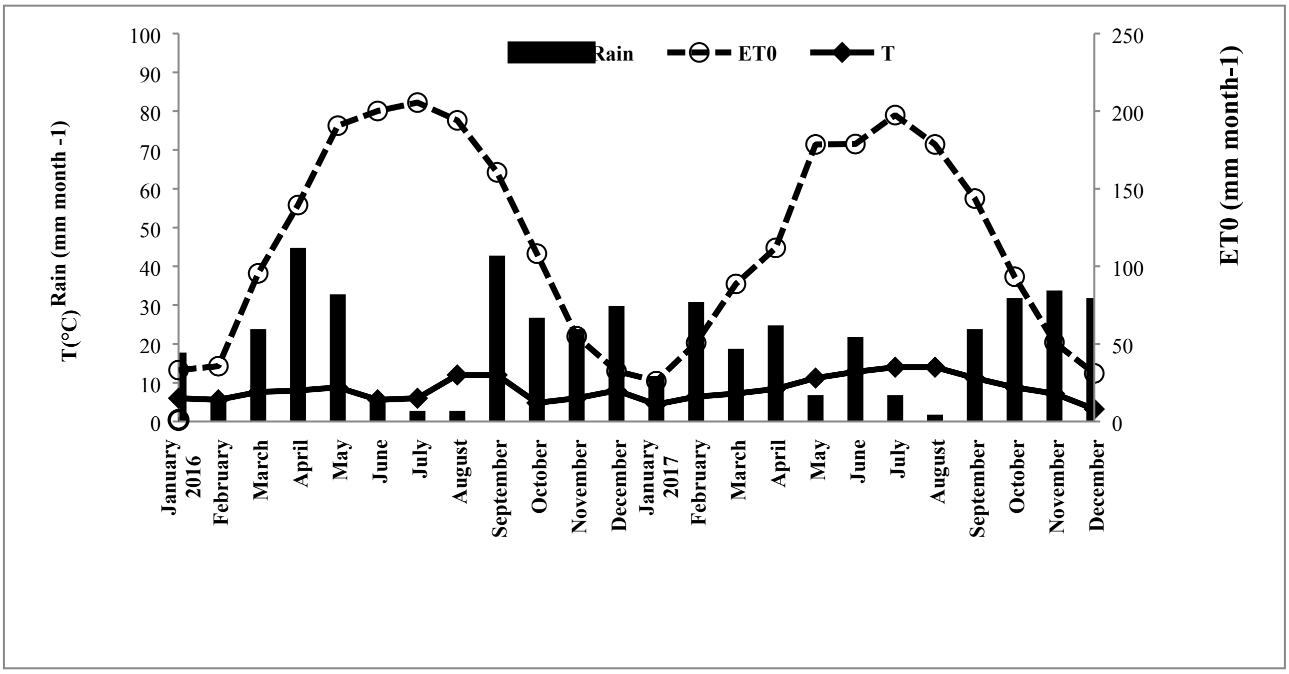

100
90
80
70
60
50
40
30
20
10
0
T(°C) Rain (mm month -1)
250
200
150
100
50
0
ET0 (mm month-1)
Rain
ET0
T
January 2016
February
March
April
May
June
July
August
September
October
November
December
January 2017
February
March
April
May
June
July
August
September
October
November
December

Figure 1

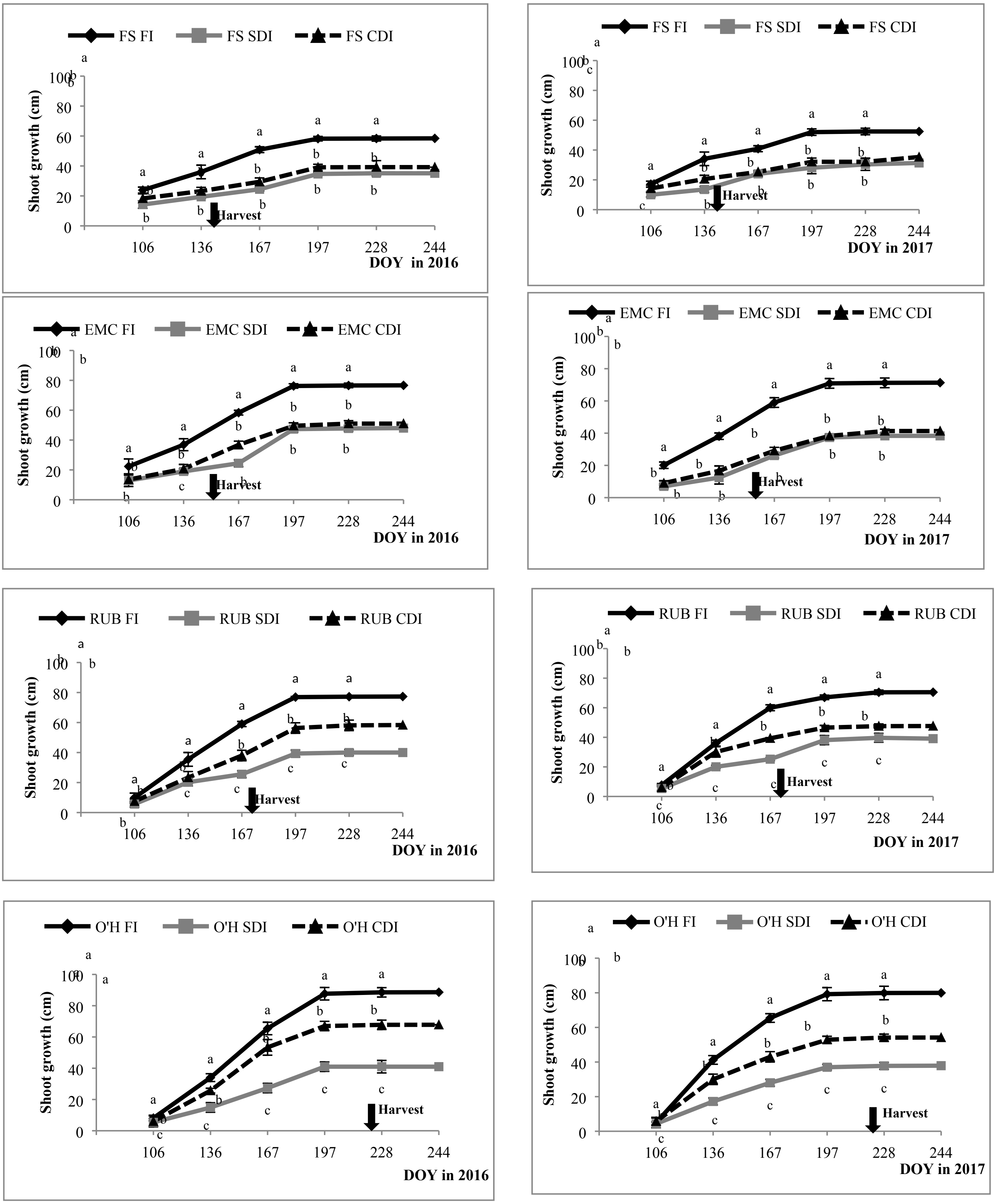
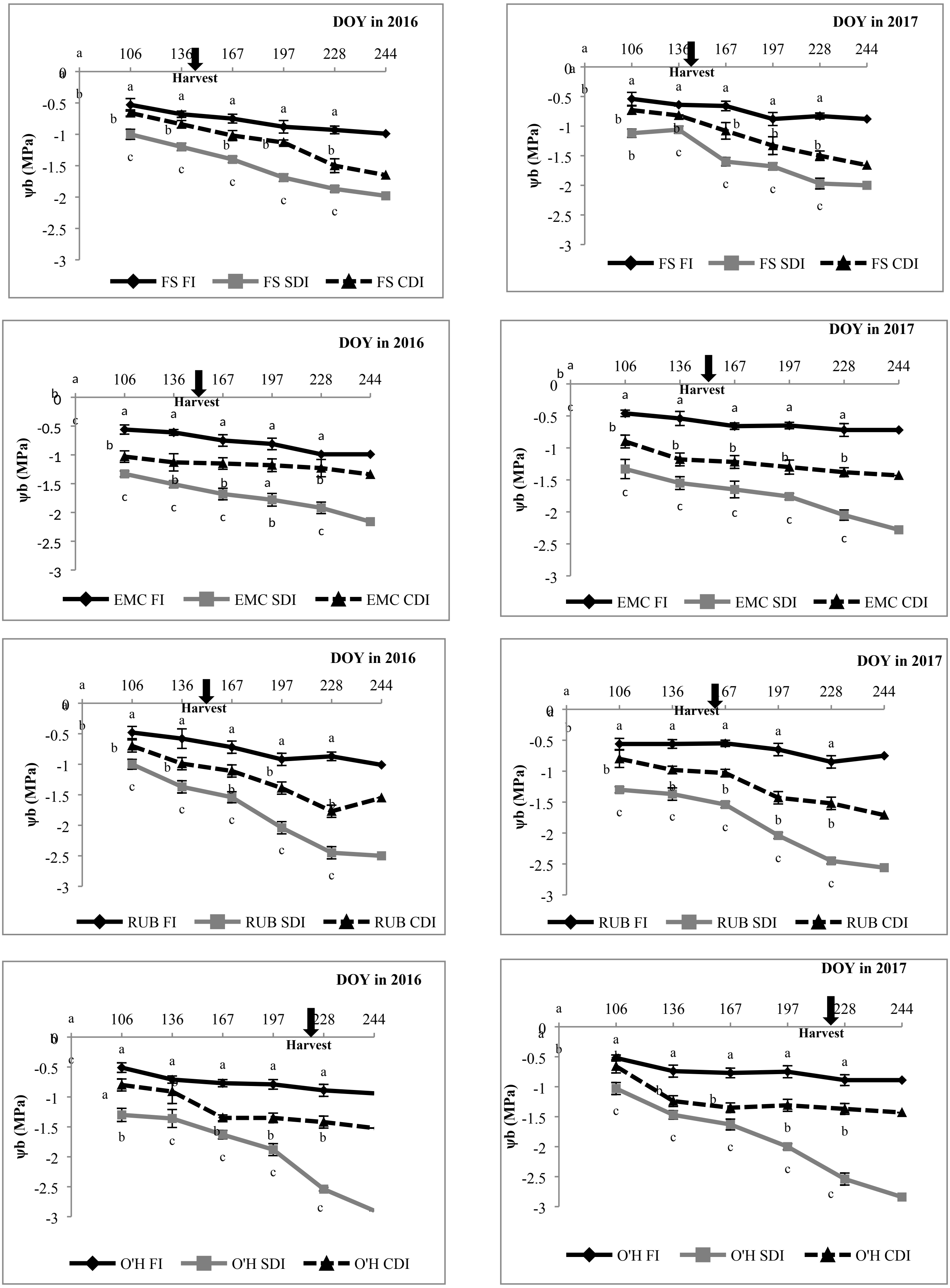

FS FI
FS SDI
FS CDI
Shoot growth (cm)
Harvest
DOY in 2016
DOY in 2017
EMC FI
EMC SDI
EMC CDI
RUB FI
RUB SDI
RUB CDI
O'H FI
O'H SDI
O'H CDI
106
136
167
197
228
244

Figure 2



DOY in 2016
DOY in 2017
106
136
167
197
228
244
Harvest
ψb (MPa)
0
-0.5
-1
-1.5
-2
-2.5
-3
FS FI
FS SDI
FS CDI
EMC FI
EMC SDI
EMC CDI
RUB FI
RUB SDI
RUB CDI
O'H FI
O'H SDI
O'H CDI

Figure 3

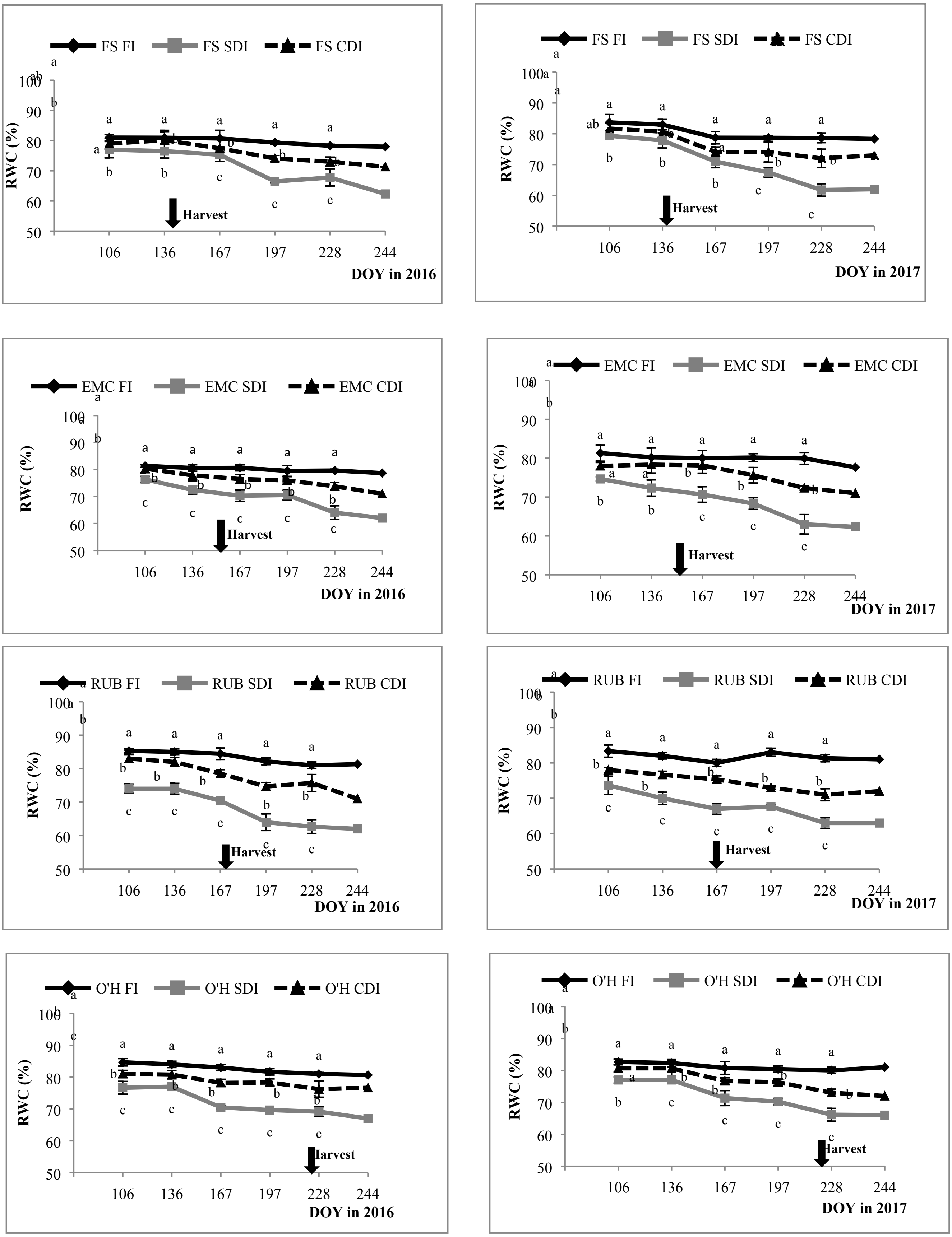
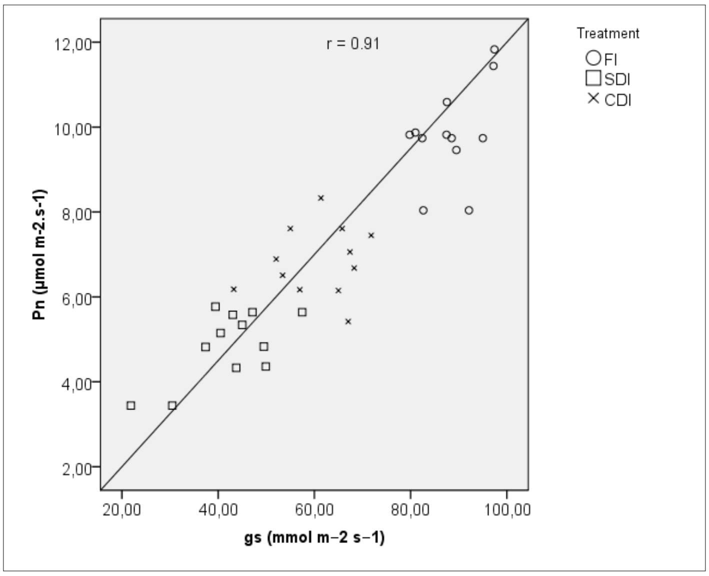
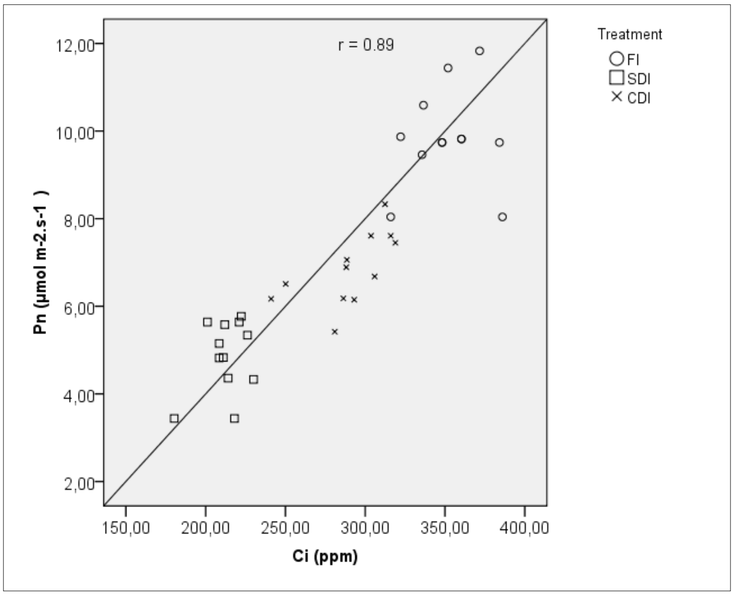

FS FI
FS SDI
FS CDI
EMC FI
EMC SDI
EMC CDI
RUB FI
RUB SDI
RUB CDI
O'H FI
O'H SDI
O'H CDI
RWC (%)
Harvest
DOY in 2016
DOY in 2017

Figure 4

(A)



r = 0.91
Treatment
FI
SDI
CDI
Pn (µmol m-2.s-1)
gs (mmol m−2 s−1)
12,00
10,00
8,00
6,00
4,00
2,00
20,00
40,00
60,00
80,00
100,00

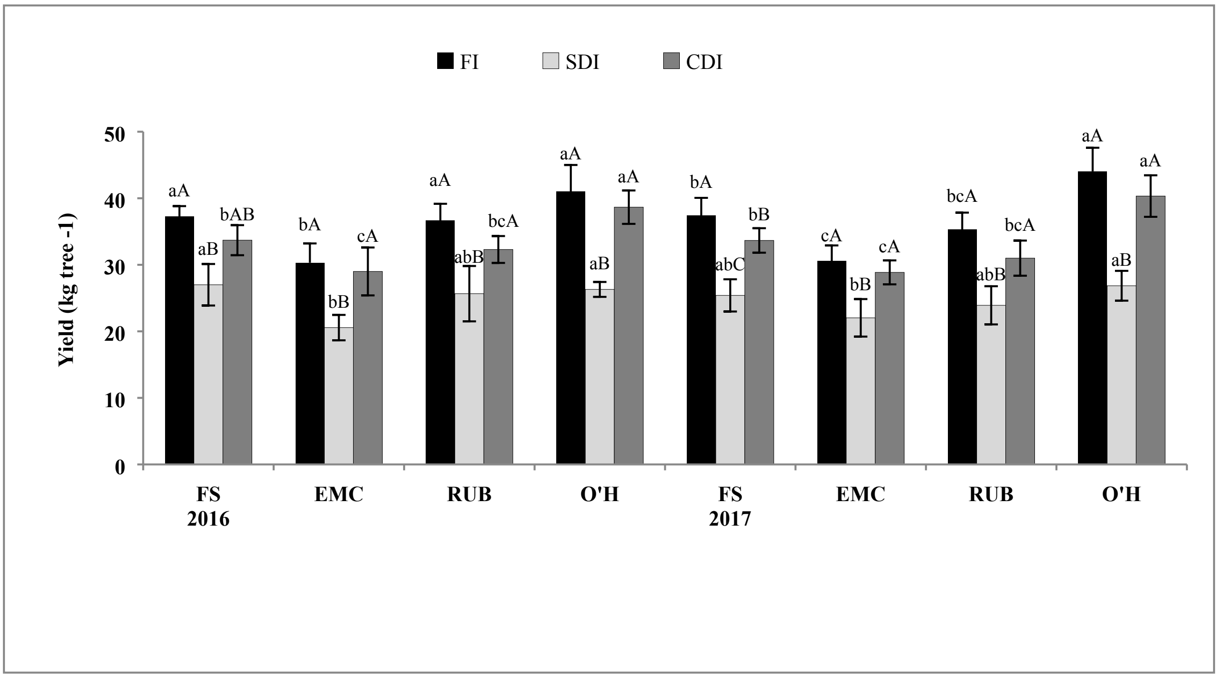


r = 0.89
Treatment
FI
SDI
CDI
Pn (µmol m-2.s-1)
Ci (ppm)
12,00
10,00
8,00
6,00
4,00
2,00
150,00
200,00
250,00
300,00
350,00
400,00

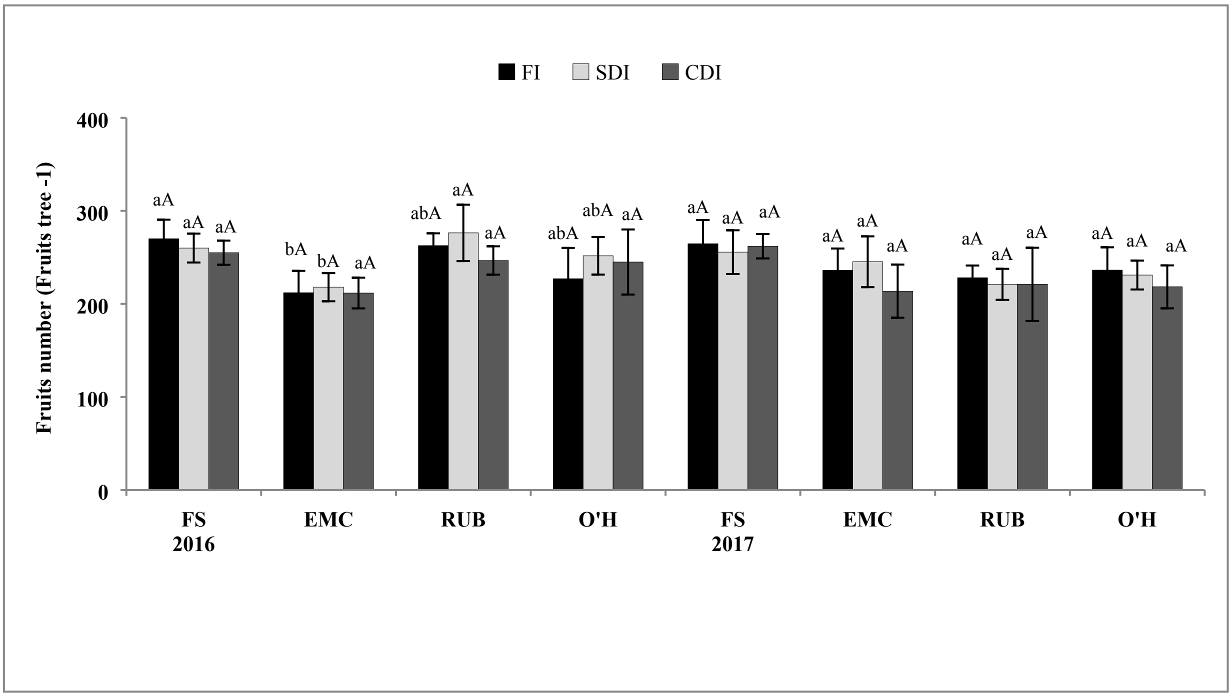
(B)

Figure 5.

(A)



FI
SDI
CDI
Yield (kg tree -1)
50
40
30
20
10
0
aA
aB
bAB
bA
bB
cA
aA
abB
bcA
aA
aB
aA
bA
abC
bB
cA
bB
cA
bcA
abB
bcA
aA
aB
aA
FS
2016
EMC
RUB
O'H
FS
2017
EMC
RUB
O'H



FI
SDI
CDI
Fruits number (Fruits tree -1)
400
300
200
100
0
aA
aA
aA
bA
bA
aA
abA
aA
aA
abA
abA
aA
aA
aA
aA
aA
aA
aA
aA
aA
aA
aA
aA
aA
FS
2016
EMC
RUB
O'H
FS
2017
EMC
RUB
O'H

(B)

Figure 6.

Table 1. Gas exchange parameters during fruit expansion and harvest for four peach cultivars subjected to three irrigation treatments during two consecutive seasons (2016 and 2017)

Year	Treatment	Cultivar	Fruits expansion				Harvest			
			P_n (μmol m^{-2} s^{-1})	g_s (mmol m^{-2} s^{-1})	Tr (mmol m^{-2} s^{-1})	WUEins (μmol $mmol^{-1}$)	P_n (μmol m^{-2} s^{-1})	g_s (mmol m^{-2} s^{-1})	Tr (mmol m^{-2} s^{-1})	WUEins (μmol $mmol^{-1}$)
2016	FI	Flordastar	9.33 ± 0.14^{cA}	62.28 ± 2.06^{cA}	3.23 ± 0.01^{aA}	3.19 ± 0.45^{cB}	9.27 ± 0.11^{bcA}	52.53 ± 2.50^{cA}	3.86 ± 0.08^{bA}	2.41 ± 0.13^{cC}
		Early Maycrest	10.41 ± 0.43^{bA}	78.07 ± 0.98^{aA}	2.85 ± 0.10^{cA}	4.00 ± 0.18^{aB}	10.67 ± 0.20^{aA}	75.15 ± 3.87^{aA}	4.15 ± 0.03^{aA}	3.05 ± 0.07^{bB}
		Rubirich	9.43 ± 0.59^{cA}	64.57 ± 1.08^{cA}	3.05 ± 0.05^{bA}	2.68 ± 0.17^{dB}	9.21 ± 0.33^{cA}	62.67 ± 3.06^{bA}	3.08 ± 0.05^{cA}	4.00 ± 0.19^{aB}
		O'Henry	11.37 ± 0.35^{aA}	72.25 ± 3.38^{bA}	3.11 ± 0.10^{abA}	3.65 ± 0.18^{bB}	9.83 ± 0.47^{bA}	70.95 ± 2.76^{aA}	3.05 ± 0.05^{cA}	3.21 ± 0.16^{bC}
	SDI	Flordastar	6.13 ± 1.27^{bC}	43.38 ± 4.65^{aB}	1.04 ± 0.04^{aC}	5.42 ± 0.41^{aA}	4.91 ± 0.04^{bC}	37.02 ± 2.65^{bcB}	1.27 ± 0.07^{aB}	3.87 ± 0.21^{bB}
		Early Maycrest	7.06 ± 0.42^{abC}	48.38 ± 2.14^{aC}	1.26 ± 0.05^{aC}	5.61 ± 0.33^{aA}	6.29 ± 0.73^{aB}	46.58 ± 2.91^{aC}	1.17 ± 0.02^{aC}	5.37 ± 0.62^{aA}
		Rubirich	6.16 ± 0.58^{bB}	34.74 ± 4.62^{bC}	1.17 ± 0.10^{aC}	5.24 ± 0.53^{aA}	5.98 ± 0.87^{aC}	32.03 ± 2.71^{cC}	1.19 ± 0.04^{aC}	5.02 ± 0.75^{aA}
		O'Henry	7.63 ± 0.23^{aC}	43.83 ± 2.36^{aC}	1.27 ± 0.20^{aB}	6.12 ± 0.96^{aA}	6.31 ± 0.30^{aC}	39.41 ± 3.64^{bC}	1.18 ± 0.13^{aB}	5.33 ± 0.37^{aB}
	CDI	Flordastar	7.78 ± 0.18^{aB}	65.18 ± 1.19^{abA}	1.68 ± 0.28^{aB}	4.60 ± 0.75^{bA}	6.29 ± 0.06^{cB}	50.10 ± 2.48^{bA}	1.57 ± 0.50^{aB}	4.31 ± 0.27^{cA}
		Early Maycrest	8.07 ± 0.42^{aB}	66.30 ± 2.66^{aB}	1.57 ± 0.02^{aB}	5.14 ± 0.90^{abAB}	8.71 ± 0.26^{aB}	63.34 ± 3.12^{aB}	1.45 ± 0.05^{aB}	6.01 ± 0.18^{abA}
		Rubirich	8.04 ± 1.32^{aA}	55.38 ± 1.04^{cB}	1.51 ± 0.13^{aB}	5.33 ± 0.99^{abA}	8.02 ± 0.08^{bB}	54.21 ± 3.87^{bB}	1.47 ± 0.03^{aB}	5.45 ± 0.32^{bA}
		O'Henry	8.91 ± 0.12^{aB}	61.20 ± 2.99^{bB}	1.39 ± 0.18^{aB}	6.48 ± 0.87^{aA}	8.49 ± 0.51^{aB}	58.07 ± 7.32^{abB}	1.21 ± 0.05^{aB}	7.04 ± 0.72^{aA}
2017	FI	Flordastar	9.81 ± 0.06^{bA}	81.06 ± 1.30^{bA}	3.67 ± 0.47^{aA}	2.71 ± 0.39^{bB}	9.20 ± 0.46^{bA}	69.89 ± 4.88^{bA}	4.25 ± 0.10^{aA}	2.16 ± 0.06^{cB}
		Early Maycrest	9.20 ± 1.00^{bA}	91.53 ± 3.80^{aA}	3.93 ± 0.10^{aA}	2.34 ± 0.21^{bB}	10.95 ± 0.69^{aA}	91.17 ± 3.15^{aA}	3.06 ± 0.28^{bA}	3.58 ± 0.11^{aC}
		Rubirich	9.08 ± 0.91^{bA}	86.89 ± 3.71^{abA}	3.72 ± 0.26^{aA}	2.45 ± 0.38^{bB}	9.95 ± 0.31^{bA}	85.28 ± 4.90^{aA}	3.95 ± 0.08^{aA}	2.52 ± 0.10^{bcB}
		O'Henry	11.28 ± 0.63^{aA}	94.05 ± 5.64^{aA}	3.44 ± 0.32^{aA}	3.29 ± 0.13^{aC}	11.44 ± 0.16^{aA}	87.56 ± 8.31^{aA}	4.13 ± 0.58^{aA}	2.81 ± 0.43^{bB}
	SDI	Flordastar	5.76 ± 0.26^{aB}	45.59 ± 7.11^{aC}	1.11 ± 0.02^{aB}	5.09 ± 0.16^{aA}	6.24 ± 0.62^{aC}	53.83 ± 3.48^{bC}	1.25 ± 0.06^{aB}	4.97 ± 0.28^{aA}
		Early Maycrest	5.41 ± 0.26^{abC}	39.94 ± 17.81^{aC}	1.08 ± 0.08^{aB}	5.00 ± 0.56^{aA}	6.04 ± 0.38^{aC}	51.04 ± 5.30^{bC}	1.16 ± 0.04^{bB}	5.17 ± 0.14^{aB}
		Rubirich	4.80 ± 0.72^{bC}	40.45 ± 2.81^{aC}	1.09 ± 0.04^{aB}	4.39 ± 0.52^{aA}	5.98 ± 0.36^{aC}	48.32 ± 6.50^{bC}	1.13 ± 0.03^{bcB}	5.27 ± 0.44^{aA}
		O'Henry	5.56 ± 0.21^{abC}	42.50 ± 2.81^{aB}	1.09 ± 0.02^{aB}	5.10 ± 0.17^{aB}	6.06 ± 0.58^{aC}	67.27 ± 10.59^{aB}	1.07 ± 0.03^{cB}	5.65 ± 0.42^{aA}
	CDI	Flordastar	6.21 ± 0.82^{aB}	66.47 ± 1.29^{aB}	1.21 ± 0.08^{aB}	5.09 ± 0.43^{aA}	7.80 ± 0.21^{aB}	61.66 ± 2.64^{bB}	1.46 ± 0.18^{aB}	5.38 ± 0.62^{cA}
		Early Maycrest	7.25 ± 0.50^{aB}	68.61 ± 3.02^{aB}	1.25 ± 0.10^{aB}	5.81 ± 0.58^{aA}	8.80 ± 0.46^{aB}	78.74 ± 2.45^{aB}	1.29 ± 0.14^{aB}	6.84 ± 0.80^{aA}
		Rubirich	6.52 ± 0.36^{aB}	54.14 ± 2.53^{bB}	1.24 ± 0.03^{aB}	5.25 ± 0.38^{aA}	7.88 ± 0.72^{aB}	66.76 ± 8.22^{abB}	1.35 ± 0.29^{aB}	5.91 ± 0.72^{bcA}
		O'Henry	7.37 ± 1.09^{aB}	53.21 ± 9.18^{bB}	1.26 ± 0.09^{aB}	5.81 ± 0.50^{aA}	8.24 ± 0.64^{aB}	73.43 ± 8.56^{abAB}	1.30 ± 0.18^{aB}	6.37 ± 0.36^{abA}

Values are the means of three different peach samples (n = 3) ± standard deviation. Letters (a, b, c, d) indicate significant differences ($p < 0.05$) between the four cultivars for each treatment separately. Letters (A, B and C) indicate significant differences ($p < 0.05$) between the three irrigation treatments for each season separately.
FI, Full irrigation; SDI, Sustained deficit irrigation; CDI, Cyclic deficit irrigation; P_n, net photosynthesis rate; g_s, stomatal conductance; Tr, transpiration rate

Table 2. Peach fruit quality traits for four peach cultivars subjected to three irrigation treatments during two consecutive seasons (2016 and 2017)

Year	Treatment	Cultivar	Length (mm)	Size (mm)	Weight (g)	Firmness (kg cm^{-2})	SSC (°Brix)	Titratable acidity (g malic acid 100 ml^{-1})	TSS/TA	Vitamin C (mg 100g^{-1})
2016	FI	Flordastar	55.09 ±3.06 ^{cA}	60.54 ± 3.11^{cA}	115.46 ±14.02^{cA}	4.18 ± 0.26^{cB}	11.85 ± 0.21^{cB}	2.07 ± 0.05^{aA}	5,72 ± 0.18^{cB}	2.83 ± 0.75 ^{cB}
		Early Maycrest	55.44 ±2.42 ^{cA}	59.81 ± 2.63^{cA}	113.56 ±11.59^{cA}	4.21 ± 0.52 ^{cC}	13.18 ± 0.23^{bB}	1.13 ± 0.08^{dA}	11,66 ± 0.61 ^{aB}	4.50 ± 0.55 ^{bB}
		Rubirich	62.04 ±3.79 ^{bA}	64.04 ± 3.22^{bA}	141.38 ±16.59^{bA}	4.84 ± 0.43^{bB}	10.50 ± 0.33^{dB}	1.58 ± 0.04^{bA}	6,65 ± 0.26 ^{bC}	4.60 ± 0.55 ^{bB}
		O'Henry	66.04 ±3.07 ^{aA}	72.58 ± 3.58^{aA}	172.07 ±16.78^{aA}	6.48 ± 0.58^{aB}	15.18 ± 0.39^{aB}	1.37 ± 0.05^{cA}	11,08 ± 0.18^{aC}	5.86 ± 1.34^{aB}
	SDI	Flordastar	51.20 ±2.85^{cB}	57.66 ±3.44^{bB}	99.19 ± 13.68^{bB}	4.98 ± 0.13^{dA}	13.36 ± 0.51^{cA}	1.74 ± 0.03^{aB}	7,66 ± 0.29 ^{cA}	3.17 ± 0.16 ^{cB}
		Early Maycrest	50.94 ± 4.07^{cB}	56.13 ±3.59^{bcB}	94.81 ±11.01^{bB}	5.28 ± 0.20^{cA}	14.81 ± 0.09 ^{bA}	1.11 ± 0.08^{dA}	13,34± 0.88 ^{aA}	5.33 ± 0.82^{aA}
		Rubirich	55.33 ±2.76^{bB}	55.63 ±3.43^{cB}	96.94 ± 5.85^{bB}	5.98 ± 0.17^{bA}	11.26 ± 0.58^{dA}	1.42 ± 0.04^{bB}	7.91 ± 0.44 ^{cB}	4.20 ± 0.44 ^{bA}
		O'Henry	60.53 ±3.79^{aB}	61.53 ±3.91^{aB}	147.6 ± 8.75^{aB}	7.6 ± 0.33^{aA}	16.00 ± 0.58^{aA}	1.31 ± 0.02^{cB}	12.21 ± 0.65 ^{bB}	6.00 ± 0.71 ^{aA}
	CDI	Flordastar	55.39 ±7.14^{bA}	60.54 ±3.53^{bA}	113.22 ±4.47^{cA}	4.66 ± 0.41^{cA}	13.95 ± 0.64^{bA}	1.73 ± 0.01^{aB}	8.06 ±0.41^{bA}	3.83 ± 0.18 ^{bA}
		Early Maycrest	52.21 ±8.61^{cAB}	58.47 ±3.04^{cA}	109.06 ±3.54^{cA}	4.70 ± 0.16^{cB}	14.38 ± 1.26^{bA}	1.01 ± 0.03^{dB}	14.23 ± 1.57 ^{aA}	5.62 ± 0.51^{aA}
		Rubirich	65.21 ±3.93^{aA}	63.13 ±2.73^{bA}	139.65 ±3.92^{bA}	5.54 ± 0.30^{bA}	11.20 ± 0.37^{cA}	1.32 ± 0.1^{bC}	8.48 ± 0.41 ^{bA}	4.20 ± 0.84 ^{bA}
		O'Henry	65.98 ± 3.86^{aA}	70.71 ±3.69^{aA}	168.47 ±17.8^{aA}	6.78 ± 0.58^{aB}	15.96 ± 0.30^{aA}	1.09 ± 0.02^{cC}	14,64 ± 0.34 ^{aA}	5.80 ± 0.45 ^{aA}
2017	FI	Flordastar	57.20 ± 3.22^{bA}	61.04 ± 3.19^{cA}	119.14 ± 9.67^{cA}	5.06 ± 0.17 ^{aA}	11.90 ± 0.10 ^{cB}	2.02 ± 0.09 ^{aA}	5.77 ± 0.29 ^{dC}	2.83 ± 0.75 ^{cC}
		Early Maycrest	54.38 ± 3.62^{cA}	54.50 ± 5.24^{dA}	121.20 ± 19.75^{cA}	3.86 ± 0.20 ^{bC}	12.85 ± 0.52 ^{bC}	1.19 ± 0.03 ^{dA}	10.72 ± 0.52 ^{aC}	3.84 ± 0.41 ^{bB}
		Rubirich	67.08 ± 4.63^{aA}	67.22 ± 3.84^{bA}	150.22 ±23.81^{bA}	4.00 ± 0.12 ^{bB}	11.88 ± 1.14^{cC}	1.88 ± 0.06 ^{bA}	6.49 ± 0.56 ^{cC}	5.52 ± 0.05 ^{aA}
		O'Henry	68.43 ± 6.57 ^{aA}	71.09 ± 2.99^{aA}	195.55 ±19.73^{aA}	5.52 ± 0.78 ^{aB}	13.98 ± 0.54 ^{aC}	1.47 ± 0.04 ^{cA}	9.51 ± 0.43 ^{bC}	5.83 ± 0.34 ^{aC}
	SDI	Flordastar	50.79 ± 3.07^{cB}	55.60 ± 3.61^{bB}	95.55 ±13.07^{cB}	4.95 ±0.17 ^{cA}	14.18 ± 0.27 ^{bA}	1.59 ± 0.03 ^{aC}	8.90 ± 0.24 ^{dA}	4.08 ± 0.66 ^{bcB}
		Early Maycrest	49.61 ± 4.04^{cB}	51.27 ± 4.74^{cB}	95.83 ± 19.29^{cB}	5.43 ±0.35 ^{bA}	14.71 ±0.38 ^{bA}	1.15 ± 0.07 ^{cA}	12.80 ± 0.92 ^{bB}	5.00 ± 0.89 ^{bA}
		Rubirich	65.93 ± 4.57^{aA}	64.91 ± 3.89^{aB}	117.93 ±19.87^{bB}	5.38 ± 0.44 ^{bcA}	14.51 ± 0.75 ^{bA}	1.40 ± 0.08 ^{bC}	10.36 ± 0.87 ^{cA}	3.83 ± 0.41 ^{cC}
		O'Henry	62.28 ± 5.04 ^{bB}	64.39 ±4.74 ^{aB}	136.87 ± 22.12 ^{aB}	7.55 ± 0.43 ^{aA}	16.96 ± 0.52 ^{aA}	1.14 ± 0.08 ^{cC}	14.84 ± 1.22 ^{aA}	6.17 ± 0.16 ^{aB}
	CDI	Flordastar	56.40 ± 1.75^{bA}	58.91 ± 3.08^{bAB}	117.24 ± 11.31^{cA}	4.66 ± 0.29 ^{bB}	13.95 ± 0.62 ^{bA}	1.84 ± 0.80 ^{aB}	7.57 ± 0.56 ^{cB}	5.33 ± 0.81 ^{bA}
		Early May crest	53.40 ±1.09 ^{cA}	53.03 ± 2.80^{cA}	118.92 ± 11.45^{cA}	4.65 ± 0.33 ^{bB}	13.71 ± 0.54 ^{bB}	0.95 ± 0.06 ^{dB}	14.43 ± 1.13 ^{aA}	5.11 ± 0.41 ^{bcA}
		Rubirich	65.06 ± 4.42^{aA}	66.77 ±3.43^{aA}	143.03 ±21.91^{bA}	4.03 ± 0.31 ^{cB}	13.20 ± 0.70 ^{bB}	1.60 ± 0.05 ^{bB}	8.23 ± 0.43 ^{cB}	4.50 ± 0.55 ^{cB}
		O'Henry	65.68 ± 3.33 ^{aA}	69.98 ± 3.32 ^{aA}	187.91 ± 9.71 ^{aA}	6.01 ± 0.72 ^{aB}	16.33 ± 0.19 ^{aB}	1.34 ± 0.04 ^{cB}	12.21 ± 0.62^{bB}	7.13 ± 0.55 ^{aA}

Values are the means of three different peach samples (n = 3) ± standard deviation. Letters (a, b, c, d) and indicate significant differences ($p < 0.05$) between the four cultivars for each treatment separately. Letters (A, B and C) indicate significant differences ($p < 0.05$) between the three irrigation treatments for each season separately.
FI, Full irrigation; SDI, Sustained deficit irrigation; CDI, Cyclic deficit irrigation; SSC, soluble solid content; TA, Titratable acidity

Table 3. Sugar contents (g 100 g^{-1} dry weight) in peel and flesh of peach fruits from four cultivars subjected to three irrigation treatments during two consecutive seasons (2016 and 2017)

Year	Treatment	Cultivar	Sucrose			Fructose			Glucose			Total sugar content		
			Flesh	Peel		Flesh	Peel		Flesh	Peel		Flesh	Peel	
2016	FI	Flordastar	30.47 ± 0.53^{cC}	18.37 ± 0.40$^{y X}$	**	9.69 ± 0.31^{bA}	7.71 ± 0.93$^{x W}$	**	3.66 ±0.16$^{c B}$	4.32 ± 0.60$^{z W}$		43.83 ± 0.33^{cC}	30.42 ± 0.82^{yX}	**
		Early Maycrest	38.53 ±0.65^{aB}	30.55 ± 0.94^{xX}	**	8.31 ±0.21$^{c B}$	4.62 ± 0.44$^{z Y}$	**	5.45 ±0.30$^{b B}$	5.14 ± 0.07$^{y Y}$		52.30 ± 0.60^{bC}	40.33 ± 1.46^{xY}	**
		Rubirich	29.04 ±0.25^{dC}	33.39 ± 0.64$^{w X}$	**	8.38 ± 0.17$^{c B}$	6.34 ± 0.00$^{y W}$	**	5.58 ±0.59$^{b A}$	6.64 ± 0.53$^{x X}$		43.02 ± 0.60^{cC}	46.37 ± 1.17^{wX}	**
		O'Henry	34.35 ±2.8^{bC}	18.42 ± 0.56$^{y Y}$	**	22.62 ± 0.59$^{a B}$	18.09± 0.63$^{w W}$	**	7.17±0.61^{aC}	9.44 ± 0.24$^{w W}$	**	64.16 ± 2.80^{aC}	45.97 ± 0.85^{wX}	**
	SDI	Flordastar	34.28± 1.16$^{c B}$	21.02 ± 0.58$^{y W}$	**	10.74 ± 1.79$^{b A}$	8.30 ± 0.69^{xW}	**	5.24 ± 0.16$^{c A}$	4.75 ± 0.36$^{y W}$		50.28 ± 1.56^{cB}	34.08 ± 0.81^{yW}	**
		Early Maycrest	45.82± 0.48^{aA}	33.47 ± 0.56$^{w W}$	**	10.59± 0.52$^{b A}$	6.53 ± 0.30$^{y X}$		6.84± 0.06$^{b A}$	7.73 ± 0.36^{xW}	*	63.26 ± 0.59^{bA}	47.74 ± 0.87^{xX}	**
		Rubirich	32.26 ± 1.02$^{d B}$	34.79 ± 1.39$^{w X}$	*	9.95 ± 0.23$^{c A}$	6.08 ± 0.68$^{y W}$	**	6.96 ± 0.37$^{b A}$	7.59 ± 0.28^{xW}		49.18 ± 2.53^{cB}	48.47 ± 1.90^{xX}	
		O'Henry	38.04± 0.37^{bB}	25.38 ± 0.59$^{x X}$	**	24.76 ± 0.71^{aA}	19.21 ± 0.84$^{w W}$	**	9.36 ± 0.08$^{a A}$	9.56 ± 0.23$^{w W}$		72.16 ±0.98^{aB}	54.16 ± 1.37^{wW}	**
	CDI	Flordastar	38.49 ± 1.14^{bA}	20.94 ± 0.72$^{z W}$	**	9.97 ± 0.10^{bA}	8.98 ± 1.29$^{x W}$	**	4.93 ± 0.70$^{c A}$	4.07 ± 0.25$^{y W}$		53.40 ± 1.05^{cA}	34.01 ± 2.07^{yW}	**
		Early Maycrest	39.20 ± 1.94$^{b B}$	34.72 ± 2.06$^{x W}$	**	10.26 ± 0.62$^{b A}$	9.60 ± 0.13$^{x W}$		6.80 ± 0.31$^{b A}$	6.75 ± 0.37$^{x X}$		56.27 ± 2.03^{bB}	51.08 ± 1.85^{xW}	**
		Rubirich	39.84 ± 0.29^{bA}	37.91 ± 0.94$^{w W}$	*	8.30 ± 0.10$^{c B}$	6.25 ± 0.11^{yW}	**	5.61±1.38$^{bc A}$	7.90 ± 0.18$^{w W}$	*	53.75 ± 1.08^{cA}	52.07 ± 1.08^{xW}	
		O'Henry	46.34 ± 0.37^{aA}	28.62 ± 0.55$^{y W}$	**	23.07 ± 1.52$^{a A}$	18.19 ± 0.62$^{w W}$	**	8.75± 0.11$^{a B}$	7.96 ± 0.37$^{w X}$	*	78.18 ± 1.95^{aA}	54.77 ± 1.49^{wW}	**
2017	FI	Flordastar	33.64 ± 1.08^{bB}	15.59 ± 2.24^{yX}	**	5.29 ± 0.41^{dA}	7.13 ± 0.68^{yW}	*	5.59 ± 0.53^{bA}	8.39 ± 0.99^{xW}	*	44.53 ± 0.54^{cB}	31.12 ± 2.41^{xX}	**
		Early Maycrest	35.79 ±1.94^{aB}	28.41 ± 2.28^{wX}	**	6.90 ± 0.22^{cB}	3.48 ± 0.31^{zY}	**	5.52 ±0.52^{bB}	5.07 ± 0.41^{yW}		48.21 ± 1.45^{bB}	36.96 ±2.89^{xY}	**
		Rubirich	26.17 ± 0.27^{cC}	26.11 ± 0.62^{wY}		7.66 ±0.19^{bB}	9.37 ± 0.14^{xX}	**	7.61 ± 0.35^{aB}	9.08 ± 0.28^{wX}	**	41.67 ± 0.74^{dC}	44.56 ±0.90^{wY}	*
		O'Henry	32.83 ± 1.75^{bC}	17.97 ± 0.48^{xY}	**	21.02 ±2.18^{aA}	16.16 ± 0.55^{wX}		5.83 ± 0.51^{bA}	8.52 ± 0.66^{xW}	**	59.67 ± 2.69^{aC}	42.65 ± 2.04^{wY}	**
	SDI	Flordastar	38.11 ± 1.02^{bA}	22.65 ± 1.91^{yW}	**	6.01 ± 0.39^{dA}	7.08 ± 0.48^{yX}	*	5.60 ± 0.24^{dA}	8.67 ± 0.35^{xW}	**	49.72 ± 0.80^{cA}	38.40 ± 2.57^{yW}	**
		Early Maycrest	43.94 ±0.68^{aA}	31.15 ± 2.32^{wW}	**	8.12 ± 0.18^{cA}	6.80 ± 0.21^{zX}		6.61± 0.14^{cC}	5.02 ± 0.83^{zW}	*	58.68 ± 0.91^{bA}	42.97 ± 2.56^{xX}	**
		Rubirich	29.81± 0.61$^{d B}$	29.94 ± 0.60^{xX}	**	9.18 ±0.46^{bA}	9.52 ± 0.48^{xW}	**	8.99 ± 0.39^{aA}	7.50 ± 0.40^{yW}	*	48.00 ± 1.42^{cB}	46.96 ± 1.45^{xX}	
		O'Henry	34.34 ± 1.91^{cB}	21.07 ± 0.36^{yX}	**	23.51 ± 0.67^{aA}	18.72 ± 0.22^{wW}	*	7.11 ± 1.47^{bA}	11.75 ± 1.35^{wW}	**	64.97 ± 2.54^{aB}	51.55 ± 1.39^{wX}	**
	CDI	Flordastar	34.62 ± 0.23^{cB}	19.48 ±2.74^{zWX}	**	5.50 ± 0.78^{cA}	7.25 ±0.61^{yW}	*	5.55 ± 0.10$^{d A}$	8.53 ± 0.83^{xW}	**	45.68 ± 0.72^{cB}	35.27 ± 4.18^{zWX}	*
		Early Maycrest	35.31 ± 1.80^{bB}	30.62 ±0.28^{xW}	*	6.06± 0.28^{cB}	9.81 ± 0.68^{xW}	*	6.20 ± 0.15^{cA}	5.59 ± 0.62^{yW}		47.57 ± 1.82^{cB}	44.03 ± 1.54^{yW}	**
		Rubirich	36.11 ± 1.13^{bA}	32.52 ±0.34^{wW}		9.65 ±0.13^{bA}	10.04 ± 0.46^{xX}		9.52 ± 0.30^{aA}	10.01 ± 0.41^{wW}		55.29 ± 0.72^{bA}	53.47 ± 1.18^{xW}	
		O'Henry	41.72 ± 0.97^{aA}	28.68 ± 0.48^{yW}	**	23.70 ± 0.43^{aA}	18.04 ± 0.40^{wW}		7.14 ± 0.14^{bA}	10.19 ± 0.46^{wW}	**	72.56 ± 1.76^{aA}	56.92 ± 1.26^{wW}	**

Values are the means of three different peach samples (n = 3) ± standard deviation. Letters (a, b, c, d) and (w, x, y, z) indicate significant differences ($p < 0.05$) between the fleshes and peels of the four cultivars, respectively for each treatment separately. Letters (A, B and C) and (W, X and Y) indicate significant differences ($p < 0.05$) between the three irrigation treatments for flesh and fruit peel, respectively for each season separately. Different symbols *, **, indicate significant differences between peel and flesh where (*) means significant difference at $p<0.05$ and (**) means significant difference at $p<0.01$ for each parameter analysed.
FI, Full irrigation ; SDI, Sustained deficit irrigation; CDI, Cyclic deficit irrigation; DW, Dry weight.

Table 4. Organic acid contents (g 100 g^{-1} dry weight) in peel and flesh of peach fruits from four cultivars subjected to three irrigation treatments during two consecutive seasons (2016 and 2017)

Year	Treatment	Cultivar	Citric acid			Malic acid			Succinic acid			Fumaric acid			Total organic acid content		
			Flesh	Peel		Flesh	Peel		Flesh	Peel		Flesh	Peel		Flesh	Peel	
2016	FI	Flordastar	4.06 ±0.11 $^{a A}$	3.07 ± 0.12$^{w W}$	**	4.93 ± 0.12 ^{aA}	2.38 ± 0.14$^{x W}$	**	1.27 ± 0.30 $^{a A}$	1.09 ± 0.16$^{w W}$		0.01 ± 0.01 $^{a A}$	0.01 ± 0.01$^{wx W}$		8.78 ± 0.33^{aA}	6.56 ± 0.40^{wW}	**
		Early May crest	0.90 ± 0.01 $^{c A}$	0.35 ± 0.04$^{z X}$	**	4.80 ± 0.20 $^{a A}$	2.28 ± 0.18$^{x W}$	**	0.03 ± 0.00 $^{b A}$	0.21 ± 0.09$^{y W}$		0.01 ± 0.01 $^{ab AB}$	0.01 ± 0.01$^{x X}$		5.73 ± 0.18^{dA}	2.84± 0.18^{yW}	**
		Rubirich	2.91 ± 0.31 $^{b A}$	1.26 ± 0.07$^{x X}$	**	4.68 ± 0.18 $^{a A}$	2.87 ± 0.21^{wW}	**	0.18 ± 0.01 $^{b A}$	0.20 ± 0.03^{yW}		tr $^{b C}$	0.01 ± 0.01$^{x X}$	**	7.78 ± 0.40^{bA}	4.34 ± 0.31^{xW}	**
		O'Henry	0.94 ± 0.09 ^{cA}	0.53 ± 0.03$^{y W}$	**	4.42 ± 0.06 $^{a A}$	2.17 ± 0.07$^{x W}$	**	0.24±0.02$^{b C}$	0.44± 0.02$^{x WX}$	**	0.01 ± 0.01 $^{ab A}$	0.01 ± 0.01$^{w W}$		5.62 ± 0.16^{cA}	3.16 ± 0.08^{yW}	**
	SDI	Flordastar	2.88 ± 0.01 $^{a B}$	2.89 ± 0.61$^{w W}$		4.65 ± 0.22 $^{a A}$	2.19 ± 0.34$^{wx W}$	**	0.62 ± 0.08 $^{a B}$	0.43 ± 0.34$^{w X}$		tr $^{b B}$	0.01 ± 0.01$^{wx W}$		8.17 ± 0.29^{aA}	5.53±1.30^{wWX}	*
		Early May crest	0.31 ± 0.01 ^{bC}	0.28 ± 0.21$^{y Y}$	**	2.70 ± 0.18 $^{c B}$	1.91 ± 0.58$^{wx WX}$	**	0.04±0.01$^{d A}$	0.13 ± 0.01^{wW}	**	0.01± 0.01 $^{a A}$	0.01 ± 0.01$^{wx WX}$		3.07 ± 0.18^{dB}	2.33 ± 0.55^{yW}	
		Rubirich	3.00 ± 0.45 $^{a A}$	1.38 ± 0.56$^{x W}$		4.26 ± 0.03 $^{b B}$	2.52 ± 0.05$^{w X}$		0.16± 0.05 $^{c A}$	0.18 ± 0.01^{wW}		tr $^{b B}$	tr $^{x X}$		7.43 ± 0.45^{bA}	4.10 ± 0.04^{xW}	**
		O'Henry	0.47± 0.01 $^{b C}$	0.33 ± 0.01$^{y Y}$	**	4.03 ± 0.10 $^{b B}$	1.60 ± 0.12$^{x X}$	**	0.48 ± 0.24 $^{b A}$	0.43 ± 0.03$^{w X}$		0.001 ± 0.01 $^{a A}$	0.01 ± 0.01$^{w W}$		4.99 ± 0.13^{cB}	2.38 ± 0.11^{yX}	**
	CDI	Flordastar	4.33± 0.30 ^{aA}	2.93 ± 0.10$^{w W}$	**	3.81 ± 0.47$^{a B}$	2.25 ± 0.12$^{x W}$	**	0.22 ± 0.04$^{b C}$	0.13 ± 0.05$^{y X}$		tr $^{ab AB}$	tr $^{x W}$		8.37 ± 0.62^{aA}	4.79 ± 0.26^{wX}	**
		Early May crest	0.59 ± 0.00^{cB}	0.68 ± 0.02$^{x W}$	**	2.55 ±0.21$^{b B}$	1.44 ± 0.07$^{y X}$	**	0.02 ± 0.00$^{d A}$	0.16 ± 0.07$^{xy W}$	*	tr ^{bB}	0.01 ± 0.01$^{w W}$	**	3.17 ± 0.22^{cB}	2.31 ± 0.11^{yW}	**
		Rubirich	1.25 ± 0.08$^{b B}$	0.68 ± 0.01$^{x Y}$	**	3.35 ± 0.17^{aC}	2.51 ± 0.19$^{w X}$	**	0.15 ± 0.01$^{c A}$	0.23 ± 0.03^{xW}	*	tr ^{aA}	0.01 ± 0.01$^{w W}$	**	4.76 ± 0.13^{bB}	3.45 ± 0.20^{xX}	**
		O'Henry	0.72 ± 0.00^{cB}	0.42 ± 0.00$^{y X}$	**	3.89 ± 0.09$^{a B}$	1.53 ± 0.12$^{y X}$	**	0.36 ± 0.05$^{a B}$	0.49 ± 0.05$^{w W}$		0.01 ± 0.01^{aA}	0.01 ± 0.01$^{w W}$	*	4.98 ± 0.66^{bB}	2.45 ± 0.12^{yX}	**
2017	FI	Flordastar	3.17 ± 0.25 ^{aA}	3.32 ± 0.27^{wW}	*	4.87 ± 0.31 ^{bA}	3.25 ± 0.20 ^{xW}	*	2.14 ± 0.25 ^{bA}	2.70 ± 0.28 ^{wW}		tr $^{bc A}$	tr ^{wW}		10.19 ± 0.39 ^{aA}	9.27 ± 0.75^{wW}	
		Early May crest	0.65 ± 0.05 ^{dB}	0.22 ± 0.01 ^{zX}	**	5.65 ± 0.29 ^{aA}	3.81± 0.10 ^{wW}	**	2.71 ± 0.07^{aA}	2.23 ± 0.09^{xX}	**	0.01 ± 0.01 ^{aA}	tr ^{wW}	*	9.01 ± 0.42 ^{bcA}	6.27 ± 0.19^{xW}	**
		Rubirich	3.24 ± 0.12 ^{aA}	2.11 ± 0.02 ^{xX}	**	4.55 ± 0.23^{cA}	2.08 ± 0.06 ^{yW}	**	1.75 ± 0.06^{bB}	1.87 ± 0.05^{yY}	*	tr $^{c A}$	tr ^{xW}	*	9.55 ± 0.41 ^{abA}	6.07 ± 0.13^{xX}	**
		O'Henry	1.58 ± 0.19^{cA}	0.60 ± 0.02 ^{yX}	**	5.09 ± 0.18^{bA}	1.65 ± 0.04 ^{zW}	**	1.91 ± 0.49^{bA}	1.25 ± 0.12 ^{zW}		tr ^{bA}	tr ^{yX}	**	8.58 ± 0.66 ^{cA}	3.51 ± 0.17^{yW}	**
	SDI	Flordastar	3.68 ± 0.17 ^{aB}	2.95 ± 0.51 ^{wW}	*	2.89 ± 0.12 $^{d C}$	2.95 ± 0.41 ^{wW}		1.95 ± 0.10 ^{bA}	2.49 ± 0.33w^{xW}		tr ^{bB}	tr ^{wW}		8.52 ± 0.29 ^{bB}	8.40 ± 1.32^{wW}	
		Early May crest	0.51 ± 0.01 ^{dC}	0.26 ± 0.03 ^{xWX}	**	4.62 ± 0.10 ^{aB}	3.10 ± 0.05 ^{wX}	**	2.63 ± 0.05^{aA}	2.84 ± 0.08^{wW}	*	tr ^{aB}	tr ^{wX}		7.77 ± 0.14 ^{cB}	6.20 ± 0.09^{xW}	**
		Rubirich	2.62 ± 0.15 ^{bC}	2.74 ± 0.15^{wW}		4.32 ± 0.17^{bA}	1.79 ± 0.13 ^{xX}	**	1.99 ± 0.16^{bA}	2.45 ± 0.16 ^{xW}	*	tr ^{aA}	tr ^{wW}		8.94 ± 0.17^{aB}	6.98 ± 0.41^{xW}	**
		O'Henry	1.48 ± 0.05 ^{cA}	0.66 ± 0.04 ^{xX}	**	3.54 ± 0.04 ^{cB}	1.58 ± 0.05 ^{xWX}	**	1.74 ± 0.07^{cA}	0.94 ± 0.06 ^{yX}	**	tr ^{aA}	tr ^{wW}		6.76 ± 0.11 ^{dB}	3.19 ± 0.14^{yX}	**
	CDI	Flordastar	4.35 ± 0.03 ^{aA}	3.26 ± 0.20 ^{wW}	**	3.63 ± 0.02 ^{bB}	2.69 ± 0.22 ^{wW}	**	1.90 ± 0.02 ^{bA}	2.73 ±0.19 ^{wW}	**	tr $^{b AB}$	tr ^{wW}	**	9.86 ± 0.07 ^{aA}	8.69 ± 0.60^{wW}	*
		Early May crest	0.97 ± 0.07 ^{dA}	0.31 ± 0.04 ^{zW}	**	4.47 ± 0.27 ^{aB}	2.14 ± 0.11 ^{xY}	**	2.76 ± 0.20^{aA}	2.70 ± 0.24 ^{wW}		tr ^{aB}	tr ^{yY}		8.20 ± 0.47 ^{bB}	5.15 ± 0.19^{yX}	**
		Rubirich	2.94 ± 0.02 ^{bB}	2.14 ± 0.02 ^{xX}	**	3.14 ± 0.04 ^{cB}	1.97 ± 0.05 ^{xW}	**	2.09 ± 0.01^{bA}	2.23 ± 0.03 ^{xX}	**	tr ^{aA}	tr ^{xW}	**	8.18 ± 0.09 ^{bC}	6.35 ± 0.10^{xX}	**
		O'Henry	1.62 ± 0.17 ^{cA}	0.88 ± 0.04 ^{yW}	**	3.21 ± 0.11 ^{cC}	1.51 ± 0.06 ^{yX}	**	2.06 ± 0.67^{bA}	0.82 ± 0.10 ^{yX}	*	tr ^{aA}	tr ^{zY}		6.89 ± 0.82 ^{cB}	3.21 ± 0.12^{zX}	**

Values are the means of three different peach samples (n = 3) ± standard deviation. Letters (a, b, c, d) and (w, x, y, z) indicate significant differences ($p < 0.05$) between the fleshes and peels of the four cultivars, respectively for each treatment separately. Letters (A, B and C) and (W, X and Y) indicate significant differences ($p < 0.05$) between the three irrigation treatments for flesh and fruit peel, respectively for each season separately. Different symbols *, **, indicate significant differences between peel and flesh where (*) means significant difference at $p<0.05$ and (**) means significant difference at $p<0.01$ for each parameter analysed.
FI, Full irrigation ; SDI, Sustained deficit irrigation; CDI, Cyclic deficit irrigation; DW, Dry weight; Tr, Traces