

Manuscript Number: AGWAT7360R1

Title: FEASIBILITY OF TRUNK DIAMETER FLUCTUATIONS IN THE SCHEDULING OF REGULATED DEFICIT IRRIGATION FOR TABLE OLIVE TREES WITHOUT REFERENCE TREES.

Article Type: Research Paper

Keywords: MDS; stress integral; TGR; water potential; water relations

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Abstract: Regulated deficit irrigation (RDI) results are affected by the actual water stress level reached during the treatments. The irrigation scheduling based on water status measurements, such as trunk diameter fluctuations, can control in an accurate way the water restrictions. However, the number of works that use these indicators as isolate parameter to control the schedule is scarce in general, and very scarce in olive trees. Building on previous works, the aim of this article is to schedule an RDI strategy in olive trees based on threshold values of maximum daily shrinkage (MDS) and trunk growth rate (TGR) without reference trees. The experiment was performed in a 40 years-old table olive orchard (cv Manzanillo) in Seville (Spain) for three years (seasons from 2011 to 2013). Three different irrigation treatments were considered in a completely randomized block design. Control trees were over-irrigated (125% crop evapotranspiration, ETc) in order to obtain fully irrigated conditions. Water stress conditions were applied during phase II (pit hardening) in the RDI-2 treatment or during phase II and phase I (full bloom) in RDI-12. In both RDIs, a treatment recovery (phase III) was performed before harvest. The trunk diameter fluctuation indicator was selected according to the phenological stage. TGR was used in conditions of full irrigation or moderate water stress level, such as phase I and phase III. TGR threshold values based on previous works were selected: 20 $\mu\text{m day}^{-1}$, RDI-2; 10 $\mu\text{m day}^{-1}$, RDI-12 (phase I) and -5 $\mu\text{m day}^{-1}$, both treatments, phase III. Only in one season RDI-2 was scheduled with TGR values (-10 $\mu\text{m day}^{-1}$) during phase II. MDS threshold values were determined as the ratio between measured MDS and fully irrigated MDS (the so called MDS signal). The latter was estimated from a baseline. During phase II, RDI-2 was irrigated with a threshold value of 0.9, while RDI-12 was irrigated with a threshold value of 0.75. MDS signal was not useful for most of the period considered and it did not agree well with fruit drop or fruit size. Conversely, the average of TGR during phase II was significantly linked to fruit drop and fruit size, and so were the midday stem water potential and stress integral. Recommendations about the management of TGR are discussed. The water stress level in the experiments was moderate and no significant differences in yield were found. However, the trend of yield reduction in RDI-12 was likely related with a fruit drop and a reduction in crown volume. The yield quality did not decrease in the RDIs treatments, on the contrary, pulp:stone ratio improved significantly in some of the seasons

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**FEASIBILITY OF TRUNK DIAMETER FLUCTUATIONS IN THE
SCHEDULING OF REGULATED DEFICIT IRRIGATION FOR TABLE OLIVE
TREES WITHOUT REFERENCE TREES.**

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Keywords: MDS, stress integral, TGR, water potential, water relations

24 **Abstract**

25 Regulated deficit irrigation (RDI) results are affected by the actual water stress level
26 reached during the treatments. The irrigation scheduling based on water status
27 measurements, such as trunk diameter fluctuations, can control in an accurate way the
28 water restrictions. However, the number of works that use these indicators as isolate
29 parameter to control the schedule is scarce in general, and very scarce in olive trees.
30 Building on previous works, the aim of this article is to schedule an RDI strategy in
31 olive trees based on threshold values of maximum daily shrinkage (MDS) and trunk
32 growth rate (TGR) without reference trees. The experiment was performed in a 40
33 years-old table olive orchard (cv Manzanillo) in Seville (Spain) for three years (seasons
34 from 2011 to 2013). Three different irrigation treatments were considered in a
35 completely randomized block design. Control trees were over-irrigated (125% crop
36 evapotranspiration, ETC) in order to obtain fully irrigated conditions. Water stress
37 conditions were applied during phase II (pit hardening) in the RDI-2 treatment or during
38 phase II and phase I (full bloom) in RDI-12. In both RDIs, a treatment recovery (phase
39 III) was performed before harvest. The trunk diameter fluctuation indicator was selected
40 according to the phenological stage. TGR was used in conditions of full irrigation or
41 moderate water stress level, such as phase I and phase III. TGR threshold values based
42 on previous works were selected: $20\mu\text{m day}^{-1}$, RDI-2; $10\mu\text{m day}^{-1}$, RDI-12 (phase I) and
43 $-5\mu\text{m day}^{-1}$, both treatments, phase III. Only in one season RDI-2 was scheduled with
44 TGR values ($-10\mu\text{m day}^{-1}$) during phase II. MDS threshold values were determined as
45 the ratio between measured MDS and fully irrigated MDS (the so called MDS signal).
46 The latter was estimated from a baseline. During phase II, RDI-2 was irrigated with a
47 threshold value of 0.9, while RDI-12 was irrigated with a threshold value of 0.75. MDS
48 signal was not useful for most of the period considered and it did not agree well with

49 fruit drop or fruit size. Conversely, the average of TGR during phase II was
50 significantly linked to fruit drop and fruit size, and so were the midday stem water
51 potential and stress integral. Recommendations about the management of TGR are
52 discussed. The water stress level in the experiments was moderate and no significant
53 differences in yield were found. However, the trend of yield reduction in RDI-12 was
54 likely related with a fruit drop and a reduction in crown volume. The yield quality did
55 not decrease in the RDIs treatments, on the contrary, pulp:stone ratio improved
56 significantly in some of the seasons.

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66 **INTRODUCTION**

67 Water scarcity around the world has been reduced the irrigation availability. Deficit
68 irrigation scheduling has been suggested in most of the fruit trees. Regulated deficit
69 irrigation (RDI) and partial root drying (PRD) are two different options of water deficit
70 management. In some fruit trees such as olive orchard, PRD has not improved the
71 results of RDI (Fernández et al. 2006). Since PRD needs more labor force, farmers
72 commonly prefer RDI scheduling. Regulated deficit irrigation (RDI) is an irrigation
73 scheduling method first reported in the 70's, based on differences in water stress
74 sensibility during the season (Chalmers et al., 1975). Traditional RDI works reduce the
75 amount of water provided during the most resistant phenological stages using the
76 percentage of crop evapotranspiration (Behboudian and Mills, 1997). Such strategy has
77 produced contradictory results. Similar recommendations in RDI scheduling caused
78 clear differences when they were performed at different sites (for instance, Girona
79 (2002) in peaches; Johnstone et al (2005) in tomato).

80 The irrigation season in olive trees could be divided into four different periods
81 according to water stress sensibility. The full bloom/fruit set period is considered the
82 most sensitive to drought conditions (Moriana et al, 2003), while the pit hardening
83 period is the most resistant (Goldhamer, 1999) in relation to yield. Oil accumulation is
84 also considered a sensitive period (Lavee and Wodner, 1991) though several works
85 suggest that moderate water stress increases oil production (Moriana et al, 2003; Lavee
86 et al., 2007). The postharvest period has not been studied, probably because in the main
87 producing zone this is the rainfall season. The results of irrigation works in olive trees
88 strongly suggest that different levels of water stress during the same phenological stage
89 change the effect on yield (Goldhamer, 1999; Moriana et al. 2003; Lavee et al., 2007).

90 Irrigation scheduling based on water status measurements could provide a useful
91 tool to control the water stress level in RDI. In this way, water stress conditions in
92 different sites will be comparable and RDI strategies could be easily performed out of
93 the experimental orchards. Trunk diameter fluctuations are daily cycles of swelling and
94 shrinking suggested in several fruit trees as an irrigation scheduling tool (Ortuño et al.,
95 2010). There are two indicators obtained from daily curves: maximum daily shrinkage
96 (MDS) and trunk growth rate (TGR) (Goldhamer and Fereres, 2001). In olive trees,
97 MDS is not reported as a useful indicator, while TGR is considered an early water stress
98 detector (Moriana and Fereres, 2002). There are only a few works using these
99 parameters in olive RDI. Recently, Moriana et al (2013) suggested a threshold value of -
100 $5\mu\text{m day}^{-1}$ of TGR during pit hardening and recovery in table olive trees and concluded
101 that MDS is not an easy tool in these conditions. However, Corell et al. (2013)
102 suggested a different approach to estimate MDS in order to reduce the influence of the
103 environment. Moriana et al (2013) used the reference tree approach (Goldhamer and
104 Fereres, 2001) which, in brief, requires trees to be fully irrigated at the orchard in order
105 to eliminate the environmental effect. These “reference trees” could affect the results
106 obtained. Threshold values based in previous experiments could change the usefulness
107 of some indicators such as MDS. The aim of this work is to combine previous results in
108 order to obtain an irrigation approach that uses only threshold values of MDS and TGR
109 without reference trees. This objective will be studied from two points of view. First,
110 the present work considers the ease of data interpretation. Secondly, the robust
111 relationship between both indicators and processes relate to yield results, such as fruit
112 drop or fruit size, will be studied as well.

113

114 **MATERIAL AND METHODS**

115 *Site description and experimental design*

116 Experiments were conducted at La Hampa, the experimental farm of the Instituto de
117 Recursos Naturales y Agrobiología (IRNAS-CSIC), located in Coria del Río near
118 Seville (Spain) (37°17'N, 6°3'W, 30 m altitude). The experiment was performed on 40-
119 year-old table olive trees (*Olea europaea* L cv Manzanillo) from the 2011 to the 2013
120 seasons. Tree spacing followed a 7m x 5m square pattern. [Age and density of the
121 experimental orchard is the common of the zone in ~~commercial~~ commercial orchards.](#)
122 The sandy loam soil (about 2m deep) of the experimental site was characterised by a
123 volumetric water content of $0.33\text{m}^3\text{ m}^{-3}$ at saturation, $0.21\text{m}^3\text{m}^{-3}$ at field capacity and
124 $0.1\text{m}^3\text{m}^{-3}$ at permanent wilting point, and 1.30 (0-10cm) and 1.50 (10-120cm) g cm^{-3}
125 bulk density. Pest control, pruning and fertilization practices were those commonly used
126 by growers and weeds were removed chemically within the orchard, only in the last
127 season no pruning was performed. Drip irrigation was carried out at night using one
128 lateral pipe per row of trees and five emitters per plant, spaced 1m and delivering 8L h^{-1}
129 each. Micrometeorological data were obtained using an automatic weather station
130 located around 40_m from the experimental site. [Although some recent works suggest
131 simple approaches for estimated daily reference evapotranspiration \(ET_o\) \(i.e. Valipour
132 2014 and 2015\).](#) Daily reference evapotranspiration (ET_o) was calculated using the
133 Penman-Monteith equation (Allen et al., 1998).

134 The experimental design was a completely randomized block experiment with 3
135 blocks and 3 irrigation treatments. Each treatment was carried out in a plot with two
136 trees located in a single row and two adjacent guard rows. There were 6 trunk diameter
137 fluctuation sensors per treatment and 1 sensor per tree.

138

139 *Irrigation phases considered*

140 The seasonal cycle of the trees was divided in 4 phases according to Rallo (1997):

141 | • Phase I occurred from the shoot flush (around mid-February, day of the year
142 | (DOY) 45) until the beginning of the period of massive pit hardening
143 | (around DOY 169).

144 | • Phase II occurred from massive pit hardening until the last week of
145 | August. We considered that massive pit hardening began when a decrease in
146 | the growth rate of the longitudinal diameter of the fruit was measured
147 | (Rapoport et al., 2013). There is no morphological indicator to establish the
148 | end of this phase. Therefore the end of this phase was established in order to
149 | obtain a complete rehydration before harvest (around DOY 240).

150 | • Phase III was the period of rehydration and occurred from the end of
151 | August until harvest (around DOY 275).

152 | • Phase IV. Postharvest. The typical date of the beginning of
153 | postharvest is the beginning of October.

154

155 *Treatment description*

156 The water stress levels were estimated according to the trunk diameter
157 fluctuation indicators. Maximum daily shrinkage (MDS) was calculated as the
158 difference between the maximum daily diameter and the minimum daily diameter
159 (Goldhamer et al., 1999). Trunk growth rate (TGR) in day “n” was calculated as the
160 difference between the maximum daily diameter in day “n+1” minus that in day “n”
161 (Cuevas et al., 2010).

162 Severe water stress conditions reduce MDS in comparison to fully irrigated trees
163 (Moriana et al., 2000). Therefore, MDS was used only during phase II. Since MDS is
164 strongly related with evaporative demand, the parameter considered was the MDS

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165 signal, which is the ratio between the measured MDS and the MDS in fully irrigated
166 conditions (Goldhamer and Fereres, 2001). Moriana et al (2011) reported that the
167 maximum temperature is the best meteorological measurements in order to estimate the
168 seasonal baseline in olive trees. The fully irrigated MDS was estimated from a baseline
169 obtained with the Corell et al (2013) approach. Corell et al (2013) suggested that
170 seasonal changes in the baseline are in the y-interception, while the slope is similar for
171 different years. Therefore, a small numbers of MDS data at the beginning of the
172 irrigation season could be used to estimate the seasonal baseline (Corell et al., 2013).

173 The TGR was used when moderate water stress levels were imposed because it
174 was reported as the most sensitive indicator to water deficit conditions (Moriana and
175 Fereres, 2002). Thresholds values from Moriana et al (2013) were used for phase I and
176 phase III. During the first two seasons, the MDS approach permitted a small amount of
177 irrigation in the RDIs and then both treatments presented a similar water status. For this
178 reason, only in the last year, the TGR was used in the irrigation scheduling of phase II
179 in one of the RDIs treatment.

180 All the treatments stopped the irrigation after harvest. During the rest of the
181 season irrigation treatments were:

- 182 • *Control treatment.* Irrigation requirements were determined according to
183 daily crop evapotranspiration (ET_c) calculated using the FAO method
184 (Allen et al., 1998). Crop coefficient values (K_c) were previously estimated
185 in the orchard (Fernández et al. 2006). In addition, a reduction according to
186 tree size was considered ($K_r=0.7$). Trees were irrigated daily with 125%
187 crop evapotranspiration (ET_c) until harvest.
- 188 • *Regulated Deficit Irrigation 2 (RDI-2).* No water stress was performed in
189 phase I. In this phase, a TGR threshold value of $20\mu\text{m day}^{-1}$ was

190 considered. The objective of this treatment during phase II was to create
191 moderate water stress conditions and a threshold value of 0.9 of MDS
192 signal was considered. Phase III was used as a rehydration period and the
193 objective was to perform a slow recovery with a $-5\mu\text{m day}^{-1}$ of TGR. Only
194 during the 2013 season, phase II was scheduled with TGR values, using -
195 $10\mu\text{m day}^{-1}$.

196 • *Regulated Deficit Irrigation 12 (RDI-12)*. Water stress conditions were
197 applied during phase I and II. During phase I, a moderate water stress level
198 was applied with a TGR threshold value of $10\mu\text{m day}^{-1}$. In phase II, severe
199 water stress conditions were the objective and the threshold values were
200 0.75 of the MDS signal. No water stress was applied in phase III and the
201 management was the same in this phase as in RDI-2.

202 *Estimation of irrigation needs*

203 Water needs in RDI trees is depended the water status of the tree. In water stress
204 conditions, crop evapotranspiration in these treatemnts is lower than the ones of
205 Control. Then, irrigation in RDI treatments was changed daily according to the
206 variation of the threshold value considered (MDS signal or TGR depending on the
207 phenological stage). Three levels of irrigation rate were estimated in relation to the
208 maximum average daily ET_c of the orchard. When the deviation of the threshold was
209 very high, water applied was around the maximum needs estimated in order to maintain
210 water status around the threshold. Otherwise, water applied was reduced in comparison
211 to this maximum or even no irrigated if the values obtained were higher than the
212 threshold considered. These estimations were calculated for the last ten years with the
213 K_c and K_r values used in the Control treatment. The percentages of variations selected

214 | [were based in previous works \(Moriana et al., 2013\).](#) The irrigation rate varied as
215 follows:

- 216 • The selected parameter changed less than 15% of the threshold value; 1mm
217 (a quarter of the maximum daily ET_c) of irrigation was applied on this date.
- 218 • The selected parameter changed 15-30% of the threshold value; 2mm (half
219 the maximum daily ET_c) of irrigation was applied on this date.
- 220 • The selected parameter changed more than 30% of the threshold value; 4mm
221 (the maximum average daily ET_c) of irrigation was applied on this date.

222 *Measurements*

223 All the measurements were made on the two measured trees located on each
224 plot. Trunk diameter fluctuations were measured throughout the experimental periods
225 using a set of linear variable displacement transducers (LVDT) (model DF±2.5mm,
226 accuracy ±10µm, Solartron Metrology, Bognor Regis, UK) attached to the main trunk,
227 with a special bracket made of Invar, an alloy of Ni and Fe with a thermal expansion
228 coefficient close to zero (Katerji et al., 1994). [Trunk diameters were very similar](#)
229 [between treatments; Control 0.24±0.01m, RDI-2 0.24±0.01m, RDI-12 0.23±0.01m.](#)
230 [According to Corell et al \(2013\) such differences would not affect to the indicators](#)
231 [derivate from trunk diameter fluctuations. The height and position of the sensor was](#)
232 [similar in all the trees around 0.5 m height and in the north side of the trunk.](#)

233 Measurements were taken every 10s and the datalogger (model CR10X with AM 416
234 multiplexer, Campbell Sci. Ltd., Logan, USA) was programmed to report 15 min
235 means. Since TGR daily data are very variable between days, the maximum diameter
236 (accumulative values of TGR) was used in the graphs. In addition, the average TGR
237 during the three periods considered were used in order to better describe the tree water
238 status.

239 The soil moisture was measured with a portable FDR sensor (HH2, Delta-T,
240 U.K.) with a calibration obtained in previous works. The measurements were made in
241 three plots per treatment. The access tubes for the FDR sensor were placed in the
242 irrigation line at about 30cm from an emitter, [which is the distance where root activity](#)
243 [is higher](#) (Fernández et al., 1991). The data were obtained at 1m depth with 10cm
244 intervals.

245 The water status of trees for each treatment was characterised by the midday
246 stem water potential (Ψ) and maximum leaf conductance. The leaves near the main
247 trunk were covered in aluminium foil at least one hour before measurements were taken.
248 The water potential was measured at midday in one leaf per tree, using the pressure
249 chamber technique (Scholander et al., 1965). The abaxial leaf conductance was
250 measured at around 10 a.m. in order to estimate the maximum daily value in two fully
251 expanded sunny leaves per tree with a steady state porometer (LICOR 1600, Lincoln,
252 Nebraska, U.S.A).

253 In order to describe the accumulative effect of the water deficit, the water stress
254 integral was calculated from the Ψ data (Myers, 1988) during the period of water stress
255 (equation 1). Equation 1 used a reference of -1.4MPa, which is the threshold value
256 suggested by Moriana et al (2012) in fully irrigated olive trees. All the values higher
257 than the reference were considered as equal to this. The expression used was:

258

$$259 \quad S\varphi = |\sum(\Psi - (-1.4)) * n| \quad (1)$$

260 where: $S\varphi$ is the stress integral

261 Ψ is the average midday stem water potential for any interval

262 n is the number of the days in the interval

263

264 At the beginning of each season, ten shoots per tree were selected randomly. For
265 each shoot, the length, number of inflorescences and fruits were measured periodically.
266 The fruit volume was estimated from a survey of ten fruits per tree in the same trees
267 where trunk diameter fluctuations were measured. Fruits were randomly selected on
268 each date of measurement. Two measurements were made for each fruit: the
269 longitudinal dimension and the transversal dimension (at the equatorial point).

270 The irrigation treatments were also evaluated from the point of view of quantity
271 and quality of yield. In table olives, the quality of the fruit is related to ~~two-three~~
272 parameters: the pulp-stone ratio (PS ratio), mature index (MI) and the fruit size. High
273 values of PS ratio are considered an indicator of better quality fruits. A sample of 18
274 fruits per plot was measured. Fruits were deboned and the fresh weight of the pulp and
275 the stone were measured. Pulp and stone were put into a stove at 70°C during 24 hours.
276 Dry weight was then measured. The pulp-stone ratio was measured by the fresh weight
277 of 18 fruits per treatment. The fruit size was estimated in 6 trees per treatment with the
278 number of fruits per kilogram. The mature index (MI) of the fruits estimated the colour
279 of the fruits (Hermoso et al., 1997). A sample of 100 fruits in each plot were classified
280 in 4 groups according to the fruit colour: 0 green, 1 yellow-green, 2 lower than 50% of
281 purple, 3 higher than 50% purple, 4 purple fruit. MI is calculated as a weighted average.
282 In table olive for green style, fruit at harvest should be an index around 1.

283 Productivity of irrigation was estimated with the irrigation water used efficiency
284 (WUE). WUE was calculated as the ratio between yield (in Kg ha⁻¹) and the amount of
285 water applied (in m³ ha⁻¹).

286 Data analyses were performed with ANOVA and the mean separation was made
287 via a Tukey's test using the Statistix (SX) program (8.0). Significant differences were
288 considered when p-level<0.05 in both tests. Calculations of the p-level were performed

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289 considering the F-test of equality of variance. When conditions of equality of variance
290 were not obtained, a decrease in the degree of freedom and, therefore, more restrictive
291 p-value was calculated. The number of samples measured is specified in the text and
292 figures.

293

294 **RESULTS**

295 *Water relations*

296 The climatic and water data applied along the three years of experiment are presented in
297 Table 1 ~~and Fig. 1~~. The length duration of the different phenological stages was similar
298 for all seasons (Table 1). Phase II, the pit hardening period, was shorter but with less
299 rain than phase I, which is the common seasonal pattern. The amount of irrigation in
300 ~~control~~ Control trees was almost linear from the end of phase I throughout the seasons,
301 with the greatest consumption during phase II. During this period, phase II, the daily
302 water consumption in Control trees was clear lower in 2011 (2.8 mm day⁻¹) than 2012
303 and 2013 (3.8 and 3.4 mm day⁻¹, respectively) likely related with the lower fruit load in
304 this season. The greatest seasonal volume of water applied during 2012 (540mm) in
305 comparison with 2011 (299mm) and 2013 (369mm) was related to an important
306 reduction of rainfall. During 2012, the seasonal amount of rain was 302mm (only 94mm
307 during spring), while in 2011 and 2013 there were 521mm (211mm in spring) and
308 418mm (173mm in spring), respectively. The Control values higher than field capacity
309 and the horizontal pattern of soil moisture (Fig. 1) suggest that this treatment was over-
310 irrigated during part of the seasons, mainly in phase II. The irrigation approach in the
311 regulated deficit irrigation (RDI) treatments provided a similar irrigation amount in both
312 treatments during 2011 and 2012 (Table 1 ~~and Fig. 1~~), though there was a slightly
313 greater amount of water in RDI-2 during phase I. Such results were related to the

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314 threshold value of MDS signal which was not reached during phase II in most of the
315 dates for both seasons. The change in the irrigation scheduling of RDI-2 during the last
316 year, the 2013 season, increased the amount of water of this treatment during phase II
317 (Table 1 ~~and Fig. 1~~). There was no significant differences between RDI-2 and Control
318 in this season, but the pattern of soil moisture suggest no drainage but also no water
319 stress conditions in RDI-2.

320 The soil moisture was affected by the irrigation treatments (~~Fig. 2~~Fig. 1). The
321 control treatment slightly increased soil moisture from phase I to phase II, though
322 values were similar along the season and between years. On the other hand, RDI
323 treatments decreased sharply during phase II, with significant differences when
324 compared to Control, but not between RDIs (~~Fig. 2~~Fig. 1). Only in the 2013 season,
325 when the irrigation approach in RDI-2 was changed, significant differences between this
326 and RDI-12 were measured (~~Fig. 2~~Fig. 1c). In this season, there were no significant
327 differences between Control and RDI-2 (~~Fig. 2~~Fig. 1c).

328 Stem water potential (Ψ) data showed clear differences between the seasonal
329 water stress levels (~~Fig. 3~~Fig. 2). Control trees presented similar values in all the
330 seasons with a minimum value around -1.5MPa. Significant differences were found
331 mainly between Control and RDI-12, most of them during phase II. In most of the dates,
332 RDI-2 was an intermediate treatment, though in the 2011 and 2012 seasons, RDI-2 was
333 very similar to RDI-12 (~~Fig. 3~~Fig. 2a and b). Only during the 2013 season, when the
334 irrigation approach was changed in RDI-2, this treatment was nearer to Control than to
335 RDI-12 (~~Fig. 3~~Fig. 2c).

336 The maximum leaf conductance (g) data presented clear differences between
337 seasons (~~Fig. 4~~Fig. 3). In 2011 (~~Fig. 4~~Fig. 3a), a low fruit load year, g was lower in all
338 the treatments in comparison with 2012 and 2013 (~~Fig. 4~~Fig. 3b and c), when the yield

339 was around the orchard average. As in previous parameters, most of the significant
340 differences were obtained between Control and RDI-12 and during phase II (Fig. 4Fig.
341 3). However, throughout the season RDI-2 was significantly lower than Control at the
342 end of the stress period (Fig. 4Fig. 3). Only in the 2011 season, g data in RDIs treatment
343 were not significantly different to the Control ones at the end of the experiment. In
344 2013, RDI-2 was completely recovered at the end of the experiment according to g;
345 while RDI-12 was still significantly lower (Fig. 4Fig. 3c).

346 The Stress Integral (SI) data indicated clearly the differences between seasons
347 and treatments (Fig. 5Fig. 4). SI at Control treatments was lower than 10MPa*day in all
348 the seasons, while the values in RDIs were at their maximum during 2012 and at their
349 minimum during the 2011 season. In all the seasons RDI-12 was significantly greater
350 than Control, while RDI-2 was significantly different to Control in 2011 and 2012 but
351 not in 2013. RDI-2 data were clearly lower than RDI-12 in all the seasons. The smallest
352 differences between RDI-2 and Control occurred during 2013.

353 The trunk growth rate (TGR) graph is difficult to read when a large number of
354 data are included. In order to improve the clarity of the results, the Maximum diameter
355 graph is presented (Fig. 7 6.), where the slope are TGR data. The average TGR values in
356 each phenological stage are included in Table 2. Seasonal patterns of Maximum
357 diameter were affected by fruit loads and spring rainfall. In 2011 and 2012, the rains
358 during phase I reduced the TGR in all the treatments (Table 2) and produced large
359 cycles of increase and decrease (Fig. 6Fig. 5). In these periods, irrigation scheduling
360 based on this parameter was extremely difficult because negative TGR were not related
361 to water stress. The significant differences in TGR during phase I for the two first
362 seasons, 2011 and 2012, were not clearly related to the irrigation treatment (Fig. 6Fig.
363 5a and b). The rain effect was similar in the 2013 season but since the wet period was

364 concentrated at the beginning of the year, a growth period was measured during phase I
365 in all the treatments. In the 2013 season, during this period there were clear trends of
366 lower values in TGR and RDI-12 than in Control and RDI-2 (Fig 6c). In 2013, TGR
367 averages were around the values suggested in the methodology for each treatment
368 (Table 2).

369 Most of the significant differences in TGR were found during pit hardening,
370 phase II, in all the seasons (Fig. 6 Fig. 5 and Table 2). In the 2011 season, TGR in
371 Control was clearly greater than in the rest of the years because of the low fruit load
372 conditions (Fig 6a and Table 2). For the rest of the seasons and treatments, the TGR was
373 around zero during phase II, when water stress was not severe or clearly negative in
374 severe conditions of water stress, mainly during 2012 when the highest level of water
375 stress was detected (Fig. 6 Fig. 5b, Table 2). No significant differences in TGR were
376 found in 2011 and 2012 between RDIs treatments. In 2013, the TGR during phase II
377 was significantly different between RDI-2 and RDI-12 because of the changes in the
378 irrigation scheduling in the former (Fig. 6 Fig. 5c). In this season, the average TGR of
379 RDI-2 tended to greater values than Control and it was clearly greater than $-10\mu\text{m day}^{-1}$,
380 the suggested threshold value in the methodology (Table 2).

381 In the recovery period, the average TGR was not around the threshold suggested
382 in the methodology for RDIs ($-5\mu\text{m day}^{-1}$) in any of the seasons (Table 2), though there
383 was a daily TGR value in these treatments lower than this value (Fig. 6 Fig. 5). In this
384 recovery phase, although no significant differences were found in the average values,
385 there were actually some differences in the daily TGR values between Control and RDIs
386 and a clear trend of greater values in RDIs than in Control (Fig. 6 Fig. 5 and Table 2).

387 The Maximum Daily Shrinkage signal (MDS signal) was the indicator for the
388 irrigation scheduling during phase II in the RDI treatments (except RDI-2 in the 2013

389 season). According to the approach for the estimated MDS signal (see Materials and
390 Methods), only MDS signal data for phase II and phase III are presented because the
391 ones for phase I were used for estimating the baseline. Although some significant
392 differences between Control and RDIs were measured, mainly at phase III, the seasonal
393 pattern of MDS signal was very confusing (~~Fig. 7~~Fig. 6). Even daily Control data were
394 clearly higher than 1 mainly during the 2011 season (a low fruit load year) (Fig.7),
395 although the average values of MDS signal in Control during the 2012 and 2013
396 seasons were around 1 (Table 3). However, the clear deviations of daily data from 1 for
397 the Control MDS signal suggest that the baseline did not represent accurately enough
398 the environmental effect. An example of this is the period from DOY 207 to DOY 212
399 in the 2012 season, when a large increase in the MDS signal was measured. Since these
400 large values occurred in all the treatments, they can be most probably attributed to the
401 environment. One of the possible reasons are the large changes in maximum
402 temperature, from 32°C in DOY 207 to 27°C in DOY 209 and the later increase to 35° C
403 in DOY 211.

404 The MDS signal did not reflect easily the effect of the water stress. The
405 threshold values considered in the methodology were not usually reached (~~Fig. 7~~Fig. 6)
406 and this produced small irrigation amounts, which were very similar between RDI
407 treatments. During short periods in phase II of the 2011 and 2012 seasons, the daily
408 MDS signal in RDI treatments tended to show greater values than Control and only at
409 the end of 2012 RDI-12 presented lower values than Control. The average MDS signal
410 values also were greater during RDI treatments than during Control in both seasons. In
411 the 2013 season, the MDS signal pattern for both RDIs tended to show clearly much
412 greater daily and average values than Control during phase II (~~Fig. 7~~Fig. 6c and Table

413 3). Moreover, during this season RDI-12 presented a decrease in MDS signal at the end
414 of Phase II that was reversed during the rehydration phase (Fig. 7 Fig. 6c).

415

416 *Vegetative growth*

417 Shoot elongation presented a similar seasonal pattern in all the years of the experiment
418 with an active growth during phase I and almost no growth in the rest of the season
419 (Fig. 8 Fig. 7). The increase in fruit load reduced the shoot elongation; thus the growth
420 during the lowest yield season (2011, Fig. 8 Fig. 7a) was half that of the highest (2013,
421 Fig. c). During the 2011 (Fig. 8 Fig. 7a) and 2012 (Fig. 8 Fig. 7b) seasons, shoot
422 elongation was not affected by the water stress and the maximum values of growth were
423 not significantly different between treatments. Only during the 2013 season, RDI-2 was
424 significantly greater than RDI-12 during most of phase I, while Control was an
425 intermediate treatment without such differences (Fig. 8 Fig. 7c). In this season, there
426 were significant differences between treatments at the end of the period of active
427 growth. During phase II, period without active growth, the maximum elongation was
428 significantly different, just as it happened during phase I (Fig. 8 Fig. 7c). In all the
429 seasons, there was no active growth during the recovery phase in any of the treatments.

430 The percentage of soil cover was estimated only at the beginning and the end of
431 the 2013 season (Fig. 8 Fig. 7c). No significant differences were found in this parameter.
432 The Control values (42%) tended to show a greater soil cover than the RDIs treatment,
433 which were almost equal at the beginning of the season (36% RDI-2 and 37% RDI-12).
434 The increase of soil cover at the end of the season was similar in all the treatments and
435 around 20%, slightly higher in Control and RDI-2 (22%) than in RDI-12 (18%).

436

437 *Fruit development*

438 Numbers of inflorescences per shoot were measured along the season and from pit
439 hardening (phase II) the number of fruit per inflorescence was counted. There were no
440 significant differences between treatments in both parameters (data not shown). The
441 fruit drop was estimated as the different between the number of fruit per inflorescence at
442 the beginning and the end of pit hardening. The seasonal pattern of the inflorescence
443 number was common in olive trees and showed with a great reduction, even in full
444 irrigated treatments, from the beginning of the season until pit hardening (Fig. 9). The
445 number of inflorescences was minimum in 2011 (low fruit load season) and maximum
446 in the 2012 season (Fig. 9a and b). The large reduction in 2012 was related to a severe
447 problem with *Spilocaea oleagina* (Cast.) Hughes in all the treatments, which partly
448 defoliated all the trees. The number of inflorescences was almost constant from phase II
449 until harvest in all the seasons and treatments. There were no significant differences
450 between treatments in any of the seasons.

451 The number of fruit per inflorescence was measured when the number of inflorescences
452 was constant in phase II (Fig. 10). Although all the marked shoots were measured, only
453 the data of the shoot that presented fruit at the beginning of pit hardening were included
454 in Fig. 10. There were no significant differences between treatments in any of the
455 seasons. The number of fruits per shoot varied between 2 and 3 for all the seasons.
456 Control trees presented almost constant values throughout the phase II, with a
457 percentage of fruit drop lower than 3% (Fig. 10). The reduction in fruit in RDI-12
458 tended towards lower values than in RDI-2 in all the years, with significant differences
459 in the 2012 season, when a greater than 25% of fruit drop was measured in RDI-12.

460 The percentage of fruit drop data (Fig. 10) were compared to the minimum midday
461 stem water potential (Fig. 3Fig. 2), stress integral (Fig. 5Fig. 4) and average TGR data
462 (Table 2) obtained during phase II (Fig. 11Fig. 8). All the relationships were significant,

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463 | though the ones with the midday stem water potential (~~Fig. 11~~Fig. 8a) and stress
464 | integral (~~Fig. 11~~Fig. 8b) were the most robust. In all the indicators, the increase of water
465 | stress enlarged the percentage of fruit drop. However, since the best fit was a quadratic
466 | adjustment, the rate of fruit drop increased with water stress. No multi-variable
467 | adjustment presented best fit. Data of fruit drop in RDI-2 in the 2013 season were
468 | greater than expected for all three indicators, while the ones for RDI-12 in the same
469 | season were not (data circled in ~~Fig. 11~~Fig. 8).

470 | The fruit volume increased in Control trees almost linearly in the three seasons
471 | of the experiment (~~Fig. 12~~Fig. 9). The differences in fruit volume between seasons in
472 | Control trees were lower than expected according to the fruit load. During 2011, with
473 | around 30% of historical average fruit load, the fruit volume was similar to 2013,
474 | around 115% of the fruit load. In all the years, significant differences were measured
475 | between Control and RDIs during phase II (always lower than 15%), but at the end of
476 | the rehydration period, the fruit volume was completely recovered. Only in the RDI-12
477 | in the 2013 season, slightly but significant differences were found (~~Fig. 12~~Fig. 9c). No
478 | significant differences were found between RDIs. When the fruit volume at the end of
479 | the phase II is normalized for the Control treatment, on that day there was a robust
480 | relationship between the data and the three indicators used in ~~Fig. 11~~Fig. 8. The best fit
481 | in the three indicators was linear and there was a reduction of the relative fruit volume
482 | with the increase in water stress (~~Fig. 13~~Fig. 10). The multi-variable fit was not better
483 | than the ones presented in ~~Fig. 13~~Fig. 10. Although significant relationships were found
484 | with the three indicators, Stress integral (SI) and average TGR (~~Fig. 13~~Fig. 10 b and c)
485 | were better than the minimum midday stem water potential (Ψ , ~~Fig. 13~~Fig. 10 a). In
486 | addition, the slope of the relationship in SI and Average TGR was sharper than the ones
487 | of the Ψ .

488

489 *Yield quality and quantity*

490 Table 4 presents the main features of the yield in the three years of the experiment.
491 Yield in Control trees was increased along the experiment. In 2011 season, the Control
492 yield was around 30% of the average yield of the orchard (8MT ha⁻¹), which then was
493 considered a low fruit load in this season. In the 2012 and 2013 seasons, the yield was
494 around or slightly greater than the average in Control trees. There were no significant
495 differences in yield between irrigation treatments. In the 2011 season, RDI-2 produced
496 the greater yield, while RDI-12 and Control were almost similar. The 2012 season was,
497 in theory, a high fruit load season according to the fruit load of the previous year.
498 However, the attack of *Spillocaea oleagina* (Cast.) Hughes reduced the fruit load in all
499 the treatments. During the 2012 season, RDIs tended to lower yield values than Control.
500 In 2013, RDI-2 was closer to Control yield than to RDI-12.

501 Fruit size is an important feature of the yield quality in table olives. Changes in
502 fruit load did not clearly affect the fruit size (Table 4). There were no significant
503 differences between treatments according to water stress conditions. Only in the 2011
504 season, RDI-2 presented significantly smaller fruit than Control and RDI-12. These
505 latter results were not confirmed in the following years, nor were there clear trends
506 suggesting a reduction in the fruit size at the end of the rehydration period.

507 The Pulp/Stone ratio is other important characteristic in table olives. A large
508 pulp/stone ratio is valued in the industrial processing after harvest. The Pulp/Stone ratio
509 was sensitive to the fruit load. In conditions of low fruit load (2011 season), Control
510 trees had a greater ratio than in high fruit load (2013 season). Only in the 2013 season,
511 the water stress increased significantly the pulp/stone ratio of RDIs in comparison to
512 Control (in dry weight), although a similar trend was measured in the 2012 season in

513 dry and fresh weight (Table 4). Differences in the 2011 season could be due more to the
514 low fruit load than to the water stress.

515 The Mature Index (MI) estimates the fruit color. An MI higher than 1, indicates
516 that there is a purple zone in the fruit which is not valued in “green table olives”. There
517 | were no significant effects of water stress on MI. The [irrigation](#) water use efficiency
518 (WUE) was greater in RDIs than in Control trees in all the seasons. There were no clear
519 differences between RDIs in 2011 and 2012. Only in the 2013 season, when RDI-1
520 irrigation scheduling was changed, RDI-12 tended towards clearly greater values than
521 RDI-1.

522 **DISCUSSION**

523 *Irrigation scheduling based on trunk diameter fluctuations indicators.*

524 Changes in the methodology of MDS signal did not improve the usefulness of the
525 indicator in comparison to previous work (i.e. Moriana et al 2013). The baselines
526 calculated according to Corell et al (2013) generated values in Control trees that, on
527 average, were near to 1 only in high fruit load seasons, although they changed widely in
528 daily values. On the other hand, in the high fruit load season the MDS signals were
529 clearly higher than 1 in both RDIs. Only in an isolated period at the end of phase II,
530 RDI-12 presented an MDS signal lower than 1. These values slightly higher than 1
531 indicate, in most cases, moderate water stress conditions. However, according to the
532 present result, the MDS signal as a unique indicator is not reliable.

533 The trunk growth rate (TGR) could be a useful indicator in irrigation scheduling.
534 According to the present data, the average TGR is a good tool for predicting the water
535 stress conditions, similarly to the stem water potential, but using daily TGR and
536 Maximum diameters could also facilitate irrigation scheduling. Rains are the main
537 problem in the use of this methodology and produce long periods, even on the dry days,

538 when trunk diameter fluctuations are useless because there is a trunk shrinkage
539 unrelated to the water stress conditions. Such response has been reported previously in
540 Moriana et al (2013).

541 The averages TGR obtained in the experiments were generally very different for
542 the daily TGR threshold used in the irrigation scheduling, mainly during the rehydration
543 periods, but also when RDI-2 was scheduled with this parameter during phase II of the
544 2013 season (Table 2 and Materials and Methods). Such results are related to the
545 response with a great increase of TGR to isolated irrigation events, mainly in the
546 rehydration period. Therefore, during rehydration the daily TGR marked the moment
547 when irrigation is needed but it was not possible to control TGR around these values
548 yet. According to the present data $-5\mu\text{m day}^{-1}$ of daily TGR was an efficient threshold
549 which provided a slow but progressive rehydration. Then, in rehydration periods such as
550 the ones presented here, irrigation scheduling based only on daily TGR seems to be
551 adequate. Having said that, the daily TGR was not as useful during a period when a
552 water stress level is going to be performed. During the 2011 and 2012 seasons, the
553 almost no irrigation in RDIs in phase II produced a continuous decrease in maximum
554 diameter with nearly constant TGR. When RDI-2 was controlled during the 2013 season
555 using the daily TGR, the average TGR and maximum diameter showed a completely
556 different pattern than expected (the objective was $-10\mu\text{m day}^{-1}$, see Materials and
557 Methods). Although water potential in this treatment and period suggests low water
558 stress conditions, the maximum diameter and average TGR data indicated that “false
559 positives” were considered during this period. Giron et al (2015a) reported a decrease in
560 TGR with vapor pressure deficit (VPD) variations not related to water stress. Therefore,
561 when water stress is imposed, the daily TGR could be useful, but only if used in
562 addition to maximum diameter and average TGR. Daily TGR values below the

563 threshold should be the alert signal but this should be confirmed for the trend of
564 maximum diameter and average TGR.

565 Maximum diameters, in addition, permits the estimation of the beginning of pit
566 hardening when there is a significant fruit yield. TGR values around 0 as in 2012 and
567 2013 seasons, produces a period of no trunk growth in full irrigated conditions which
568 has been related with maximum endocarp size and the beginning of massive pit
569 hardening (Pérez-López et al., 2008).

570

571 *Effect of regulated deficit irrigation in table olive yield*

572 The yield response in RDI scheduling could be evaluated for the short and long term. In
573 the present work, there were no significant differences in yield, although there was a
574 clear trend towards a reduction in RDI-12 in comparison to Control and this could be
575 related to both effects. Long-term effects are mainly associated with floral induction and
576 tree growth. According to present data, the level of water stress did not affect the floral
577 induction in any of the treatments. On the other hand, data of soil cover at the end of the
578 experiment suggested that there was a slight reduction in crown volume, which could
579 explain part of the trends towards yield reductions in 2013 in the RDI-12 treatment.
580 Caruso et al (2013) suggested that, in young olive trees, the most important differences
581 between irrigation treatments were related to crown volume. In the present work, the
582 absence of pruning during 2012 and 2013 allowed estimating the influence of growth.
583 RDI-2 almost had a similar water status to Control during virtually the entire 2013
584 season and the reduction in yield could be likely related only to differences in crown
585 volume at the beginning of the season, this reduction was only around 9%. Therefore,
586 this level of water stress could be sustainable because the differences in yield are low
587 and in mature trees, pruning could level out the differences in seasonal growth.

588 Yield effects in the short term are processes that occur during the current season.
589 In the present work, the fruit growth and fruit drop are the two main effects described.
590 The fruit volume reduction in the RDIs treatments was recovered during the rehydration
591 period and the data suggest no effect on this yield component. Such results suggest that
592 the water stress level did not have a significant impact on the capacity of the fruit to
593 recover. In phase II, when these differences were measured, only the mesocarp was
594 growing and the reduction in fruit size was likely related to a reduction in mesocarp cell
595 size or in the number of cells. Rapoport et al (2004) reported differences in the cell size
596 but not in the cell number in olive trees during water stress conditions. Girón et al
597 (2015b) suggest that in olive trees, fruits are a stronger water sink than leaves at the end
598 of a moderate drought period, which could facilitate a complete recovery even in a slow
599 and/or short rehydration period. Such response is likely related with the traditional
600 recommendation of reduction of irrigation during pit hardening (Goldhamer, 1999).

601 Olive trees are very sensitive to drought conditions during phase I, when a
602 severe fruit drop could be caused by low levels of water stress (Morianana et al., 2003).
603 However, according to the present data of water status, number of inflorescences and
604 fruits, there was not fruit drop during this period. In this work, the fruit drop was
605 affected during phase II at shoot level, although the reduction was not always in
606 agreement with the one measured in the final yield. These differences between fruit
607 drop at shoot and total tree level could be related to sampling problems, since the level
608 of radiation was lower at the sampling height than at the upper part of the tree,
609 especially during 2012 or 2013, when there was no pruning. Radiation is an important
610 factor in the location of fruits in the tree. Several authors reported that olive trees tend to
611 accumulate fruit in the best illuminated part of hedgerow olive orchards (Pastor et al.,
612 2007; Cherbiy-Hoffmann et al., 2013).

613 The quantification of total fruit drop in relation with water stress is not easy.
614 Fruit drop in 2011 was negligible in all the treatments. During the 2013 season, the
615 reduction in yield in RDI-12 was probably related to differences in crown volume and
616 fruit drop. Since the yield reduction due to crown volume was around 9% in RDI-2 and
617 both RDIs have similar tree sizes, the fruit drop would produce around 16% of yield
618 reduction in RDI-12. During 2012, the moderate defoliation of the trees due to the
619 *Spilocaea* attack could have leveled the differences in crown volume and most of the
620 yield reduction in both RDIs could have been related to fruit drop. In this season, the
621 yield reduction was lower than expected in RDI-12 based on to the water stress level
622 and fruit drop at shoot level, while the opposite occurred at RDI-2. Unidentified factors
623 probably related to locations of the *Spilocaea* defoliation could be linked to these
624 disagreements. Considering all the data, the water stress level of the 2012 season and
625 RDI-12 in the 2013 season would be not advisable because of the excessive fruit drop.
626 However, further works will be performed in order to quantify the total fruit drop
627 related to water stress.

628 Yield quality was not significantly deteriorated in RDIs treatments, in fact, the
629 pulp:stone ratio improved. Since during the endocarp growth, phase I, the water stress
630 level was not significant, such differences should be related to mesocarp growth. In
631 addition, clearer trends for improvements in the pulp:stone ratio were measured in dry
632 weight than in fresh weight. Such results suggest that a moderate water stress level,
633 likely to occur during the recovery period, could enhance the accumulation of dry
634 matter. In other species the accumulation of carbohydrate is commonly reported when a
635 period of water stress is imposed before harvest (i.e., tomato, Johnstone et al., 2005;
636 vineyards, Girona et al. 2006). In olive trees, although the oil accumulation has been
637 reported as sensitive to water stress (Lavee and Wonder, 1991), some authors have

638 suggested that moderate water stress conditions could increase oil accumulation (Lavee
639 et al., 2007)

640

641 *Sustainable water stress levels and indicators in table olive trees*

642 Trunk growth rate (TGR), midday water potential (Ψ) and water stress integral (SI)
643 were sustainable indicators in the present work with a good correspondence with fruit
644 drop and fruit growth. Several authors described these indicators as useful in olive trees,
645 mainly Ψ (among others, Goldhamer, 1999, Moriana and Fereres, 2002, Gucci et al.,
646 2007, Iniesta et al 2009) but also TGR (Moriana and Fereres, 2002; Moriana et al.,
647 2013). However, there are few publications about threshold values, even in Ψ . In the
648 present work there was no clear results during phase I, because of the weather during
649 this period (which affected the TGR values) and the very small differences, if any, of
650 water stress level in the trees. The TGR threshold value during the recovery ($-5\mu\text{m day}^{-1}$)
651 ¹⁾ provided a similar response for the different years in all the RDIs treatments with a
652 slow, sometimes even incomplete, recovery of water status. Having said that, the
653 recovery was still sufficient, according to the previous discussion and no clear
654 differences in yield related to fruit size were observed. Moriana et al (2013) suggested
655 that this threshold value was useful during recovery and even phase II.

656 The water stress level during phase II was more variable between seasons and
657 the relationship with fruit drop would allow selecting a threshold value for future works.
658 According to data of the 2011 season, a fruit drop at the shoots of around 5% could be
659 acceptable, mainly when these values usually over-estimated the yield reduction. Then,
660 values of -2.2MPa in Ψ and $-2.0\text{MPa}\cdot\text{day}$ in SI could be useful as a first approach.
661 Dell'Amico et al (2012) and Girón et al (2015b) suggested water stress values between -
662 1.8MPa and -2.5MPa for olive trees. Rosecrance et al (2015) reported that a Ψ around -

663 2.2MPa increased oil yield and reduced shoot growth in olive trees. Although Girón et
664 al (2015b) suggested that SI could be complementary information to Ψ in the
665 description of water stress in olive trees, the present work suggests that, at least in
666 relation with fruit drop, both indicators provided similar information. Although TGR vs
667 fruit drop was weaker than in the other two indicators, values around $-10\mu\text{m day}^{-1}$ of
668 TGR average could be useful in future works.

669 Environment around the tree is a common source of error in all the water status
670 measurements. Although Control Ψ values in the three seasons were commonly very
671 similar around the threshold suggested, several dates in all the season, even in low fruit
672 load conditions, were lower than expected likely related with the extreme climatic
673 conditions. Moriana and Fereres (2004) and Moriana et al (2012) suggested though
674 there was an effect of evaporative demand in the Ψ values, such variations were small
675 and constant values could be used. This strategy is easy for commercial orchard
676 management but it could be over-estimated the water stress level of the trees. Fruit load
677 is other factor which could affect the values of these indicators, mainly TGR seasonal
678 patter according to the present work but also Ψ and, then, the stress integral. This
679 response in all these indicators has been reported in different works (Moriana et al 2003;
680 Martín-Vertedor et al., 2011) and could avoid with a good selection of the trees at the
681 orchard.

682 Usefulness of each indicator could be also analyzed according to the present
683 data. Although the present work suggests thresholds and management of TGR, further
684 works are needed to confirm such recommendations in other orchards. On the other
685 hand, the utility and ease of Ψ measurements and its capacity for using at commercial
686 orchard is clearly greater than TGR. Even for the present data, some conclusions of
687 previous work such as Moriana and Fereres (2002) about the higher accuracy of TGR vs

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688 Ψ are not clearly demonstrated. However one of the main advantages of the TGR which
689 is the continuous monitoring, suggest that it is advisable to continue with the line of
690 research in order to improve this methodology.

691

692 CONCLUSIONS

693 MDS was not a clear indicator of water stress in most of the dates in the three seasons.
694 Isolated values of MDS were difficult to interpret, even with the changes included in the
695 calculation. On the opposite, the average TGR presented good fit with fruit drop and
696 fruit size and could be useful for irrigation scheduling during phase II. However,
697 although the daily TGR should be used in the daily scheduling, the pattern of maximum
698 diameter and average TGR should be considered in a deficit approach as well. During
699 the recovery period, the daily TGR was a simple approach that permitted a good
700 management of the rehydration, although the average TGR was clearly different from
701 daily TGR due to the tree response to irrigation events.

702 Water stress level during the three years of experiments reduced fruit size during the
703 period of stress, but it was recovered during rehydration. The most severe water stress
704 levels increased fruit drop at shoot level, although it was not possible to quantify exactly
705 the effect on the total yield. According to the relationship obtained between fruit drop
706 and water stress indicators, the threshold values of midday stem water potential around -
707 2.2MPa, stress integral around -2.0MPa*day and average TGR around $-10\mu\text{m day}^{-1}$
708 during phase II could be sustainable in a RDI strategy. During the recovery period, a
709 daily TGR of $-5\mu\text{m day}^{-1}$ provided a slow but adequate rehydration in relation to fruit
710 size.

711

712 ACKNOWLEDGE

713 This research was supported by the Spanish Ministerio de Ciencia e Innovación
714 (MICINN), (AGL2010-19201-CO4-03 and AGL2013-45922-C2-1-R). Thanks are due
715 to J. Rodriguez and A. Montero for help with field measurements.

716

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844 **Figure captions**

845 ~~Fig. 1. Cumulative applied water during the three seasons of the experiment (a) 2011,~~
846 ~~(b)2012, (c) 2013. Vertical lines represent the pit hardening period (phase II).~~

847

848 ~~Fig. 2~~Fig. 1. Soil water content (θ , m^3m^{-3}) in 1 m depth along the season during the
849 three years of the experiment. (a) 2011, (b) 2012, (c) 2013. Each point is the average of
850 3 measurements. Vertical bars represent standard error. Vertical lines delimitate the pit
851 hardening period (phase II). Asterisks at the bottom indicate significant differences at
852 that date.

853

854 ~~Fig. 3~~Fig. 2. Midday stem water potential (MPa) along the season during the three years
855 of the experiment (a) 2011, (b) 2012, (c) 2013. Each symbol is the average of 6 data.
856 Vertical bars represent standard error. Vertical lines delimitate the pit hardening period
857 (phase II). Asterisks at the bottom indicate significant differences at that date.

858

859 ~~Fig. 4~~Fig. 3. Maximum leaf conductance during the three years of the experiment (a)
860 2011, (b) 2012, (c) 2013. Each symbol is the average of 12 data. Vertical bars represent
861 standard error. Vertical lines delimitate the pit hardening period (phase II). Asterisks at
862 the bottom indicate significant differences at that date.

863

864 ~~Fig. 5~~Fig. 4. Stress integral (SI) during the three years of the experiment. Each bar is the
865 average of 6 data. Vertical lines represented standard error. Different letters at the same
866 season indicate significant differences ($p < 0.05$, Tukey Test).

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869 | ~~Fig. 6~~Fig. 5. Seasonal pattern of Maximum diameter in the three years of the experiment
870 | (a) 2011, (b) 2012, (c) 2013. The slopes of these data are the Trunk growth rate (TGR).
871 | Each symbol is the average of 6 data. Vertical bars at the bottom represent rainfall.
872 | Vertical lines limited the period of pit hardening. Asteriks indicated the date when
873 | significant differences between TGR values were measured.

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875 | ~~Fig. 7~~Fig. 6. Seasonal pattern of Maximum daily shrinkage signal (MDS signal) in the
876 | three years of the experiment (a) 2011, (b) 2012, (c) 2013. Each symbol is the average
877 | of 6 data. Vertical lines limited the period of pit hardening. Asteriks indicated the date
878 | when significant differences between treatments were measured.

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880 | ~~Fig. 8~~Fig. 7. Shoot elongation during the three seasons of the experiment (a) 2011, (b)
881 | 2012, (c) 2013. Vertical bars represent percentage of soil cover at the beginning and the
882 | end of 2013 season (c). Left bars are Control data, center bars are RDI-2 data and right
883 | bars are RDI-12 data. Each symbol is the average of 60 data and each bar is the average
884 | of 6 data. Small vertical lines represent standard error. Long dash vertical lines
885 | delimitate phase II. Asteriks represent significant differences in shoot elongation data at
886 | that date ($p < 0.05$, Tukey Test). No significant differences were found in the percentage
887 | of soil cover.-Shoot elongation during the three seasons of the experiment (a) 2011, (b)
888 | 2012, (c) 2013. Vertical bars represent percentage of soil cover only at 2013 season (c).
889 | Each symbol is the average of 60 data and each bar is the average of 6 data. Small
890 | vertical lines represent standard error. Long dash vertical lines delimitate phase II.
891 | Asteriks represent significant differences in shoot elongation data at that date ($p < 0.05$,
892 | Tukey Test). No significant differences were found in the percentage of soil cover.

893

894 ~~Fig. 9. Seasonal pattern of the number of inflorescences during the three years of the~~
895 ~~experiment. (a) 2011, (b) 2012, (c) 2013. Each symbol is the average of 60 data.~~
896 ~~Vertical small lines represent standard error. Long dash vertical line delimited the phase~~
897 ~~II. Asteriks represent significant differences in shoot elongation data at that date~~
898 ~~($p < 0.05$, Tukey Test).~~

899
900 ~~Fig. 10. Changes in the number of fruit per shoots during the three seasons of the~~
901 ~~experiment. In each year, the number of fruits at the beginning and at the end of the~~
902 ~~phase II is presented. Each bar is the average of 60 data. Vertical lines represented~~
903 ~~standard error. Between brackets the percentage of fruit drop of each treatment. There~~
904 ~~were no significant differences in the number of fruits. Different letters in the~~
905 ~~percentage of fruit drop indicates significant differences between treatment in that~~
906 ~~season ($p < 0.05$, Tukey Test).~~

907
908 ~~Fig. 811. Relationship between fruit drop (%) and three different indicators. (a)~~
909 ~~Minimum Midday Stem Water Potential (Ψ) during phase II (% Fruit~~
910 ~~Drop= $134.4+140.4*\Psi+37.6*\Psi^2$, $R^2=0.84^{**}$, Standard Error=3.96%, n=9) (b) Stress~~
911 ~~Integral (SI) during phase II (% Fruits Drop= $3.1-0.19IS+0.02SI^2$, $R^2=0.84^{**}$, Standard~~
912 ~~Error=3.99%, n=9) (c) Average TGR. During phase II (% Fruit Drop= $4.74-$~~
913 ~~$0.41TGR+0.02TGR^2$, $R^2=0.68^*$, Standard Error=5.5, n=9). Horizontal line represents an~~
914 ~~acceptable percentage of fruit drop. Data with a circle are the ones measured during~~
915 ~~2013 season at RDIs treatments.~~

916
917 ~~Fig. 9. Seasonal pattern of fruit volume during the three years of the experiment. (a)~~
918 ~~2011, (b) 2012, (c) 2013. Vertical lines limited the period of phase II. Vertical bars are~~

919 | standard error. Asterisks indicate significant differences at that date (p<0.05, Tukey
920 | Test).

921 | ~~Fig. 12. Seasonal pattern of fruit volume during the three years of the experiment. (a)~~
922 | ~~2011, (b) 2012, (c) 2013. Vertical lines limited the period of phase II. Vertical bars are~~
923 | ~~standard error and it is not visible when symbol are greater. Asterisks indicate~~
924 | ~~significant differences at that date (p<0.05, Tukey Test).~~

925

926 | ~~Fig. 13~~Fig. 10. Relationship between three different indicators and the relative fruit
927 | volume of each treatment at the end of the phase II. (a) Minimum Middy Stem water
928 | potential during phase II (Ψ); Relative Fruit Volume= $119.7+12.7 \Psi$; $R^2=0.61^*$; Error
929 | Standard=3.6%; n=9 (b) Stress Integral (SI) during phase II; Relative fruit
930 | Volume= $100.5-0.35IS$; $R^2=0.72^{**}$; Error Standard =3.1 (c) Average TGR during phase
931 | II; Volume Relative Fruit = $95.2+0.47 TCT$; $R^2=0.75^{**}$; Error Standard =2.9; n=9. For
932 | each season, the relative fruit volume is the rate between the fruit volume of each
933 | treatment at the end of the phase II and the one of the Control.

934

935 Table 1. Irrigation amount (mm), reference evapotranspiration (ETo, mm) and rainfall
 936 (mm) during ~~each of the~~ the corresponding phenological stages of the three seasons ~~of~~
 937 ~~the~~ experiments. ~~The duration of each phenological stage is presented between brackets.~~
 938 ~~The beginning of phase I was considered in all the seasons at DOY (day of the year) 60.~~
 939 ~~In the columns ETo and rain, between brackets, the values of each variable from the~~
 940 ~~beginning of the irrigation period.~~
 941

		Irrigation			ETo	Rain
		Control	RDI-2	RDI-12		
2011	Ph I (97)	40	34	28	444 (130)	211(5)
	Ph II (78)	216	33	12	513	3
	Ph III (28)	43	78	75	137	37
	Postharv	0	0	0	270	163
2012	Ph I (113)	229	128	111	484 (425)	94(86)
	Ph II (60)	230	13	9	368	0
	Ph III(30)	81	30	41	147	1
	Postharv	0	0	0	137	115
2013	Ph I (116)	108	72	62	440(279)	173(9)
	Ph II(57)	193	89	0	361	0
	Ph III (30)	68	46	44	139	0
	Postharv	0	0	0	212	152

942
 943 The duration of each phenological stage is presented between brackets. The beginning
 944 of phase I was considered in all the seasons at DOY (day of the year) 60. In the columns
 945 ETo and rainfall, between brackets, the values of each variable from the beginning of
 946 the irrigation period. Ph I (Phase I), Ph II (Phase II), Ph III (Phase III), Postharv
 947 (Postharvest). Description of each phenological stage is provided in Materials and
 948 Methods.
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962 **Table 2.** Average trunk growth rate (TGR) during each phenological phase along the
 963 experiment. **The column “fruit load” indicated the rate between the Control yield of**
 964 **each year and the average biennial Control yield in the last 8 seasons (8 MT ha⁻¹).**
 965 **Different letters at the same year and phenological phase indicated significant**
 966 **differences between treatments (p<0.05, Tukey Test).**

Fruit load		Average TGR (μmday^{-1})			
		Control	RDI-2	RDI-12	
2011	30%	Phase I	7.9±5.6	7.3±8.8	16.7±2.2
		Phase II	11.9±4.5	-5.1±3.0	0.2±6.4
		Phase III	14.1±9.1	23.6±12.2	26.8±9.1
2012	83%	Phase I	-2.1±2.3	-2.6±5.5	-6.3±2.7
		Phase II	3.3±3.1a	-14.8±5.7b	-20.7±2.9b
		Phase III	6.1±3.4	31.5±12.4	28.2±7.1
2013	113%	Phase I	15.1±2.5	19.0±4.4	6.2±4.5
		Phase II	1.6±1.2	4.7±2.8	-5.9±4.8
		Phase III	3.8±1.9	7.4±3.2	9.8±6.0

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The column “fruit load” indicated the rate between the Control yield of each year and the average biennial Control yield in the last 8 seasons (8 MT ha⁻¹). When different letters are presented in the same row indicates significant differences between treatments (p<0.05, Tukey Test).

976 |
 977 | Table 3. Average maximum daily shrinkage signal (MDS signal) during each
 978 | phenological phase along the experiment. ~~The column “fruit load” indicated the rate~~
 979 | ~~between the Control yield of each year and the average biennial Control yield in the last~~
 980 | ~~8 seasons (8 MT ha⁻¹). Different letters at the same year and phenological phase~~
 981 | ~~indicated significant differences between treatments (p<0.05, Tukey Test).~~

	Fruit Load	MDS Signal			
			Control	RDI-2	RDI-12
2011	30%	Phase II	1.39±0.08	1.40±0.07	1.21±0.05
		Phase III	1.31±0.13	1.33±0.08	1.12±0.11
2012	83%	Phase II	1.08±0.14	1.19±0.07	1.20±0.16
		Phase III	1.00±0.14	1.28±0.07	1.33±0.13
2013	113%	Phase II	0.92±0.08	1.10±0.06	1.06±0.07
		Phase III	0.86±0.09b	1.14±0.08a	1.15±0.08a

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 986 | The column “fruit load” indicated the rate between the Control yield of each year and
 987 | the average biennial Control yield in the last 8 seasons (8 MT ha⁻¹). When different
 988 | letters are presented in the same row indicates significant differences between
 989 | treatments (p<0.05, Tukey Test). Different letters at the same year and phenological
 990 | phase indicated significant differences between treatments (p<0.05, Tukey Test).

991 Table 4. Features of the yield in the three seasons of the experiments. Yield (MT ha⁻¹),
 992 Number of fruit per Kg (fruits Kg⁻¹), Pulp/stone ratio in fresh weight (PS fresh),
 993 pulp/stone ratio in dry weight (PS dry), Mature Index (M.I.), Water Use Efficiency
 994 (WUE, Kg m⁻³). Different letter indicates significant differences at the same season and
 995 feature (p<0.05, Tukey Test). No statistical analysis were performed at the WUE
 996

2011	Yield	2.5±0.5	4.1±0.6	2.9±0.6	Formatted: English (U.S.)
	Fruit per Kg	188±5 b	206±5 a	190±4 ab	Formatted: English (U.K.)
	PS Fresh	6.2±0.1 a	5.7±0.1 b	6.1±0.1 a	Formatted: English (U.K.)
	PS Dry	2.8±0.1	2.5±0.1	2.8±0.1	Formatted: English (U.K.)
	M.I.	2.9±0.2 a	1.6±0.1 b	2.3±0.2 a	Formatted: English (U.K.)
	WUE	0.8	2.8	2.5	Formatted: English (U.K.)
2012	Yield	6.6±0.7	5.0±0.8	5.9±0.7	Formatted: English (U.K.)
	Fruit per Kg	233±13	249±10	240±10	Formatted: English (U.K.)
	PS Fresh	4.1±0.1	4.1±0.2	4.4±0.2	Formatted: English (U.K.)
	PS Dry	1.9±0.1	2.2±0.1	2.3±0.1	Formatted: English (U.K.)
	M.I.	0.8±0.2	0.8±0.1	0.9±0.1	Formatted: English (U.K.)
	WUE	1.2	2.9	3.7	Formatted: English (U.K.)
2013	Yield	9.0±1.1	8.2±0.6	6.7±0.7	Formatted: English (U.K.)
	Fruit per Kg	229±13	209±7	208±11	Formatted: English (U.K.)
	PS Fresh	4.6±0.3	5.2±0.2	5.0±0.3	Formatted: English (U.K.)
	PS Dry	2.1±0.1 b	2.5±0.1 a	2.3±0.1 ab	Formatted: English (U.K.)
	M.I.	1.0±0.1	1.3±0.2	1.1±0.1	Formatted: English (U.K.)
	WUE	2.4	4.0	6.3	Formatted: English (U.K.)

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		Control	RDI 2	RDI 12	Formatted: English (U.K.)
2011	Yield	2.5±0.5	4.1±0.6	2.9±0.6	
	Fruit per Kg	188±5 b	206±5 a	190±4 ab	
	PS Fresh	6.2±0.1 a	5.7±0.1 b	6.1±0.1 a	
	PS Dry	2.8±0.1	2.5±0.1	2.8±0.1	
	M.I.	2.9±0.2 a	1.6±0.1 b	2.3±0.2 a	
	WUE	0.8	2.8	2.5	
2012	Yield	6.6±0.7	5.0±0.8	5.9±0.7	
	Fruit per Kg	233±13	249±10	240±10	
	PS Fresh	4.1±0.1	4.1±0.2	4.4±0.2	
	PS Dry	1.9±0.1	2.2±0.1	2.3±0.1	
	M.I.	0.8±0.2	0.8±0.1	0.9±0.1	
	WUE	1.2	2.9	3.7	
2013	Yield	9.0±1.1	8.2±0.6	6.7±0.7	
	Fruit per Kg	229±13	209±7	208±11	
	PS Fresh	4.6±0.3	5.2±0.2	5.0±0.3	
	PS Dry	2.1±0.1 b	2.5±0.1 a	2.3±0.1 ab	
	WUE				

<u>M.I.</u>	<u>1.0±0.1</u>	<u>1.3±0.2</u>	<u>1.1±0.1</u>
<u>WUE</u>	<u>2.4</u>	<u>4.0</u>	<u>6.3</u>

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Yield (MT ha⁻¹), Number of fruit per Kg (fruits Kg⁻¹), Pulp/stone ratio in fresh weight (PS fresh), pulp/stone ratio in dry weight (PS dry), Mature Index (M.I.), Irrigation Water Use Efficiency (WUE, Kg m⁻³). Different letter indicates significant differences at the same season and feature (p<0.05, Tukey Test). No statistical analysis were performed at the WUE

Figure 1

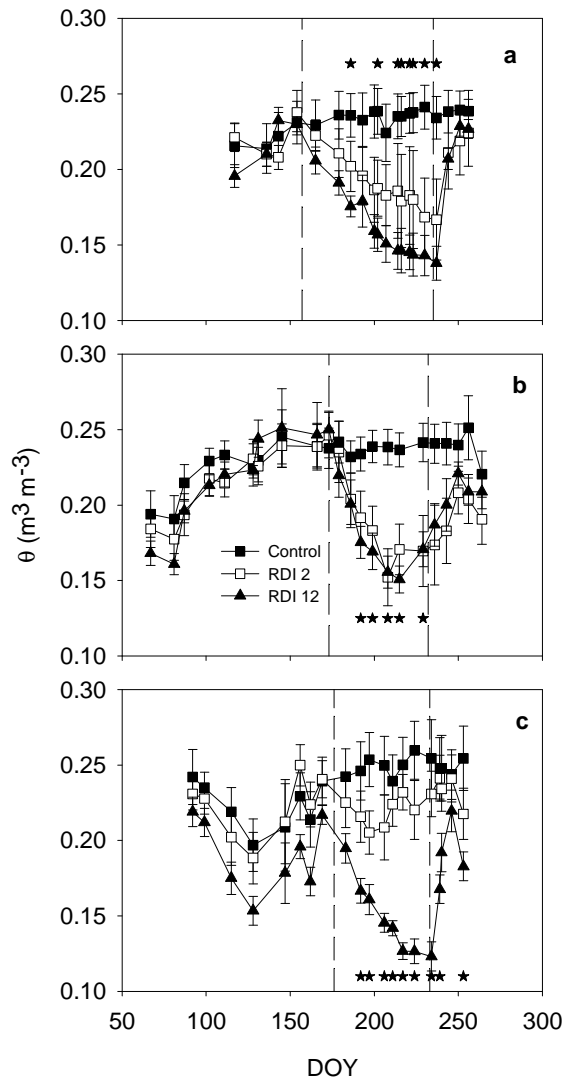


Fig. 1. Soil water content (θ , $\text{m}^3 \text{m}^{-3}$) in 1 m depth along the season during the three years of the experiment. (a) 2011, (b) 2012, (c) 2013. Each point is the average of 3 measurements. Vertical bars represent standard error. Vertical lines delimitate the pit hardening period (phase II). Asterisks at the bottom indicate significant differences at that date.

Figure 2

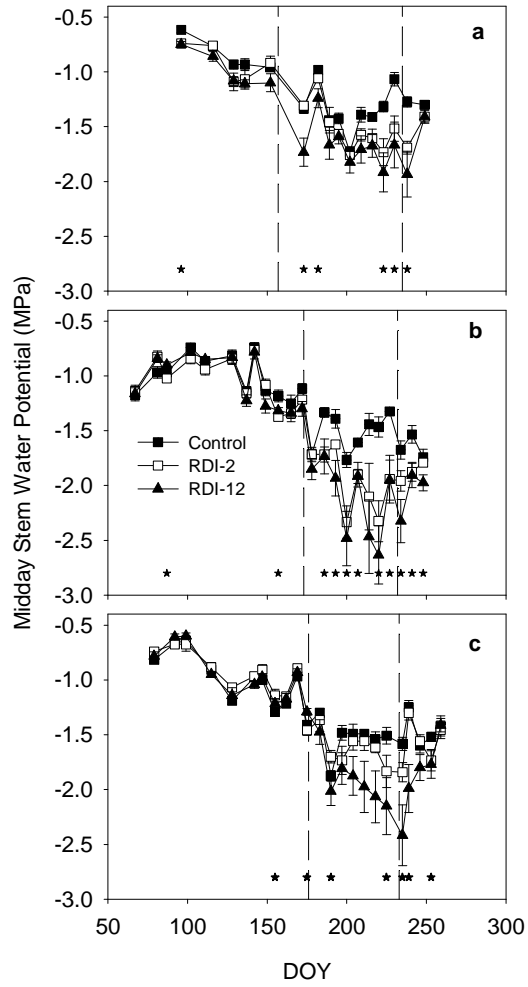


Fig. 2. Midday stem water potential (MPa) along the season during the three years of the experiment (a) 2011, (b) 2012, (c) 2013. Each symbol is the average of 6 data. Vertical bars represent standard error. Vertical lines delimitate the pit hardening period (phase II). Asterisks at the bottom indicate significant differences at that date.

Figure 3

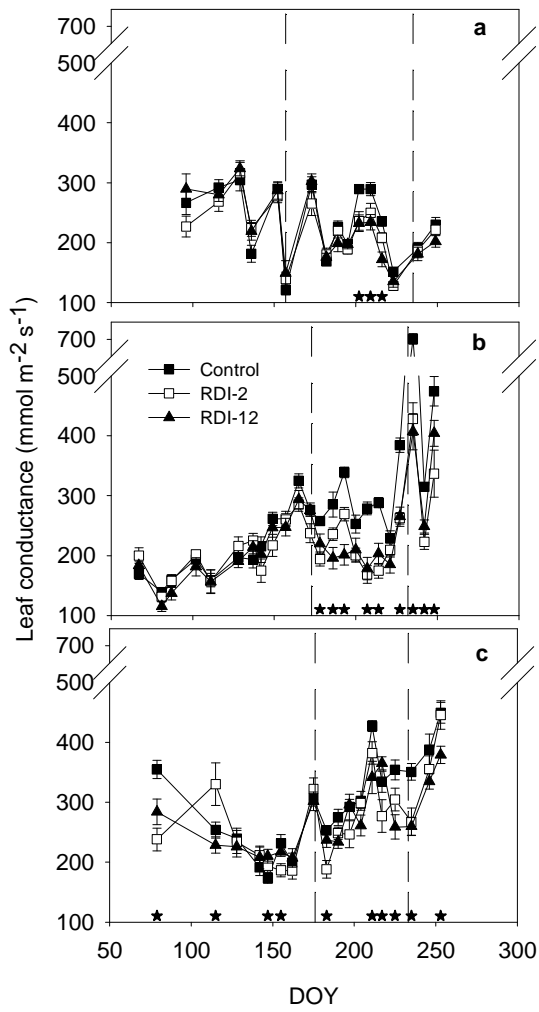


Fig. 3. Maximum leaf conductance during the three years of the experiment (a) 2011, (b) 2012, (c) 2013. Each symbol is the average of 12 data. Vertical bars represent standard error. Vertical lines delimitate the pit hardening period (phase II). Asterisks at the bottom indicate significant differences at that date.

Figure 4

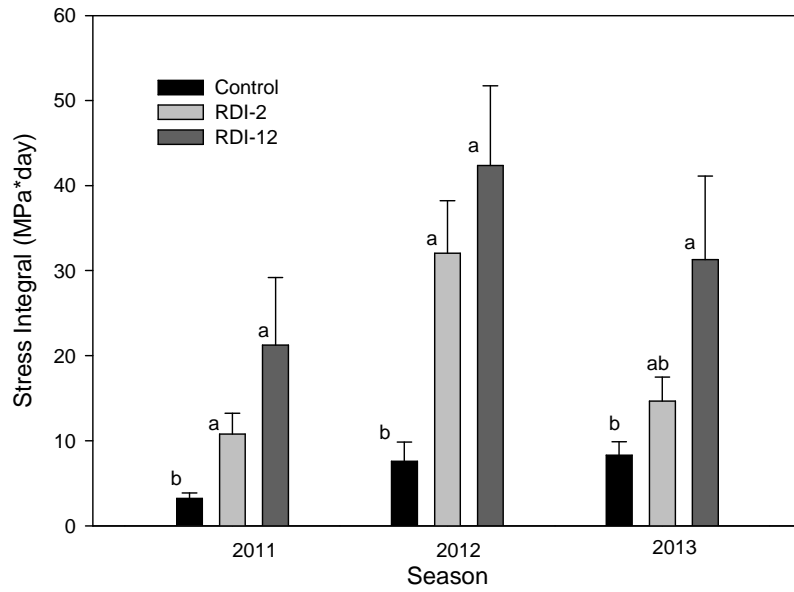


Fig. 4. Stress integral (SI) during the three years of the experiment. Each bar is the average of 6 data. Vertical lines represented standard error. Different letters at the same season indicate significant differences ($p < 0.05$, Tukey Test).

Figure 5

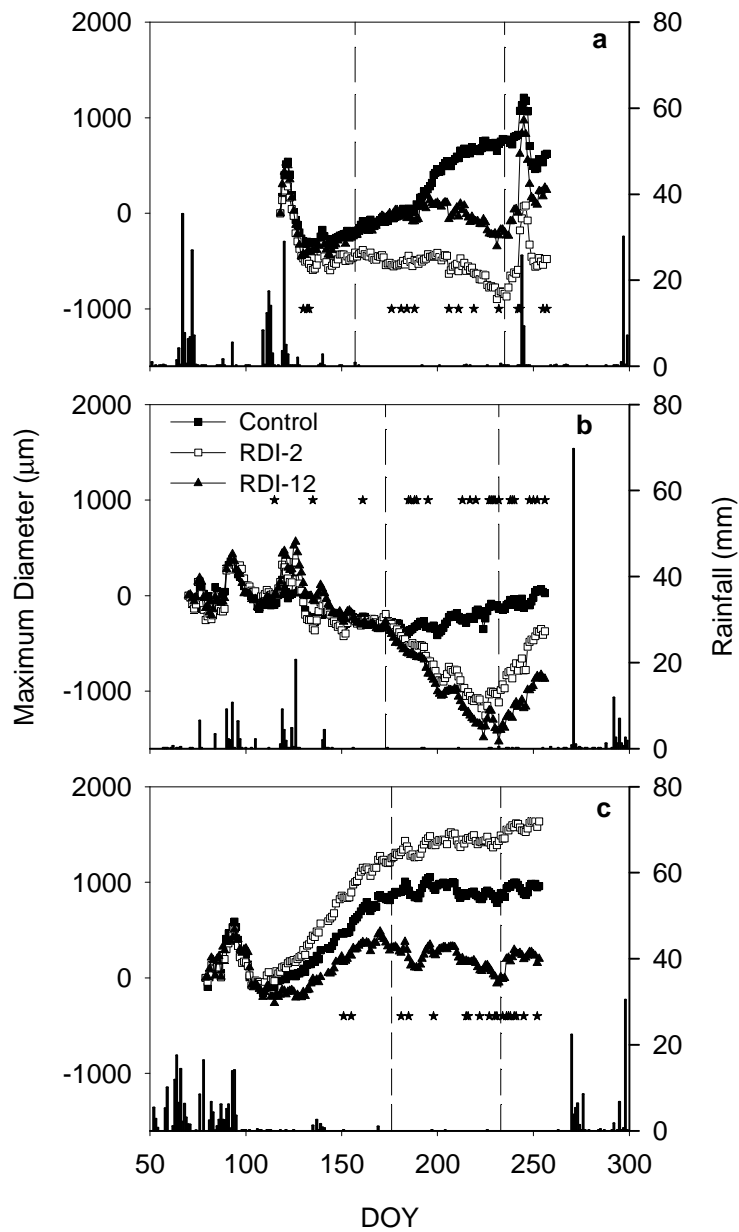


Fig. 5. Seasonal pattern of Maximum diameter in the three years of the experiment (a) 2011, (b) 2012, (c) 2013. The slopes of these data are the Trunk growth rate (TGR). Each symbol is the average of 6 data. Vertical bars at the bottom represent rainfall. Vertical lines limited the period of pit hardening. Asteriks indicated the date when significant differences between TGR values were measured.

Figure 6

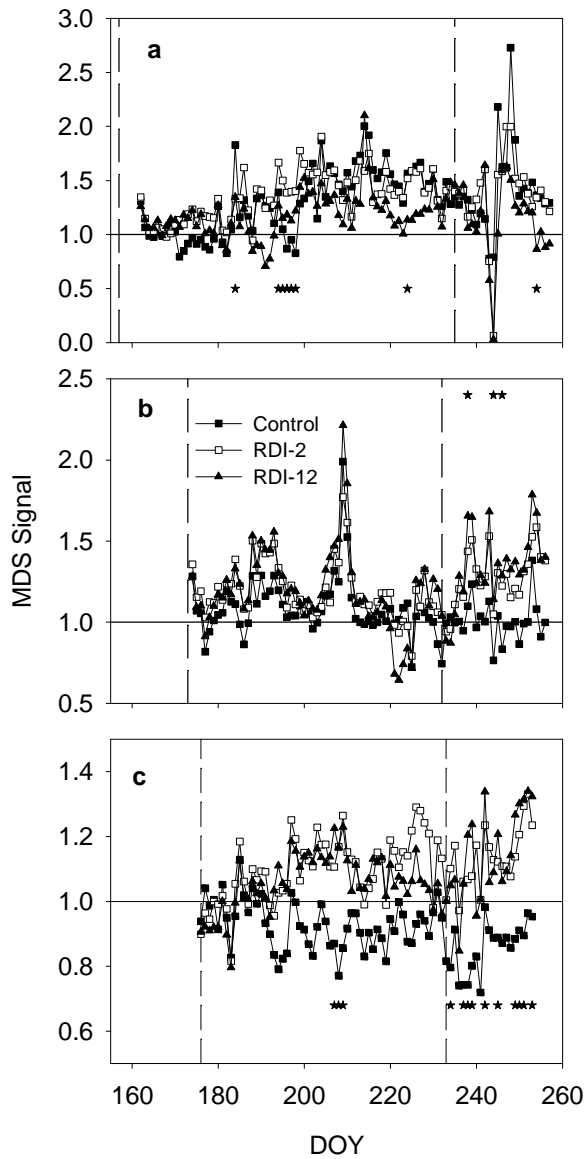


Fig. 6. Seasonal pattern of Maximum daily shrinkage signal (MDS signal) in the three years of the experiment (a) 2011, (b) 2012, (c) 2013. Each symbol is the average of 6 data. Vertical lines limited the period of pit hardening. Asteriks indicated the date when significant differences between treatments were measured.

Figure 7

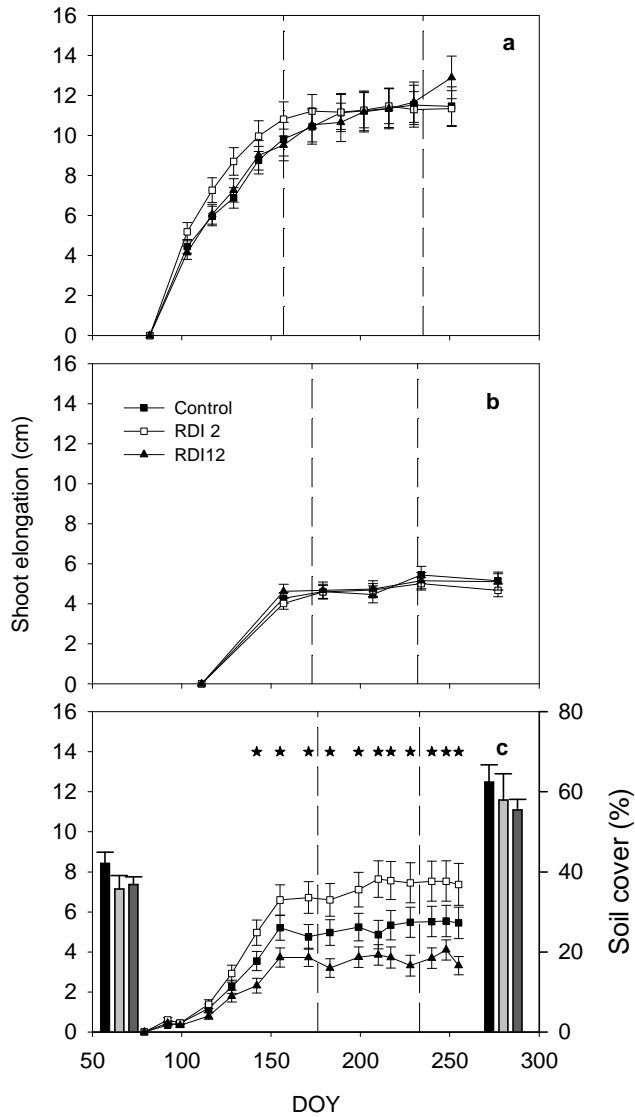


Fig. 7. Shoot elongation during the three seasons of the experiment (a) 2011, (b) 2012, (c) 2013. Vertical bars represent percentage of soil cover at the beginning and the end of 2013 season (c). Left bars are Control data, center bars are RDI-2 data and right bars are RDI-12 data. Each symbol is the average of 60 data and each bar is the average of 6 data. Small vertical lines represent standard error. Long dash vertical lines delimitate phase II. Asterisks represent significant differences in shoot elongation data at that date ($p < 0.05$, Tukey Test). No significant differences were found in the percentage of soil cover.

Figure 8

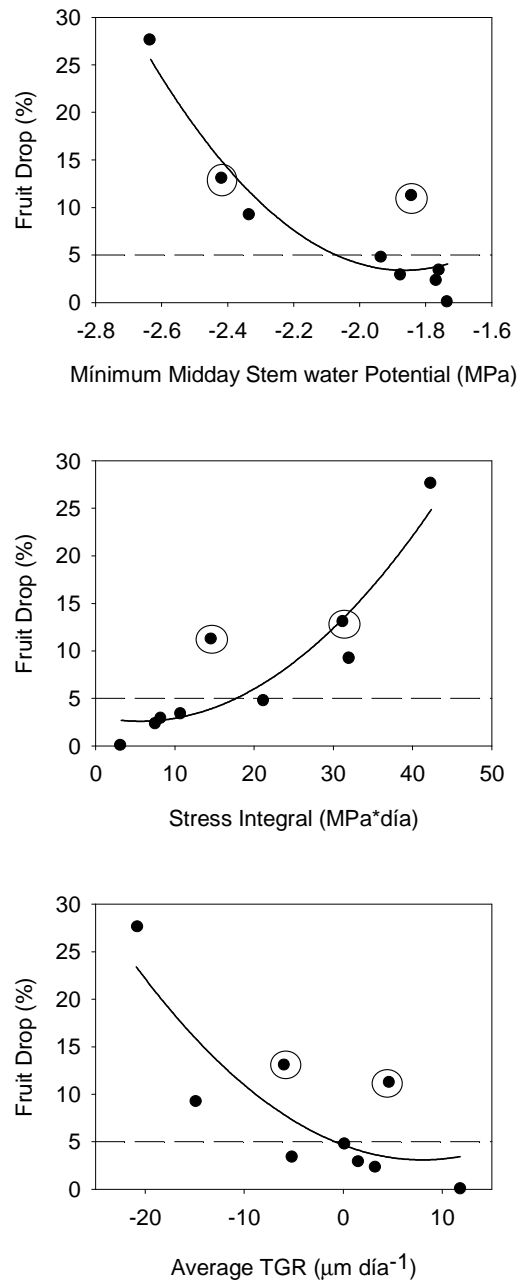


Fig. 8. Relationship between fruit drop (%) and three different indicators. (a) Minimum Midday Stem Water Potential (Ψ) during phase II (% Fruit Drop= $134.4+140.4*\Psi+37.6*\Psi^2$, $R^2=0.84^{**}$, Standard Error=3.96%, n=9) (b) Stress Integral (SI) during phase II (% Fruits Drop= $3.1-0.19SI+0.02SI^2$, $R^2=0.84^{**}$, Standard Error=3.99%, n=9) (c) Average TGR. During phase II (% Fruit Drop= $4.74-0.41TGR+0.02TGR^2$, $R^2=0.68^*$, Standard Error=5.5, n=9). Horizontal line represents an acceptable percentage of fruit drop. Data with a circle are the ones measured during 2013 season at RDIs treatments.

Figure 9

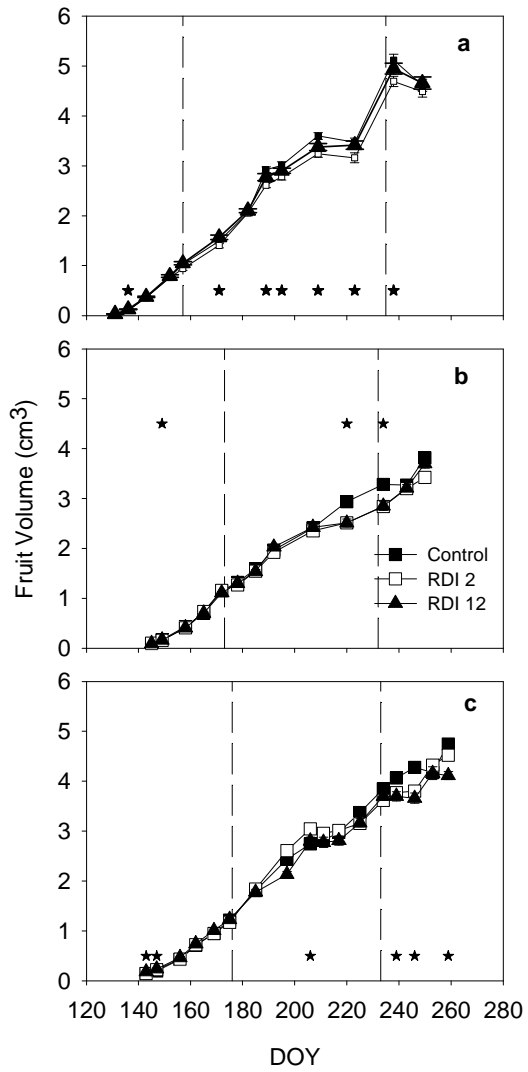


Fig. 9. Seasonal pattern of fruit volume during the three years of the experiment. (a) 2011, (b) 2012, (c) 2013. Vertical lines limited the period of phase II. Vertical bars are standard error. Asterisks indicate significant differences at that date ($p < 0.05$, Tukey Test).

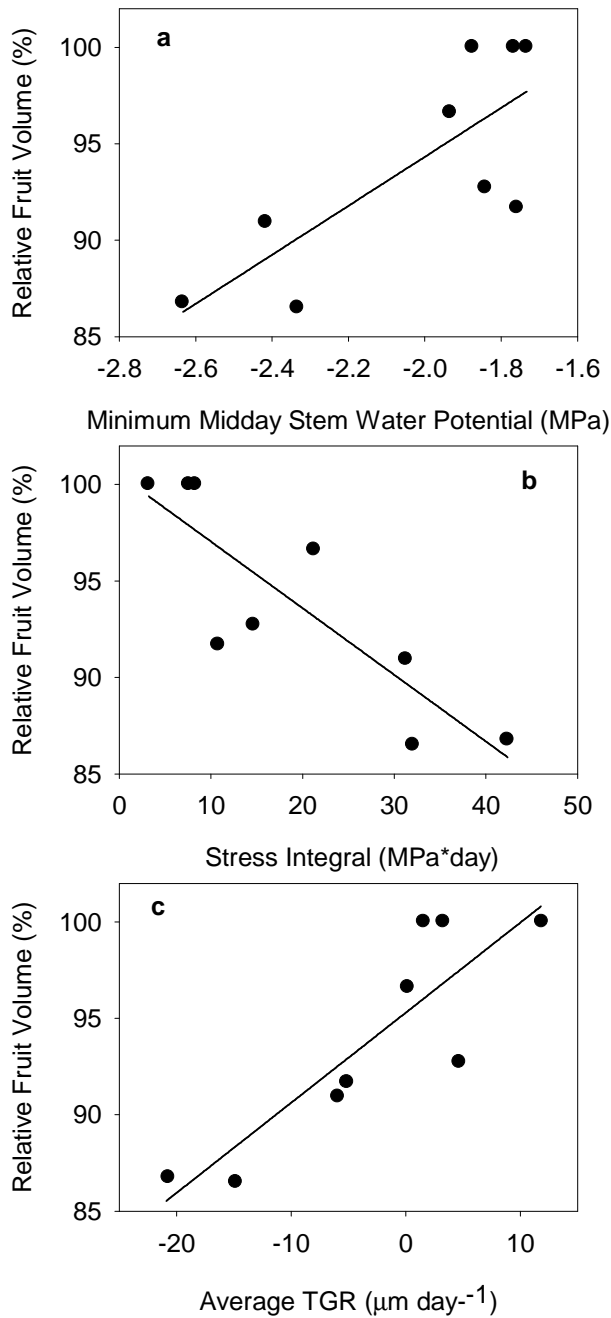


Fig. 10. Relationship between three different indicators and the relative fruit volume of each treatment at the end of the phase II. (a) Minimum Midday Stem water potential during phase II (Ψ); Relative Fruit Volume= $119.7+12.7 \Psi$; $R^2=0.61^*$; Error Standard= 3.6% ; $n=9$ (b) Stress Integral (SI) during phase II; Relative fruit Volume= $100.5-0.35IS$; $R^2=0.72^{**}$; Error Standard = 3.1 (c) Average TGR during phase II; Volume Relative Fruit = $95.2+0.47 TCT$; $R^2=0.75^{**}$; Error Standard = 2.9 ; $n=9$. For each season, the relative fruit volume is the rate between the fruit volume of each treatment at the end of the phase II and the one of the Control.

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2 **FEASIBILITY OF TRUNK DIAMETER FLUCTUATIONS IN THE**
3 **SCHEDULING OF REGULATED DEFICIT IRRIGATION FOR TABLE OLIVE**
4 **TREES WITHOUT REFERENCE TREES.**

5

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23 **Keywords: MDS, stress integral, TGR, water potential, water relations**

24 **Abstract**

25 Regulated deficit irrigation (RDI) results are affected by the actual water stress level
26 reached during the treatments. The irrigation scheduling based on water status
27 measurements, such as trunk diameter fluctuations, can control in an accurate way the
28 water restrictions. However, the number of works that use these indicators as isolate
29 parameter to control the schedule is scarce in general, and very scarce in olive trees.
30 Building on previous works, the aim of this article is to schedule an RDI strategy in
31 olive trees based on threshold values of maximum daily shrinkage (MDS) and trunk
32 growth rate (TGR) without reference trees. The experiment was performed in a 40
33 years-old table olive orchard (cv Manzanillo) in Seville (Spain) for three years (seasons
34 from 2011 to 2013). Three different irrigation treatments were considered in a
35 completely randomized block design. Control trees were over-irrigated (125% crop
36 evapotranspiration, ET_c) in order to obtain fully irrigated conditions. Water stress
37 conditions were applied during phase II (pit hardening) in the RDI-2 treatment or during
38 phase II and phase I (full bloom) in RDI-12. In both RDIs, a treatment recovery (phase
39 III) was performed before harvest. The trunk diameter fluctuation indicator was selected
40 according to the phenological stage. TGR was used in conditions of full irrigation or
41 moderate water stress level, such as phase I and phase III. TGR threshold values based
42 on previous works were selected: 20 $\mu\text{m day}^{-1}$, RDI-2; 10 $\mu\text{m day}^{-1}$, RDI-12 (phase I) and
43 -5 $\mu\text{m day}^{-1}$, both treatments, phase III. Only in one season RDI-2 was scheduled with
44 TGR values (-10 $\mu\text{m day}^{-1}$) during phase II. MDS threshold values were determined as
45 the ratio between measured MDS and fully irrigated MDS (the so called MDS signal).
46 The latter was estimated from a baseline. During phase II, RDI-2 was irrigated with a
47 threshold value of 0.9, while RDI-12 was irrigated with a threshold value of 0.75. MDS
48 signal was not useful for most of the period considered and it did not agree well with

49 fruit drop or fruit size. Conversely, the average of TGR during phase II was
50 significantly linked to fruit drop and fruit size, and so were the midday stem water
51 potential and stress integral. Recommendations about the management of TGR are
52 discussed. The water stress level in the experiments was moderate and no significant
53 differences in yield were found. However, the trend of yield reduction in RDI-12 was
54 likely related with a fruit drop and a reduction in crown volume. The yield quality did
55 not decrease in the RDIs treatments, on the contrary, pulp:stone ratio improved
56 significantly in some of the seasons.

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66 **INTRODUCTION**

67 Water scarcity around the world has been reduced the irrigation availability. Deficit
68 irrigation scheduling has been suggested in most of the fruit trees. Regulated deficit
69 irrigation (RDI) and partial root drying (PRD) are two different options of water deficit
70 management. In some fruit trees such as olive orchard, PRD has not improved the
71 results of RDI (Fernández et al. 2006). Since PRD needs more labor force, farmers
72 commonly prefer RDI scheduling. Regulated deficit irrigation (RDI) is an irrigation
73 scheduling method first reported in the 70's, based on differences in water stress
74 sensibility during the season (Chalmers et al., 1975). Traditional RDI works reduce the
75 amount of water provided during the most resistant phenological stages using the
76 percentage of crop evapotranspiration (Behboudian and Mills, 1997). Such strategy has
77 produced contradictory results. Similar recommendations in RDI scheduling caused
78 clear differences when they were performed at different sites (for instance, Girona
79 (2002) in peaches; Johnstone et al (2005) in tomato).

80 The irrigation season in olive trees could be divided into four different periods
81 according to water stress sensibility. The full bloom/fruit set period is considered the
82 most sensitive to drought conditions (Moriana et al, 2003), while the pit hardening
83 period is the most resistant (Goldhamer, 1999) in relation to yield. Oil accumulation is
84 also considered a sensitive period (Lavee and Wodner, 1991) though several works
85 suggest that moderate water stress increases oil production (Moriana et al, 2003; Lavee
86 et al., 2007). The postharvest period has not been studied, probably because in the main
87 producing zone this is the rainfall season. The results of irrigation works in olive trees
88 strongly suggest that different levels of water stress during the same phenological stage
89 change the effect on yield (Goldhamer, 1999; Moriana et al. 2003; Lavee et al., 2007).

90 Irrigation scheduling based on water status measurements could provide a useful
91 tool to control the water stress level in RDI. In this way, water stress conditions in
92 different sites will be comparable and RDI strategies could be easily performed out of
93 the experimental orchards. Trunk diameter fluctuations are daily cycles of swelling and
94 shrinking suggested in several fruit trees as an irrigation scheduling tool (Ortuño et al.,
95 2010). There are two indicators obtained from daily curves: maximum daily shrinkage
96 (MDS) and trunk growth rate (TGR) (Goldhamer and Fereres, 2001). In olive trees,
97 MDS is not reported as a useful indicator, while TGR is considered an early water stress
98 detector (Moriana and Fereres, 2002). There are only a few works using these
99 parameters in olive RDI. Recently, Moriana et al (2013) suggested a threshold value of -
100 $5\mu\text{m day}^{-1}$ of TGR during pit hardening and recovery in table olive trees and concluded
101 that MDS is not an easy tool in these conditions. However, Corell et al. (2013)
102 suggested a different approach to estimate MDS in order to reduce the influence of the
103 environment. Moriana et al (2013) used the reference tree approach (Goldhamer and
104 Fereres, 2001) which, in brief, requires trees to be fully irrigated at the orchard in order
105 to eliminate the environmental effect. These “reference trees” could affect the results
106 obtained. Threshold values based in previous experiments could change the usefulness
107 of some indicators such as MDS. The aim of this work is to combine previous results in
108 order to obtain an irrigation approach that uses only threshold values of MDS and TGR
109 without reference trees. This objective will be studied from two points of view. First,
110 the present work considers the ease of data interpretation. Secondly, the robust
111 relationship between both indicators and processes relate to yield results, such as fruit
112 drop or fruit size, will be studied as well.

113

114 **MATERIAL AND METHODS**

115 *Site description and experimental design*

116 Experiments were conducted at La Hampa, the experimental farm of the Instituto de
117 Recursos Naturales y Agrobiología (IRNAS-CSIC), located in Coria del Río near
118 Seville (Spain) (37°17'N, 6°3'W, 30 m altitude). The experiment was performed on 40-
119 year-old table olive trees (*Olea europaea* L cv Manzanillo) from the 2011 to the 2013
120 seasons. Tree spacing followed a 7m x 5m square pattern. Age and density of the
121 experimental orchard is the common of the zone in commercial orchards. The sandy
122 loam soil (about 2m deep) of the experimental site was characterised by a volumetric
123 water content of $0.33\text{m}^3\text{ m}^{-3}$ at saturation, $0.21\text{m}^3\text{m}^{-3}$ at field capacity and $0.1\text{m}^3\text{m}^{-3}$ at
124 permanent wilting point, and 1.30 (0-10cm) and 1.50 (10-120cm) g cm^{-3} bulk density.
125 Pest control, pruning and fertilization practices were those commonly used by growers
126 and weeds were removed chemically within the orchard, only in the last season no
127 pruning was performed. Drip irrigation was carried out at night using one lateral pipe
128 per row of trees and five emitters per plant, spaced 1m and delivering 8L h^{-1} each.
129 Micrometeorological data were obtained using an automatic weather station located
130 around 40 m from the experimental site. Although some recent works suggest simple
131 approaches for estimated daily reference evapotranspiration (ET_o) (i.e. Valipour 2014
132 and 2015), daily reference evapotranspiration (ET_o) was calculated using the Penman-
133 Monteith equation (Allen et al., 1998).

134 The experimental design was a completely randomized block experiment with 3
135 blocks and 3 irrigation treatments. Each treatment was carried out in a plot with two
136 trees located in a single row and two adjacent guard rows. There were 6 trunk diameter
137 fluctuation sensors per treatment and 1 sensor per tree.

138

139 *Irrigation phases considered*

140 The seasonal cycle of the trees was divided in 4 phases according to Rallo (1997):

- 141 • Phase I occurred from the shoot flush (around mid-February, day of the year
142 (DOY) 45) until the beginning of the period of massive pit hardening
143 (around DOY 169).
- 144 • Phase II occurred from massive pit hardening until the last week of August.
145 We considered that massive pit hardening began when a decrease in the
146 growth rate of the longitudinal diameter of the fruit was measured (Rapoport
147 et al., 2013). There is no morphological indicator to establish the end of this
148 phase. Therefore the end of this phase was established in order to obtain a
149 complete rehydration before harvest (around DOY 240).
- 150 • Phase III was the period of rehydration and occurred from the end of August
151 until harvest (around DOY 275).
- 152 • Phase IV. Postharvest. The typical date of the beginning of postharvest is the
153 beginning of October.

154

155 *Treatment description*

156 The water stress levels were estimated according to the trunk diameter
157 fluctuation indicators. Maximum daily shrinkage (MDS) was calculated as the
158 difference between the maximum daily diameter and the minimum daily diameter
159 (Goldhamer et al., 1999). Trunk growth rate (TGR) in day “n” was calculated as the
160 difference between the maximum daily diameter in day “n+1” minus that in day “n”
161 (Cuevas et al., 2010).

162 Severe water stress conditions reduce MDS in comparison to fully irrigated trees
163 (Moriani et al., 2000). Therefore, MDS was used only during phase II. Since MDS is
164 strongly related with evaporative demand, the parameter considered was the MDS

165 signal, which is the ratio between the measured MDS and the MDS in fully irrigated
166 conditions (Goldhamer and Fereres, 2001). Moriana et al (2011) reported that the
167 maximum temperature is the best meteorological measurements in order to estimate the
168 seasonal baseline in olive trees. The fully irrigated MDS was estimated from a baseline
169 obtained with the Corell et al (2013) approach. Corell et al (2013) suggested that
170 seasonal changes in the baseline are in the y-interception, while the slope is similar for
171 different years. Therefore, a small numbers of MDS data at the beginning of the
172 irrigation season could be used to estimate the seasonal baseline (Corell et al., 2013).

173 The TGR was used when moderate water stress levels were imposed because it
174 was reported as the most sensitive indicator to water deficit conditions (Moriana and
175 Fereres, 2002). Thresholds values from Moriana et al (2013) were used for phase I and
176 phase III. During the first two seasons, the MDS approach permitted a small amount of
177 irrigation in the RDIs and then both treatments presented a similar water status. For this
178 reason, only in the last year, the TGR was used in the irrigation scheduling of phase II
179 in one of the RDIs treatment.

180 All the treatments stopped the irrigation after harvest. During the rest of the
181 season irrigation treatments were:

- 182 • *Control treatment.* Irrigation requirements were determined according to
183 daily crop evapotranspiration (ET_c) calculated using the FAO method
184 (Allen et al., 1998). Crop coefficient values (K_c) were previously estimated
185 in the orchard (Fernández et al. 2006). In addition, a reduction according to
186 tree size was considered ($K_r=0.7$). Trees were irrigated daily with 125%
187 crop evapotranspiration (ET_c) until harvest.
- 188 • *Regulated Deficit Irrigation 2 (RDI-2).* No water stress was performed in
189 phase I. In this phase, a TGR threshold value of $20\mu\text{m day}^{-1}$ was

190 considered. The objective of this treatment during phase II was to create
191 moderate water stress conditions and a threshold value of 0.9 of MDS
192 signal was considered. Phase III was used as a rehydration period and the
193 objective was to perform a slow recovery with a $-5\mu\text{m day}^{-1}$ of TGR. Only
194 during the 2013 season, phase II was scheduled with TGR values, using -
195 $10\mu\text{m day}^{-1}$.

196 • *Regulated Deficit Irrigation 12 (RDI-12)*. Water stress conditions were
197 applied during phase I and II. During phase I, a moderate water stress level
198 was applied with a TGR threshold value of $10\mu\text{m day}^{-1}$. In phase II, severe
199 water stress conditions were the objective and the threshold values were
200 0.75 of the MDS signal. No water stress was applied in phase III and the
201 management was the same in this phase as in RDI-2.

202 *Estimation of irrigation needs*

203 Water needs in RDI trees is depended the water status of the tree. In water stress
204 conditions, crop evapotranspiration in these treatemnts is lower than the ones of
205 Control. Then, irrigation in RDI treatments was changed daily according to the variation
206 of the threshold value considered (MDS signal or TGR depending on the phenological
207 stage). Three levels of irrigation rate were estimated in relation to the maximum average
208 daily ET_c of the orchard. When the deviation of the threshold was very high, water
209 applied was around the maximum needs estimated in order to maintain water status
210 around the threshold. Otherwise, water applied was reduced in comparison to this
211 maximum or even no irrigated if the values obtained were higher than the threshold
212 considered. These estimations were calculated for the last ten years with the K_c and K_r
213 values used in the Control treatment. The percentages of variations selected were based
214 in previous works (Moriana et al., 2013). The irrigation rate varied as follows:

- 215 • The selected parameter changed less than 15% of the threshold value; 1mm
216 (a quarter of the maximum daily ET_c) of irrigation was applied on this date.
- 217 • The selected parameter changed 15-30% of the threshold value; 2mm (half
218 the maximum daily ET_c) of irrigation was applied on this date.
- 219 • The selected parameter changed more than 30% of the threshold value; 4mm
220 (the maximum average daily ET_c) of irrigation was applied on this date.

221 *Measurements*

222 All the measurements were made on the two measured trees located on each
223 plot. Trunk diameter fluctuations were measured throughout the experimental periods
224 using a set of linear variable displacement transducers (LVDT) (model DF±2.5mm,
225 accuracy ±10µm, Solartron Metrology, Bognor Regis, UK) attached to the main trunk,
226 with a special bracket made of Invar, an alloy of Ni and Fe with a thermal expansion
227 coefficient close to zero (Katerji et al., 1994). Trunk diameters were very similar
228 between treatments; Control 0.24±0.01m, RDI-2 0.24±0.01m, RDI-12 0.23±0.01m.
229 According to Corell et al (2013) such differences would not affect to the indicators
230 derivate from trunk diameter fluctuations. The height and position of the sensor was
231 similar in all the trees around 0.5 m height and in the north side of the trunk.
232 Measurements were taken every 10s and the datalogger (model CR10X with AM 416
233 multiplexer, Campbell Sci. Ltd., Logan, USA) was programmed to report 15 min
234 means. Since TGR daily data are very variable between days, the maximum diameter
235 (accumulative values of TGR) was used in the graphs. In addition, the average TGR
236 during the three periods considered were used in order to better describe the tree water
237 status.

238 The soil moisture was measured with a portable FDR sensor (HH2, Delta-T,
239 U.K.) with a calibration obtained in previous works. The measurements were made in

240 three plots per treatment. The access tubes for the FDR sensor were placed in the
241 irrigation line at about 30cm from an emitter, which is the distance where root activity
242 is higher (Fernández et al., 1991). The data were obtained at 1m depth with 10cm
243 intervals.

244 The water status of trees for each treatment was characterised by the midday
245 stem water potential (Ψ) and maximum leaf conductance. The leaves near the main
246 trunk were covered in aluminium foil at least one hour before measurements were taken.
247 The water potential was measured at midday in one leaf per tree, using the pressure
248 chamber technique (Scholander et al., 1965). The abaxial leaf conductance was
249 measured at around 10 a.m. in order to estimate the maximum daily value in two fully
250 expanded sunny leaves per tree with a steady state porometer (LICOR 1600, Lincoln,
251 Nebraska, U.S.A).

252 In order to describe the accumulative effect of the water deficit, the water stress
253 integral was calculated from the Ψ data (Myers, 1988) during the period of water stress
254 (equation 1). Equation 1 used a reference of -1.4MPa, which is the threshold value
255 suggested by Moriana et al (2012) in fully irrigated olive trees. All the values higher
256 than the reference were considered as equal to this. The expression used was:

257

$$258 \quad S\varphi = |\sum(\Psi - (-1.4)) * n| \quad (1)$$

259 where: $S\varphi$ is the stress integral

260 Ψ is the average midday stem water potential for any interval

261 n is the number of the days in the interval

262

263 At the beginning of each season, ten shoots per tree were selected randomly. For
264 each shoot, the length, number of inflorescences and fruits were measured periodically.

265 The fruit volume was estimated from a survey of ten fruits per tree in the same trees
266 where trunk diameter fluctuations were measured. Fruits were randomly selected on
267 each date of measurement. Two measurements were made for each fruit: the
268 longitudinal dimension and the transversal dimension (at the equatorial point).

269 The irrigation treatments were also evaluated from the point of view of quantity
270 and quality of yield. In table olives, the quality of the fruit is related to three parameters:
271 the pulp-stone ratio (PS ratio), mature index (MI) and the fruit size. High values of PS
272 ratio are considered an indicator of better quality fruits. A sample of 18 fruits per plot
273 was measured. Fruits were deboned and the fresh weight of the pulp and the stone were
274 measured. Pulp and stone were put into a stove at 70°C during 24 hours. Dry weight was
275 then measured. The fruit size was estimated in 6 trees per treatment with the number of
276 fruits per kilogram. The mature index (MI) of the fruits estimated the colour of the fruits
277 (Hermoso et al., 1997). A sample of 100 fruits in each plot were classified in 4 groups
278 according to the fruit colour: 0 green, 1 yellow-green, 2 lower than 50% of purple, 3
279 higher than 50% purple, 4 purple fruit. MI is calculated as a weighted average. In table
280 olive for green style, fruit at harvest should be an index around 1.

281 Productivity of irrigation was estimated with the irrigation water used efficiency
282 (WUE). WUE was calculated as the ratio between yield (in Kg ha⁻¹) and the amount of
283 water applied (in m³ ha⁻¹).

284 Data analyses were performed with ANOVA and the mean separation was made
285 via a Tukey's test using the Statistix (SX) program (8.0). Significant differences were
286 considered when p-level<0.05 in both tests. Calculations of the p-level were performed
287 considering the F-test of equality of variance. When conditions of equality of variance
288 were not obtained, a decrease in the degree of freedom and, therefore, more restrictive

289 p-value was calculated. The number of samples measured is specified in the text and
290 figures.

291

292 **RESULTS**

293 *Water relations*

294 The climatic and water data applied along the three years of experiment are presented in
295 Table 1. The duration of the different phenological stages was similar for all seasons
296 (Table 1). Phase II, the pit hardening period, was shorter but with less rain than phase I,
297 which is the common seasonal pattern. The amount of irrigation in Control trees was
298 almost linear from the end of phase I throughout the seasons, with the greatest
299 consumption during phase II. During this period, phase II, the daily water consumption
300 in Control trees was clear lower in 2011 (2.8 mm day^{-1}) than 2012 and 2013 (3.8 and
301 3.4 mm day^{-1} , respectively) likely related with the lower fruit load in this season. The
302 greatest seasonal volume of water applied during 2012 (540mm) in comparison with
303 2011 (299mm) and 2013 (369mm) was related to an important reduction of rainfall.
304 During 2012, the seasonal amount of rain was 302mm (only 94mm during spring),
305 while in 2011 and 2013 there were 521mm (211mm in spring) and 418mm (173mm in
306 spring), respectively. The Control values higher than field capacity and the horizontal
307 pattern of soil moisture (Fig. 1) suggest that this treatment was over-irrigated during
308 part of the seasons, mainly in phase II. RDI treatments provided a similar irrigation
309 amount in both treatments during 2011 and 2012 (Table 1), though there was a slightly
310 greater amount of water in RDI-2 during phase I. Such results were related to the
311 threshold value of MDS signal which was not reached during phase II in most of the
312 dates for both seasons. The change in the irrigation scheduling of RDI-2 during the last
313 year, the 2013 season, increased the amount of water of this treatment during phase II

314 (Table 1). There was no significant differences between RDI-2 and Control in this
315 season, but the pattern of soil moisture suggest no drainage but also no water stress
316 conditions in RDI-2.

317 The soil moisture was affected by the irrigation treatments (Fig. 1). The control
318 treatment slightly increased soil moisture from phase I to phase II, though values were
319 similar along the season and between years. On the other hand, RDI treatments
320 decreased sharply during phase II, with significant differences when compared to
321 Control, but not between RDIs (Fig. 1). Only in the 2013 season, when the irrigation
322 approach in RDI-2 was changed, significant differences between this and RDI-12 were
323 measured (Fig. 1c). In this season, there were no significant differences between
324 Control and RDI-2 (Fig. 1c).

325 Stem water potential (Ψ) data showed clear differences between the seasonal
326 water stress levels (Fig. 2). Control trees presented similar values in all the seasons with
327 a minimum value around -1.5MPa. Significant differences were found mainly between
328 Control and RDI-12, most of them during phase II. In most of the dates, RDI-2 was an
329 intermediate treatment, though in the 2011 and 2012 seasons, RDI-2 was very similar to
330 RDI-12 (Fig. 2a and b). Only during the 2013 season, when the irrigation approach was
331 changed in RDI-2, this treatment was nearer to Control than to RDI-12 (Fig. 2c).

332 The maximum leaf conductance (g) data presented clear differences between
333 seasons (Fig. 3). In 2011 (Fig. 3a), a low fruit load year, g was lower in all the
334 treatments in comparison with 2012 and 2013 (Fig. 3b and c), when the yield was
335 around the orchard average. As in previous parameters, most of the significant
336 differences were obtained between Control and RDI-12 and during phase II (Fig. 3).
337 However, throughout the season RDI-2 was significantly lower than Control at the end
338 of the stress period (Fig. 3). Only in the 2011 season, g data in RDIs treatment were not

339 significantly different to the Control ones at the end of the experiment. In 2013, RDI-2
340 was completely recovered at the end of the experiment according to g; while RDI-12
341 was still significantly lower (Fig. 3c).

342 The Stress Integral (SI) data indicated clearly the differences between seasons
343 and treatments (Fig. 4). SI at Control treatments was lower than 10MPa*day in all the
344 seasons, while the values in RDIs were at their maximum during 2012 and at their
345 minimum during the 2011 season. In all the seasons RDI-12 was significantly greater
346 than Control, while RDI-2 was significantly different to Control in 2011 and 2012 but
347 not in 2013. RDI-2 data were clearly lower than RDI-12 in all the seasons. The smallest
348 differences between RDI-2 and Control occurred during 2013.

349 The trunk growth rate (TGR) graph is difficult to read when a large number of
350 data are included. In order to improve the clarity of the results, the Maximum diameter
351 graph is presented (Fig. 6.), where the slope are TGR data. The average TGR values in
352 each phenological stage are included in Table 2. Seasonal patterns of Maximum
353 diameter were affected by fruit loads and spring rainfall. In 2011 and 2012, the rains
354 during phase I reduced the TGR in all the treatments (Table 2) and produced large
355 cycles of increase and decrease (Fig. 5). In these periods, irrigation scheduling based on
356 this parameter was extremely difficult because negative TGR were not related to water
357 stress. The significant differences in TGR during phase I for the two first seasons, 2011
358 and 2012, were not clearly related to the irrigation treatment (Fig. 5a and b). The rain
359 effect was similar in the 2013 season but since the wet period was concentrated at the
360 beginning of the year, a growth period was measured during phase I in all the
361 treatments. In the 2013 season, during this period there were clear trends of lower
362 values in TGR and RDI-12 than in Control and RDI-2 (Fig 6c). In 2013, TGR averages
363 were around the values suggested in the methodology for each treatment (Table 2).

364 Most of the significant differences in TGR were found during pit hardening,
365 phase II, in all the seasons (Fig. 5 and Table 2). In the 2011 season, TGR in Control was
366 clearly greater than in the rest of the years because of the low fruit load conditions (Fig
367 6a and Table 2). For the rest of the seasons and treatments, the TGR was around zero
368 during phase II, when water stress was not severe or clearly negative in severe
369 conditions of water stress, mainly during 2012 when the highest level of water stress
370 was detected (Fig. 5b, Table 2). No significant differences in TGR were found in 2011
371 and 2012 between RDIs treatments. In 2013, the TGR during phase II was significantly
372 different between RDI-2 and RDI-12 because of the changes in the irrigation scheduling
373 in the former (Fig. 5c). In this season, the average TGR of RDI-2 tended to greater
374 values than Control and it was clearly greater than $-10\mu\text{m day}^{-1}$, the suggested threshold
375 value in the methodology (Table 2).

376 In the recovery period, the average TGR was not around the threshold suggested
377 in the methodology for RDIs ($-5\mu\text{m day}^{-1}$) in any of the seasons (Table 2), though there
378 was a daily TGR value in these treatments lower than this value (Fig. 5). In this
379 recovery phase, although no significant differences were found in the average values,
380 there were actually some differences in the daily TGR values between Control and RDIs
381 and a clear trend of greater values in RDIs than in Control (Fig. 5 and Table 2).

382 The Maximum Daily Shrinkage signal (MDS signal) was the indicator for the
383 irrigation scheduling during phase II in the RDI treatments (except RDI-2 in the 2013
384 season). According to the approach for the estimated MDS signal (see Materials and
385 Methods), only MDS signal data for phase II and phase III are presented because the
386 ones for phase I were used for estimating the baseline. Although some significant
387 differences between Control and RDIs were measured, mainly at phase III, the seasonal
388 pattern of MDS signal was very confusing (Fig. 6). Even daily Control data were clearly

389 higher than 1 mainly during the 2011 season (a low fruit load year) (Fig.7), although the
390 average values of MDS signal in Control during the 2012 and 2013 seasons were
391 around 1 (Table 3). However, the clear deviations of daily data from 1 for the Control
392 MDS signal suggest that the baseline did not represent accurately enough the
393 environmental effect. An example of this is the period from DOY 207 to DOY 212 in
394 the 2012 season, when a large increase in the MDS signal was measured. Since these
395 large values occurred in all the treatments, they can be most probably attributed to the
396 environment. One of the possible reasons are the large changes in maximum
397 temperature, from 32°C in DOY 207 to 27°C in DOY 209 and the later increase to 35° C
398 in DOY 211.

399 The MDS signal did not reflect easily the effect of the water stress. The
400 threshold values considered in the methodology were not usually reached (Fig. 6) and
401 this produced small irrigation amounts, which were very similar between RDI
402 treatments. During short periods in phase II of the 2011 and 2012 seasons, the daily
403 MDS signal in RDI treatments tended to show greater values than Control and only at
404 the end of 2012 RDI-12 presented lower values than Control. The average MDS signal
405 values also were greater during RDI treatments than during Control in both seasons. In
406 the 2013 season, the MDS signal pattern for both RDIs tended to show clearly much
407 greater daily and average values than Control during phase II (Fig. 6c and Table 3).
408 Moreover, during this season RDI-12 presented a decrease in MDS signal at the end of
409 Phase II that was reversed during the rehydration phase (Fig. 6c).

410

411 *Vegetative growth*

412 Shoot elongation presented a similar seasonal pattern in all the years of the experiment
413 with an active growth during phase I and almost no growth in the rest of the season

414 (Fig. 7). The increase in fruit load reduced the shoot elongation; thus the growth during
415 the lowest yield season (2011, Fig. 7a) was half that of the highest (2013, Fig. c).
416 During the 2011 (Fig. 7a) and 2012 (Fig. 7b) seasons, shoot elongation was not affected
417 by the water stress and the maximum values of growth were not significantly different
418 between treatments. Only during the 2013 season, RDI-2 was significantly greater than
419 RDI-12 during most of phase I, while Control was an intermediate treatment without
420 such differences (Fig. 7c). In this season, there were significant differences between
421 treatments at the end of the period of active growth. During phase II, period without
422 active growth, the maximum elongation was significantly different, just as it happened
423 during phase I (Fig. 7c). In all the seasons, there was no active growth during the
424 recovery phase in any of the treatments.

425 The percentage of soil cover was estimated only at the beginning and the end of
426 the 2013 season (Fig. 7c). No significant differences were found in this parameter. The
427 Control values (42%) tended to show a greater soil cover than the RDIs treatment,
428 which were almost equal at the beginning of the season (36% RDI-2 and 37% RDI-12).
429 The increase of soil cover at the end of the season was similar in all the treatments and
430 around 20%, slightly higher in Control and RDI-2 (22%) than in RDI-12 (18%).

431

432 *Fruit development*

433 Numbers of inflorescences per shoot were measured along the season and from pit
434 hardening (phase II) the number of fruit per inflorescence was counted. There were no
435 significant differences between treatments in both parameters (data not shown). The
436 fruit drop was estimated as the different between the number of fruit per inflorescence at
437 the beginning and the end of pit hardening. The percentage of fruit drop data were
438 compared to the minimum midday stem water potential (Fig. 2), stress integral (Fig. 4)

439 and average TGR data (Table 2) obtained during phase II (Fig. 8). All the relationships
440 were significant, though the ones with the midday stem water potential (Fig. 8a) and
441 stress integral (Fig. 8b) were the most robust. In all the indicators, the increase of water
442 stress enlarged the percentage of fruit drop. However, since the best fit was a quadratic
443 adjustment, the rate of fruit drop increased with water stress. No multi-variable
444 adjustment presented best fit. Data of fruit drop in RDI-2 in the 2013 season were
445 greater than expected for all three indicators, while the ones for RDI-12 in the same
446 season were not (data circled in Fig. 8).

447 The fruit volume increased in Control trees almost linearly in the three seasons
448 of the experiment (Fig. 9). The differences in fruit volume between seasons in Control
449 trees were lower than expected according to the fruit load. During 2011, with around
450 30% of historical average fruit load, the fruit volume was similar to 2013, around 115%
451 of the fruit load. In all the years, significant differences were measured between Control
452 and RDIs during phase II (always lower than 15%), but at the end of the rehydration
453 period, the fruit volume was completely recovered. Only in the RDI-12 in the 2013
454 season, slightly but significant differences were found (Fig. 9c). No significant
455 differences were found between RDIs. When the fruit volume at the end of the phase II
456 is normalized for the Control treatment, on that day there was a robust relationship
457 between the data and the three indicators used in Fig. 8. The best fit in the three
458 indicators was linear and there was a reduction of the relative fruit volume with the
459 increase in water stress (Fig. 10). The multi-variable fit was not better than the ones
460 presented in Fig. 10. Although significant relationships were found with the three
461 indicators, Stress integral (SI) and average TGR (Fig. 10 b and c) were better than the
462 minimum midday stem water potential (Ψ , Fig. 10 a). In addition, the slope of the
463 relationship in SI and Average TGR was sharper than the ones of the Ψ .

464

465 *Yield quality and quantity*

466 Table 4 presents the main features of the yield in the three years of the experiment.
467 Yield in Control trees was increased along the experiment. In 2011 season, the Control
468 yield was around 30% of the average yield of the orchard (8MT ha⁻¹), which then was
469 considered a low fruit load in this season. In the 2012 and 2013 seasons, the yield was
470 around or slightly greater than the average in Control trees. There were no significant
471 differences in yield between irrigation treatments. In the 2011 season, RDI-2 produced
472 the greater yield, while RDI-12 and Control were almost similar. The 2012 season was,
473 in theory, a high fruit load season according to the fruit load of the previous year.
474 However, the attack of *Spilocaea oleagina* (Cast.) Hughes reduced the fruit load in all
475 the treatments. During the 2012 season, RDIs tended to lower yield values than Control.
476 In 2013, RDI-2 was closer to Control yield than to RDI-12.

477 Fruit size is an important feature of the yield quality in table olives. Changes in
478 fruit load did not clearly affect the fruit size (Table 4). There were no significant
479 differences between treatments according to water stress conditions. Only in the 2011
480 season, RDI-2 presented significantly smaller fruit than Control and RDI-12. These
481 latter results were not confirmed in the following years, nor were there clear trends
482 suggesting a reduction in the fruit size at the end of the rehydration period.

483 The Pulp/Stone ratio is other important characteristic in table olives. A large
484 pulp/stone ratio is valued in the industrial processing after harvest. The Pulp/Stone ratio
485 was sensitive to the fruit load. In conditions of low fruit load (2011 season), Control
486 trees had a greater ratio than in high fruit load (2013 season). Only in the 2013 season,
487 the water stress increased significantly the pulp/stone ratio of RDIs in comparison to
488 Control (in dry weight), although a similar trend was measured in the 2012 season in

489 dry and fresh weight (Table 4). Differences in the 2011 season could be due more to the
490 low fruit load than to the water stress.

491 The Mature Index (MI) estimates the fruit color. An MI higher than 1, indicates
492 that there is a purple zone in the fruit which is not valued in “green table olives”. There
493 were no significant effects of water stress on MI. The irrigation water use efficiency
494 (WUE) was greater in RDIs than in Control trees in all the seasons. There were no clear
495 differences between RDIs in 2011 and 2012. Only in the 2013 season, when RDI-1
496 irrigation scheduling was changed, RDI-12 tended towards clearly greater values than
497 RDI-1.

498 **DISCUSSION**

499 *Irrigation scheduling based on trunk diameter fluctuations indicators.*

500 Changes in the methodology of MDS signal did not improve the usefulness of the
501 indicator in comparison to previous work (i.e. Moriana et al 2013). The baselines
502 calculated according to Corell et al (2013) generated values in Control trees that, on
503 average, were near to 1 only in high fruit load seasons, although they changed widely in
504 daily values. On the other hand, in the high fruit load season the MDS signals were
505 clearly higher than 1 in both RDIs. Only in an isolated period at the end of phase II,
506 RDI-12 presented an MDS signal lower than 1. These values slightly higher than 1
507 indicate, in most cases, moderate water stress conditions. However, according to the
508 present result, the MDS signal as a unique indicator is not reliable.

509 The trunk growth rate (TGR) could be a useful indicator in irrigation scheduling.
510 According to the present data, the average TGR is a good tool for predicting the water
511 stress conditions, similarly to the stem water potential, but using daily TGR and
512 Maximum diameters could also facilitate irrigation scheduling. Rains are the main
513 problem in the use of this methodology and produce long periods, even on the dry days,

514 when trunk diameter fluctuations are useless because there is a trunk shrinkage
515 unrelated to the water stress conditions. Such response has been reported previously in
516 Moriana et al (2013).

517 The averages TGR obtained in the experiments were generally very different for
518 the daily TGR threshold used in the irrigation scheduling, mainly during the rehydration
519 periods, but also when RDI-2 was scheduled with this parameter during phase II of the
520 2013 season (Table 2 and Materials and Methods). Such results are related to the
521 response with a great increase of TGR to isolated irrigation events, mainly in the
522 rehydration period. Therefore, during rehydration the daily TGR marked the moment
523 when irrigation is needed but it was not possible to control TGR around these values
524 yet. According to the present data $-5\mu\text{m day}^{-1}$ of daily TGR was an efficient threshold
525 which provided a slow but progressive rehydration. Then, in rehydration periods such as
526 the ones presented here, irrigation scheduling based only on daily TGR seems to be
527 adequate. Having said that, the daily TGR was not as useful during a period when a
528 water stress level is going to be performed. During the 2011 and 2012 seasons, the
529 almost no irrigation in RDIs in phase II produced a continuous decrease in maximum
530 diameter with nearly constant TGR. When RDI-2 was controlled during the 2013 season
531 using the daily TGR, the average TGR and maximum diameter showed a completely
532 different pattern than expected (the objective was $-10\mu\text{m day}^{-1}$, see Materials and
533 Methods). Although water potential in this treatment and period suggests low water
534 stress conditions, the maximum diameter and average TGR data indicated that “false
535 positives” were considered during this period. Giron et al (2015a) reported a decrease in
536 TGR with vapor pressure deficit (VPD) variations not related to water stress. Therefore,
537 when water stress is imposed, the daily TGR could be useful, but only if used in
538 addition to maximum diameter and average TGR. Daily TGR values below the

539 threshold should be the alert signal but this should be confirmed for the trend of
540 maximum diameter and average TGR.

541 Maximum diameters, in addition, permits the estimation of the beginning of pit
542 hardening when there is a significant fruit yield. TGR values around 0 as in 2012 and
543 2013 seasons, produces a period of no trunk growth in full irrigated conditions which
544 has been related with maximum endocarp size and the beginning of massive pit
545 hardening (Pérez-López et al., 2008).

546

547 *Effect of regulated deficit irrigation in table olive yield*

548 The yield response in RDI scheduling could be evaluated for the short and long term. In
549 the present work, there were no significant differences in yield, although there was a
550 clear trend towards a reduction in RDI-12 in comparison to Control and this could be
551 related to both effects. Long-term effects are mainly associated with floral induction and
552 tree growth. According to present data, the level of water stress did not affect the floral
553 induction in any of the treatments. On the other hand, data of soil cover at the end of the
554 experiment suggested that there was a slight reduction in crown volume, which could
555 explain part of the trends towards yield reductions in 2013 in the RDI-12 treatment.
556 Caruso et al (2013) suggested that, in young olive trees, the most important differences
557 between irrigation treatments were related to crown volume. In the present work, the
558 absence of pruning during 2012 and 2013 allowed estimating the influence of growth.
559 RDI-2 almost had a similar water status to Control during virtually the entire 2013
560 season and the reduction in yield could be likely related only to differences in crown
561 volume at the beginning of the season, this reduction was only around 9%. Therefore,
562 this level of water stress could be sustainable because the differences in yield are low
563 and in mature trees, pruning could level out the differences in seasonal growth.

564 Yield effects in the short term are processes that occur during the current season.
565 In the present work, the fruit growth and fruit drop are the two main effects described.
566 The fruit volume reduction in the RDI treatments was recovered during the rehydration
567 period and the data suggest no effect on this yield component. Such results suggest that
568 the water stress level did not have a significant impact on the capacity of the fruit to
569 recover. In phase II, when these differences were measured, only the mesocarp was
570 growing and the reduction in fruit size was likely related to a reduction in mesocarp cell
571 size or in the number of cells. Rapoport et al (2004) reported differences in the cell size
572 but not in the cell number in olive trees during water stress conditions. Girón et al
573 (2015b) suggest that in olive trees, fruits are a stronger water sink than leaves at the end
574 of a moderate drought period, which could facilitate a complete recovery even in a slow
575 and/or short rehydration period. Such response is likely related with the traditional
576 recommendation of reduction of irrigation during pit hardening (Goldhamer, 1999).

577 Olive trees are very sensitive to drought conditions during phase I, when a
578 severe fruit drop could be caused by low levels of water stress (Moriani et al., 2003).
579 However, according to the present data of water status, number of inflorescences and
580 fruits, there was not fruit drop during this period. In this work, the fruit drop was
581 affected during phase II at shoot level, although the reduction was not always in
582 agreement with the one measured in the final yield. These differences between fruit
583 drop at shoot and total tree level could be related to sampling problems, since the level
584 of radiation was lower at the sampling height than at the upper part of the tree,
585 especially during 2012 or 2013, when there was no pruning. Radiation is an important
586 factor in the location of fruits in the tree. Several authors reported that olive trees tend to
587 accumulate fruit in the best illuminated part of hedgerow olive orchards (Pastor et al.,
588 2007; Cherbiy-Hoffmann et al., 2013).

589 The quantification of total fruit drop in relation with water stress is not easy.
590 Fruit drop in 2011 was negligible in all the treatments. During the 2013 season, the
591 reduction in yield in RDI-12 was probably related to differences in crown volume and
592 fruit drop. Since the yield reduction due to crown volume was around 9% in RDI-2 and
593 both RDIs have similar tree sizes, the fruit drop would produce around 16% of yield
594 reduction in RDI-12. During 2012, the moderate defoliation of the trees due to the
595 *Spilocaea* attack could have leveled the differences in crown volume and most of the
596 yield reduction in both RDIs could have been related to fruit drop. In this season, the
597 yield reduction was lower than expected in RDI-12 based on to the water stress level
598 and fruit drop at shoot level, while the opposite occurred at RDI-2. Unidentified factors
599 probably related to locations of the *Spilocaea* defoliation could be linked to these
600 disagreements. Considering all the data, the water stress level of the 2012 season and
601 RDI-12 in the 2013 season would be not advisable because of the excessive fruit drop.
602 However, further works will be performed in order to quantify the total fruit drop
603 related to water stress.

604 Yield quality was not significantly deteriorated in RDIs treatments, in fact, the
605 pulp:stone ratio improved. Since during the endocarp growth, phase I, the water stress
606 level was not significant, such differences should be related to mesocarp growth. In
607 addition, clearer trends for improvements in the pulp:stone ratio were measured in dry
608 weight than in fresh weight. Such results suggest that a moderate water stress level,
609 likely to occur during the recovery period, could enhance the accumulation of dry
610 matter. In other species the accumulation of carbohydrate is commonly reported when a
611 period of water stress is imposed before harvest (i.e., tomato, Johnstone et al., 2005;
612 vineyards, Girona et al. 2006). In olive trees, although the oil accumulation has been
613 reported as sensitive to water stress (Lavee and Wonder, 1991), some authors have

614 suggested that moderate water stress conditions could increase oil accumulation (Lavee
615 et al., 2007)

616

617 *Sustainable water stress levels and indicators in table olive trees*

618 Trunk growth rate (TGR), midday water potential (Ψ) and water stress integral (SI)
619 were sustainable indicators in the present work with a good correspondence with fruit
620 drop and fruit growth. Several authors described these indicators as useful in olive trees,
621 mainly Ψ (among others, Goldhamer, 1999, Moriana and Fereres, 2002, Gucci et al.,
622 2007, Iniesta et al 2009) but also TGR (Moriana and Fereres, 2002; Moriana et al.,
623 2013). However, there are few publications about threshold values, even in Ψ . In the
624 present work there was no clear results during phase I, because of the weather during
625 this period (which affected the TGR values) and the very small differences, if any, of
626 water stress level in the trees. The TGR threshold value during the recovery ($-5\mu\text{m day}^{-1}$)
627 ¹⁾ provided a similar response for the different years in all the RDIs treatments with a
628 slow, sometimes even incomplete, recovery of water status. Having said that, the
629 recovery was still sufficient, according to the previous discussion and no clear
630 differences in yield related to fruit size were observed. Moriana et al (2013) suggested
631 that this threshold value was useful during recovery and even phase II.

632 The water stress level during phase II was more variable between seasons and
633 the relationship with fruit drop would allow selecting a threshold value for future works.
634 According to data of the 2011 season, a fruit drop at the shoots of around 5% could be
635 acceptable, mainly when these values usually over-estimated the yield reduction. Then,
636 values of -2.2MPa in Ψ and $-2.0\text{MPa}\cdot\text{day}$ in SI could be useful as a first approach.
637 Dell'Amico et al (2012) and Girón et al (2015b) suggested water stress values between -
638 1.8MPa and -2.5MPa for olive trees. Rosecrance et al (2015) reported that a Ψ around -

639 2.2MPa increased oil yield and reduced shoot growth in olive trees. Although Girón et
640 al (2015b) suggested that SI could be complementary information to Ψ in the
641 description of water stress in olive trees, the present work suggests that, at least in
642 relation with fruit drop, both indicators provided similar information. Although TGR vs
643 fruit drop was weaker than in the other two indicators, values around $-10\mu\text{m day}^{-1}$ of
644 TGR average could be useful in future works.

645 Environment around the tree is a common source of error in all the water status
646 measurements. Although Control Ψ values in the three seasons were commonly very
647 similar around the threshold suggested, several dates in all the season, even in low fruit
648 load conditions, were lower than expected likely related with the extreme climatic
649 conditions. Moriana and Fereres (2004) and Moriana et al (2012) suggested though
650 there was an effect of evaporative demand in the Ψ values, such variations were small
651 and constant values could be used. This strategy is easy for commercial orchard
652 management but it could be over-estimated the water stress level of the trees. Fruit load
653 is other factor which could affect the values of these indicators, mainly TGR seasonal
654 patten according to the present work but also Ψ and, then, the stress integral. This
655 response in all these indicators has been reported in different works (Moriana et al 2003;
656 Martín-Vertedor et al., 2011) and could avoid with a good selection of the trees at the
657 orchard.

658 Usefulness of each indicator could be also analyzed according to the present
659 data. Although the present work suggests thresholds and management of TGR, further
660 works are needed to confirm such recommendations in other orchards. On the other
661 hand, the utility and ease of Ψ measurements and its capacity for using at commercial
662 orchard is clearly greater than TGR. Even for the present data, some conclusions of
663 previous work such as Moriana and Fereres (2002) about the higher accuracy of TGR vs

664 Ψ are not clearly demonstrated. However one of the main advantages of the TGR which
665 is the continuous monitoring, suggest that it is advisable to continue with the line of
666 research in order to improve this methodology.

667

668 **CONCLUSIONS**

669 MDS was not a clear indicator of water stress in most of the dates in the three seasons.
670 Isolated values of MDS were difficult to interpret, even with the changes included in the
671 calculation. On the opposite, the average TGR presented good fit with fruit drop and
672 fruit size and could be useful for irrigation scheduling during phase II. However,
673 although the daily TGR should be used in the daily scheduling, the pattern of maximum
674 diameter and average TGR should be considered in a deficit approach as well. During
675 the recovery period, the daily TGR was a simple approach that permitted a good
676 management of the rehydration, although the average TGR was clearly different from
677 daily TGR due to the tree response to irrigation events.

678 Water stress level during the three years of experiments reduced fruit size during the
679 period of stress, but it was recovered during rehydration. The most severe water stress
680 levels increased fruit drop at shoot level, although it was not possible to quantify exactly
681 the effect on the total yield. According to the relationship obtained between fruit drop
682 and water stress indicators, the threshold values of midday stem water potential around -
683 2.2MPa, stress integral around -2.0MPa*day and average TGR around -10 $\mu\text{m day}^{-1}$
684 during phase II could be sustainable in a RDI strategy. During the recovery period, a
685 daily TGR of -5 $\mu\text{m day}^{-1}$ provided a slow but adequate rehydration in relation to fruit
686 size.

687

688 **ACKNOWLEDGE**

689 This research was supported by the Spanish Ministerio de Ciencia e Innovación
690 (MICINN), (AGL2010-19201-CO4-03 and AGL2013-45922-C2-1-R). Thanks are due
691 to J. Rodriguez and A. Montero for help with field measurements.

692

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820 **Figure captions**

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823 Fig. 1. Soil water content (θ , m^3m^{-3}) in 1 m depth along the season during the three
824 years of the experiment. (a) 2011, (b) 2012, (c) 2013. Each point is the average of 3
825 measurements. Vertical bars represent standard error. Vertical lines delimitate the pit
826 hardening period (phase II). Asterisks at the bottom indicate significant differences at
827 that date.

828

829 Fig. 2. Midday stem water potential (MPa) along the season during the three years of
830 the experiment (a) 2011, (b) 2012, (c) 2013. Each symbol is the average of 6 data.
831 Vertical bars represent standard error. Vertical lines delimitate the pit hardening period
832 (phase II). Asterisks at the bottom indicate significant differences at that date.

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834 Fig. 3. Maximum leaf conductance during the three years of the experiment (a) 2011,
835 (b) 2012, (c) 2013. Each symbol is the average of 12 data. Vertical bars represent
836 standard error. Vertical lines delimitate the pit hardening period (phase II). Asterisks at
837 the bottom indicate significant differences at that date.

838

839 Fig. 4. Stress integral (SI) during the three years of the experiment. Each bar is the
840 average of 6 data. Vertical lines represented standard error. Different letters at the same
841 season indicate significant differences ($p < 0.05$, Tukey Test).

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843

844 Fig. 5. Seasonal pattern of Maximum diameter in the three years of the experiment (a)
845 2011, (b) 2012, (c) 2013. The slopes of these data are the Trunk growth rate (TGR).
846 Each symbol is the average of 6 data. Vertical bars at the bottom represent rainfall.
847 Vertical lines limited the period of pit hardening. Asteriks indicated the date when
848 significant differences between TGR values were measured.

849

850 Fig. 6. Seasonal pattern of Maximum daily shrinkage signal (MDS signal) in the three
851 years of the experiment (a) 2011, (b) 2012, (c) 2013. Each symbol is the average of 6
852 data. Vertical lines limited the period of pit hardening. Asteriks indicated the date when
853 significant differences between treatments were measured.

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855 Fig. 7. Shoot elongation during the three seasons of the experiment (a) 2011, (b) 2012,
856 (c) 2013. Vertical bars represent percentage of soil cover at the beginning and the end of
857 2013 season (c). Left bars are Control data, center bars are RDI-2 data and right bars are
858 RDI-12 data. Each symbol is the average of 60 data and each bar is the average of 6
859 data. Small vertical lines represent standard error. Long dash vertical lines delimitate
860 phase II. Asteriks represent significant differences in shoot elongation data at that date
861 ($p < 0.05$, Tukey Test). No significant differences were found in the percentage of soil
862 cover.

863

864 Fig. 8. Relationship between fruit drop (%) and three different indicators. (a) Minimum
865 Midday Stem Water Potential (Ψ) during phase II (% Fruit
866 Drop = $134.4 + 140.4 * \Psi + 37.6 * \Psi^2$, $R^2 = 0.84^{**}$, Standard Error = 3.96%, $n = 9$) (b) Stress
867 Integral (SI) during phase II (% Fruits Drop = $3.1 - 0.19IS + 0.02SI^2$, $R^2 = 0.84^{**}$, Standard
868 Error = 3.99%, $n = 9$) (c) Average TGR. During phase II (% Fruit Drop = $4.74 -$

869 $0.41TGR+0.02TGR^2$, $R^2=0.68^*$, Standard Error=5.5, n=9). Horizontal line represents an
870 acceptable percentage of fruit drop. Data with a circle are the ones measured during
871 2013 season at RDIs treatments.

872

873 Fig. 9. Seasonal pattern of fruit volume during the three years of the experiment. (a)
874 2011, (b) 2012, (c) 2013. Vertical lines limited the period of phase II. Vertical bars are
875 standard error. Asterisks indicate significant differences at that date ($p<0.05$, Tukey
876 Test).

877

878 Fig. 10. Relationship between three different indicators and the relative fruit volume of
879 each treatment at the end of the phase II. (a) Minimum Midday Stem water potential
880 during phase II (Ψ); Relative Fruit Volume= $119.7+12.7 \Psi$; $R^2=0.61^*$; Error
881 Standard=3.6%; n=9 (b) Stress Integral (SI) during phase II; Relative fruit
882 Volume= $100.5-0.35IS$; $R^2=0.72^{**}$; Error Standard =3.1 (c) Average TGR during phase
883 II; Volume Relative Fruit = $95.2+0.47 TCT$; $R^2=0.75^{**}$; Error Standard =2.9; n=9. For
884 each season, the relative fruit volume is the rate between the fruit volume of each
885 treatment at the end of the phase II and the one of the Control.

886

887 Table 1. Irrigation amount (mm), reference evapotranspiration (ETo, mm) and rainfall
 888 (mm) during the corresponding phenological stages of the three seasons experiments.

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891 The duration of each phenological stage is presented between brackets. The beginning
 892 of phase I was considered in all the seasons at DOY (day of the year) 60. In the columns
 893 ETo and rainfall, between brackets, the values of each variable from the beginning of

		Irrigation			ETo	Rain
		Control	RDI-2	RDI-12		
2011	Ph I (97)	40	34	28	444 (130)	211(5)
	Ph II (78)	216	33	12	513	3
	Ph III (28)	43	78	75	137	37
	Postharv	0	0	0	270	163
2012	Ph I (113)	229	128	111	484 (425)	94(86)
	Ph II (60)	230	13	9	368	0
	Ph III(30)	81	30	41	147	1
	Postharv	0	0	0	137	115
2013	Ph I (116)	108	72	62	440(279)	173(9)
	Ph II(57)	193	89	0	361	0
	Ph III (30)	68	46	44	139	0
	Postharv	0	0	0	212	152

894 the irrigation period. Ph I (Phase I), Ph II (Phase II), Ph III (Phase III), Postharv
 895 (Postharvest). Description of each phenological stage is provided in Materials and
 896 Methods.

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910 Table 2. Average trunk growth rate (TGR) during each phenological phase along the
 911 experiment.
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Fruit load		Average TGR (μmday^{-1})			
		Control	RDI-2	RDI-12	
2011	30%	Phase I	7.9±5.6	7.3±8.8	16.7±2.2
		Phase II	11.9±4.5	-5.1±3.0	0.2±6.4
		Phase III	14.1±9.1	23.6±12.2	26.8±9.1
2012	83%	Phase I	-2.1±2.3	-2.6±5.5	-6.3±2.7
		Phase II	3.3±3.1a	-14.8±5.7b	-20.7±2.9b
		Phase III	6.1±3.4	31.5±12.4	28.2±7.1
2013	113%	Phase I	15.1±2.5	19.0±4.4	6.2±4.5
		Phase II	1.6±1.2	4.7±2.8	-5.9±4.8
		Phase III	3.8±1.9	7.4±3.2	9.8±6.0

915
 916 The column “fruit load” indicated the rate between the Control yield of each year and
 917 the average biennial Control yield in the last 8 seasons (8 MT ha⁻¹). When different
 918 letters are presented in the same row indicates significant differences between
 919 treatments (p<0.05, Tukey Test).
 920

921 Table 3. Average maximum daily shrinkage signal (MDS signal) during each
 922 phenological phase along the experiment.

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926 The column “fruit load” indicated the rate between the Control yield of each year and
 927 the average biennial Control yield in the last 8 seasons (8 MT ha⁻¹). When different

	Fruit Load		MDS Signal		
			Control	RDI-2	RDI-12
2011	30%	Phase II	1.39±0.08	1.40±0.07	1.21±0.05
		Phase III	1.31±0.13	1.33±0.08	1.12±0.11
2012	83%	Phase II	1.08±0.14	1.19±0.07	1.20±0.16
		Phase III	1.00±0.14	1.28±0.07	1.33±0.13
2013	113%	Phase II	0.92±0.08	1.10±0.06	1.06±0.07
		Phase III	0.86±0.09b	1.14±0.08a	1.15±0.08a

928 letters are presented in the same row indicates significant differences between
 929 treatments (p<0.05, Tukey Test).

930 Table 4. Features of the yield in the three seasons of the experiments.
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		Control	RDI 2	RDI 12
2011	Yield	2.5±0.5	4.1±0.6	2.9±0.6
	Fruit per Kg	188±5 b	206±5 a	190±4 ab
	PS Fresh	6.2±0.1 a	5.7±0.1 b	6.1±0.1 a
	PS Dry	2.8±0.1	2.5±0.1	2.8±0.1
	M.I.	2.9±0.2 a	1.6±0.1 b	2.3±0.2 a
	WUE	0.8	2.8	2.5
2012	Yield	6.6±0.7	5.0±0.8	5.9±0.7
	Fruit per Kg	233±13	249±10	240±10
	PS Fresh	4.1±0.1	4.1±0.2	4.4±0.2
	PS Dry	1.9±0.1	2.2±0.1	2.3±0.1
	M.I.	0.8±0.2	0.8±0.1	0.9±0.1
	WUE	1.2	2.9	3.7
2013	Yield	9.0±1.1	8.2±0.6	6.7±0.7
	Fruit per Kg	229±13	209±7	208±11
	PS Fresh	4.6±0.3	5.2±0.2	5.0±0.3
	PS Dry	2.1±0.1 b	2.5±0.1 a	2.3±0.1 ab
	M.I.	1.0±0.1	1.3±0.2	1.1±0.1
	WUE	2.4	4.0	6.3

939 Yield (MT ha⁻¹), Number of fruit per Kg (fruits Kg⁻¹), Pulp/stone ratio in fresh weight
 940 (PS fresh), pulp/stone ratio in dry weight (PS dry), Mature Index (M.I.), Irrigation
 941 Water Use Efficiency (WUE, Kg m⁻³). Different letter indicates significant differences
 942 at the same season and feature (p<0.05, Tukey Test). No statistical analysis were
 943 performed at the WUE
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