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Title: Limitations and usefulness of Maximum Daily Shrinkage (MDS) and trunk growth rate (TGR) indicators in the irrigation scheduling of table olive trees.

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Abstract: Maximum daily trunk shrinkage (MDS) is the most popular indicator derived from trunk diameter fluctuations in most fruit trees and has been reported to be one of the earliest signs in the detection of water stress. However, in some species such as olive trees (Olea europaea L), MDS does not usually change in water stress conditions and trunk growth rate (TGR) has been suggested as better indicator. Most of this lack of sensitivity to drought conditions has been related to the relationship between the MDS and the water potential. This curvilinear relationship produces an uncertain zone were great variations of water potential do not imply any changes of MDS. The MDS signal, the ratio between measured MDS and estimated MDS with full irrigation, has been thought to be a better indicator than MDS, as it reduces the effect of the environment. New methodologies for estimation of the MDS signal in olive trees have been recently suggested. On the other hand, though literature results suggest an effect of environment in TGR values, there are not clear relationship between this indicator and meteorological data. The aims of this work are, on one hand, to study the improvements of the baseline approach in the MDS signal and on the other study the influence of several meteorological variables in TGR. Three years' data from an irrigation experiment were used in to carry out the MDS analysis and six years' data for full irrigated trees were used for TGR study. The comparison between MDS vs water potential and MDS signal vs water potential presented a great scattering in both relationships. However, in the interval of water potential between -1.4 and -2MPa, the MDS signal presented a clear increase, which was not identified in the relationship of MDS vs. water potential. It is likely that the seasonal estimation of the baseline would provide a better adjustment of the MDS signal in relation to the water potential and could be useful at the beginning of the water stress period. On the other hand, TGR was affected significantly for the increment of the daily average vapour pressure deficit (VPD) of the previous day and this relationship was affected for the fruit load level.

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Opposed Reviewers:

B. Clothier
Editor
Agricultural Water Management

Dear Dr.Clothier:

We should be grateful if you would consider the attached manuscript entitled "**LIMITATIONS AND USEFULNESS OF MAXIMUM DAILY SHRINKAGE (MDS) AND TRUNK GROWTH RATE (TGR) INDICATORS IN THE IRRIGATION SCHEDULING OF TABLE OLIVE TREES.**" for publication in the special issue of Plant Water Saving of the Journal Agricultural Water Management.

Our work reports data that provide information about the management of trunk diameter fluctuations indicators in table olive trees. In one hand, we have reported the relationship between maximum daily shrinkage (MDS) signal and water potential using the approach of Corell et al (2013) in order to verify if it is useful in moderate water stress conditions. On the other hand, we have compared meteorological data of 5 different high fruit load seasons with trunk diameter fluctuations (TGR) in order to study the influence of environment in this indicator. The present work suggests that MDS signal cold be partially useful in moderate water stress conditions and TGR is affected for the increment in the vapour pressure deficit (VPD).

All the authors have read the manuscript and approved it for publication.

Sincerely yours

Alfonso Moriana

Headlights

MDS signal greater than 1.1 identified moderate water stress conditions

MDS signal increase from 1.1 is not linearity related with higher water stress levels

MDS signal increased in low fruit load with no relation with water stress

TGR was related with the increment of daily average VPD of the previous day

TGR vs VPD relationship was affected for the fruit load in full irrigated orchards

1   **Limitations and usefulness of Maximum Daily Shrinkage (MDS) and trunk growth**

2   **rate (TGR) indicators in the irrigation scheduling of table olive trees.**

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Abstract

25

26 Maximum daily trunk shrinkage (MDS) is the most popular indicator derived from

27 trunk diameter fluctuations in most fruit trees and has been reported to be one of the

28 earliest signs in the detection of water stress. However, in some species such as olive

29 trees (*Olea europaea* L), MDS does not usually change in water stress conditions and

30 trunk growth rate (TGR) has been suggested as better indicator. Most of this lack of

31 sensitivity to drought conditions has been related to the relationship between the MDS

32 and the water potential. This curvilinear relationship produces an uncertain zone were

33 great variations of water potential do not imply any changes of MDS. The MDS signal,

34 the ratio between measured MDS and estimated MDS with full irrigation, has been

35 thought to be a better indicator than MDS, as it reduces the effect of the environment.

36 New methodologies for estimation of the MDS signal in olive trees have been recently

37 suggested. On the other hand, though literature results suggest an effect of environment

38 in TGR values, there are not clear relationship between this indicator and

39 meteorological data. The aims of this work are, on one hand, to study the improvements

40 of the baseline approach in the MDS signal and on the other study the influence of

41 several meteorological variables in TGR. Three years' data from an irrigation

42 experiment were used in to carry out the MDS analysis and six years' data for full

43 irrigated trees were used for TGR study. The comparison between MDS vs water

44 potential and MDS signal vs water potential presented a great scattering in both

45 relationships. However, in the interval of water potential between -1.4 and -2MPa, the

46 MDS signal presented a clear increase, which was not identified in the relationship of

47 MDS vs. water potential. It is likely that the seasonal estimation of the baseline would

48 provide a better adjustment of the MDS signal in relation to the water potential and

49 could be useful at the beginning of the water stress period. On the other hand, TGR was

50 affected significantly for the increment of the daily average vapour pressure deficit

51 (VPD) of the previous day and this relationship was affected for the fruit load level.

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53 **Keywords: Olea europaea, trunk diameter fluctuations, water potential, water**

54 **relations.**

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Introduction

Trunk diameter fluctuations (TDF) are a daily cycle of shrinking and swelling of the trunk that have been reported since the 60's (Ortuño et al., 2010). The development of sensors and dataloggers during the 90's allowed a re-discovery of the usefulness of these indicators in irrigation scheduling. Research works about drought response of TDF indicators in fruit trees and even automatic irrigation scheduling based on these indicators have been reported (i.e. "Pepista", Huguet et al., 1992).

Several types of indicators can be obtained from the daily TDF curves. The most common and early sign of water stress in most fruit trees is the maximum daily shrinkage (MDS) (Ortuño et al. 2010). The increase of MDS compared to fully irrigated trees was reported, from the first works, as an indicator of water stress conditions (Klepper et al, 1971). However, the increase in MDS is also related to the evaporative demand (Herzog et al., 1995). Thus, evaporative demand is an interference of this indicator that reduces its usefulness in commercial orchards. In order to reduce this limitation, Goldhamer and Fereres (2001) suggested the MDS signal: the ratio between measured MDS and MDS with full irrigation. Fully irrigated conditions could be estimated from baseline equations, where MDS is related to a meteorological variable, such as reference evapotranspiration (ETo), vapour pressure deficit (VPD) or temperature (Ortuño et al, 2010; Fernández and Cuevas. 2010).

The usefulness of MDS, however, is not the same in all fruit species. In young olive trees, MDS was not affected by water stress, even when gas exchange was reduced (Moriana and Fereres, 2002). This lack of response has been reported in mature olive trees and in different cultivars and conditions (Moriana et al., 2003; Moriana et al., 2010; Fernández et al., 2011). Moriana et al (2010) suggested that the absence of response to water stress in MDS is related to the pattern of this indicator during a

drought cycle. The relationship between MDS and water potential is curvilinear in all fruit trees, showing an initial increase of MDS with the reduction of the water potential until reaching a maximum value, and then MDS values decrease as the severity of water stress continues to increase (Ortuño et al, 2010). This relationship presented the highest MDS values in olive trees (maximum around 0.8-1mm) (Moriana et al., 2000) and the first linear phase, until the maximum MSD values, has been considered to be caused by variations in the conditions of the evaporative demand (Pérez-López et al., 2013). Since the MDS values during summer in fully irrigated olive trees were around the maximum, moderate water stress conditions would be in the uncertain zone were clear differences of water potential (between -1.4MPa and -2MPa) presented similar MDS values. In addition, Moriana et al (2013) reported greater values of MDS in fully irrigated conditions for trees which were deficit irrigated in the previous season than in trees with full irrigation. The MDS baseline is likely to reduce the influence of the environment on this indicator but it is not known if it would be a reliable indicator in moderate water stress conditions. Corell et al (2013) recently reported on a methodology for the estimated MDS baseline at the beginning of the season which could reduce some of the limitations presented above.

These limitations in the usefulness of MDS in olive trees have produced that other indicators such as trunk growth rate (TGR) have been considered for irrigation scheduling (Moriana et al., 2013). TGR is clearly affected for the fruit load and during pit hardening period in mature trees almost no growth is detected (Moriana et al., 2003). However, even in these conditions, TGR in full irrigated olive trees is very variable and extremely negative values are measured (Moriana et al., 2013). Such response suggests an environmental effect which has been poorly described in olive trees.

125   The aim of this work is analysed this two source of variations in MDS and TGR

126   indicators. In one way, the present work compares the relationships MDS vs. water

127   potential and MDS signal vs. water potential for three sets of seasonal data in order to

128   study the pattern in moderate water stress conditions. On the other way, the relationship

129   between TGR and meteorological data is analysed.

130

131   **Materials and Methods**

132   *Experimental orchard description*

133   Experiments were conducted at La Hampa, the experimental farm of the

134   Instituto de Recursos Naturales y Agrobiología (IRNAS-CSIC). This orchard is located

135   in Coria del Río, near Seville (Spain) (37º17''N, 6º3'W, 30 m altitude). The sandy loam

136   soil (about 2m deep) of the experimental site was characterized by a volumetric water

137   content of $0.33m^3 m^{-3}$ at the saturation point, $0.21m^3 m^{-3}$ at field capacity and $0.1m^3 m^{-3}$

138   at the permanent wilting point, and a bulk density of 1.30 (0-10cm) and 1.50 (10-

139   120cm) $g cm^{-3}$. The experiment was performed on 43-year-old table olive trees (*Olea*

140   *europaea* L cv Manzanillo) from the 2008 to the 2014 seasons. Tree spacing followed a

141   7m x 5m square pattern. Pest control and fertilization practices were those commonly

142   used by the growers and no weeds were allowed to develop within the orchard.

143   Irrigation was carried out during the night by drip, using one lateral pipe per row of

144   trees and five emitters per plant, delivering $8L h^{-1}$ each. The irrigation requirements

145   were determined according to the daily reference evapotranspiration (ET_o) and a crop

146   factor based on the time of year and the percentage of ground area shaded by the tree

147   canopy (Fernández et al., 1997).

148   Maximum daily shrinkage (MDS) study was performed only with data of the

149   seasons from 2011 to 2013. Trunk growth rate (TGR) data were obtained from seasons

150   2008, 2010, 2012, 2013 and 2014 of this orchard and only in 2012 also in a contiguous

151   orchard with the same age and cultivar but 7*7 m spaced. The study of both indicators

152   was performed only in the period of pit hardening.

153

154   *Trunk diameter fluctuation indicators*

155   The maximum daily shrinkage (MDS) was calculated as the difference between the

156   maximum daily diameter and the minimum daily diameter (Goldhamer et al., 1999).

157   Trunk growth rate (TGR) in day "n" was calculated as the difference between the

158   maximum daily diameter of day "n+1" minus that of day "n" (Cuevas et al., 2010).

159   According to Goldhamer and Fereres' approach (2001), the MDS signal was established

160   as the ratio between the value of MDS with a deficit treatment and the estimated MDS

161   with full irrigation. Estimations of the MDS with full irrigation values for each

162   treatment were performed with the data obtained for the last 15 days before the

163   beginning of pit hardening, according to the Corell et al (2013) methodology. In brief,

164   this methodology suggests estimating the seasonal baseline using the relationship

165   between MDS and the maximum temperature of the 15 days previous to pit hardening

166   and assumes that the slope of the equation is the same as the one calculated by Moriana

167   et al (2011). The baseline of each treatment was the linear equation that runs through the

168   average point of the MDS/Maximum temperature data and has a slope of 36 (MDS in

169   μm, Moriana et al 2011). The water potential average data during the period previous to

170   pit hardening are presented in Table 1. No significant differences were measured in each

171   season, though RDI treated trees tended to produce lower values than the Control ones.

172   However, in all cases the midday stem water potential was greater than -1.2MPa, the

173   threshold value suggested for this phenological period in fully irrigated trees (Moriana

174   et al., 2012).

Treatment description

176   Full irrigated Control trees from 2008 to 2014 were used to obtain relationship between

177   TGR and environmental variables. Control trees were irrigated with 100% of crop

178   evapotranspiration (ETc) in order to obtain non-limiting soil water conditions during the

179   entire season. MDS data were obtained from three different irrigation treatments

180   performed from 2011 to 2013 seasons. These regulated deficit irrigation (RDI)

181   treatments considered the phenological stage of the trees in the water stress conditions.

182   The beginning of pit hardening, the most resistant to water stress phenological stage,

183   was determined according to Rapoport et al. (2013) and the recovery phase started in

184   the last week of August (three weeks before harvest). The RDI scheduling was

185   performed according to the trunk diameter variation indicators (Maximum Daily

186   Shrinkage, MDS, and Trunk Growth Rate, TGR). The threshold values used in the

187   present work were selected from previous data (Moriana et al., 2013). The treatments

188   were:

189   • Control. Trees were irrigated with 100% of crop

190   evapotranspiration (ET_c) in order to obtain non-limiting soil water

191   conditions during the entire season.

192   • Regulated deficit irrigation 2 (RDI 2). The objective of

193   this treatment was to create a moderate water stress during the pit

194   hardening and then a slow recovery. Irrigation was scheduled taking into

195   account the maximum daily shrinkage (MDS) and the trunk growth rate

196   (TGR) indicators. Before the period of massive pit hardening (from

197   April to late June) water was supplied only when TGR was lower than

198    $20\mu m\ day^{-1}$. During the pit hardening, irrigation was supplied only when

199   the MDS signal was lower than 0.9. Finally, the recovery started during

the last week of August and in this period, water was supplied when

TGR was lower than -5μm day^{-1}. This schedule was used during 2011

and 2012 seasons but the water status during pit hardening of this

treatment and the next one were similar in these seasons (data not

shown). For this reason, RDI 2 was changed during the 2013 season, and

during the pit hardening water was supplied when TGR was lower than -

10μm day^{-1}.

- RDI 12. The objective of this treatment was to create a moderate water

    stress before the pit hardening, a severe water stress during pit hardening

    and a slow recovery. Before the pit hardening, water was supplied only

    when TGR was lower than 10μm day^{-1}. During the pit hardening, the

    threshold value for the MDS signal was 0.75. In the recovery period the

    irrigation schedule was the same as in RDI 2.

The main features that could affect the tree water relations are presented in Table

2. The present work is focus on pit hardenign period (phase II). The length of this

period was similar in all the seasons, only in 2011 the beginning was estimated clearly

before. The environmental conditions during this period (almost all Summer) were the

traditional at the Mediterranean basin with higher Reference evapotranspiration (ETo)

and low or null rainfall (Table 2). Only applied water of the treatments which data are

used in the presented work are presented (Table 2). Control trees were irrigated with

more water than those undergoing the RDI treatments. The volume of water supplied in

both RDI treatments was similar, only were clearly different during the 2013 season for

the changes in the irrigation scheduling. Control yield was also different between

seasons (Table 2), however all the treatments presented the similar pattern in each

season (data not shown). There was an alternate bearing period from 2008 to 2012

225 season, with very high yields in 2008, 2010 and 2014 and almost null in 2011. Only the

226 seasons with significant fruit load that produced a trunk growth stop during pit

227 hardening period were considered for the TGR analysis (2008, 2010, 2012, 2013, 2014).

228 *Measurements*

229   All the measurements were made on six trees used for each treatment. Trunk

230 diameter fluctuations were measured throughout the experiment periods, using a set of

231 linear variable displacement transducers (LVDT) (model DF$\pm$2.5mm, accuracy $\pm$10μm,

232 Solartron Metrology, Bognor Regis, UK) attached to the main trunk with a special

233 bracket made of Invar, an alloy of Ni and Fe with a thermal expansion coefficient close

234 to zero (Katerji et al., 1994). Measurements were taken every 10s and the datalogger

235 (model CR10X with AM 416 multiplexer, Campbell Sci. Ltd., Logan, USA) was

236 programmed to report 15 min means.

237   The water status of trees for each treatment was defined by the midday stem

238 water potential. Leaves near the main trunk were covered with aluminium foil at least

239 one hour before measurements were taken. The water potential was measured at midday

240 in one leaf per tree, using the pressure chamber technique (Scholander et al., 1965).

241   Micrometeorological 30 min data, namely air temperature (minimum, maximum

242 and average), solar radiation, relative humidity of air and wind speed at 2 m above the

243 soil surface were collected by an automatic weather station located some 40 m from the

244 experimental site. Daily reference evapotranspiration (ETo) was calculated using the

245 Penman-Monteith equation (Allen et al., 1998). Mean daily vapour pressure deficit

246 (VPDm) was calculated from the mean daily vapour pressure and relative humidity. The

247 daily increment (Δ) of each variable at day "n" was calculated as the difference between

248 the value at the day "n+1" and "n". Linear regression analysis was carried out to explore

249 relationships between variables (TGR and climatic variables). Differences between

250   regression lines were determined with a T-test of the slope and y-intercept. Since no

251   significant relationships were obtained in most of the regressions only the four best

252   results will be presented in other to improve the data clarity.

253

254   **Results**

255   *MDS baseline usefulness*

256   Figure 1 shows the relationship between Ψ and the Maximum Daily Shrinkage (MDS).

257   Ψ ranged from -1.0MPa to -2.6MPa, while MDS varied from 300μm to around 800μm.

258   There was no clear relationship between both indicators, although the trend was a large

259   increase of MDS from the lowest values of Ψ until around -1.6MPa. The same values

260   are represented in Figure 2, but the MDS signal calculated for each treatment was

261   considered instead. The scatter is also high and there was no significant relationship

262   between both indicators. However in Figure 2, there is a reference value in the y-axis.

263   Conditions of full irrigation produce values of the MDS signal around 1. In Figure 2,

264   most of the Control data in the 2012 season (9 of 12) and all of them in 2013 presented

265   an MDS signal lower than 1.1, but in the 2011 season, this only happened in 3 out of 11.

266   Moreover, for all the Control values where Ψ was higher than -1.4MPa, the MDS signal

267   was lower than 1.1 in 2012 and 2013, but only in 2 out of 6 cases in 2011. In RDI

268   treatments, most of the values with a Ψ lower than -1.4MPa presented a MDS signal

269   lower than 1.1 (5 out of 6 values when considering all the seasons).

270   In order to obtain a clearer pattern, data from MDS (Figure 1) were grouped in

271   Ψ intervals (Figure 3). These changes reduced the scatter of the relationship and a

272   clearer curvilinear pattern emerged. Most of the Control data were below 600μm of

273   MDS and there was a progressive increase of MDS with the decrease in Ψ from -

274   1.6MPa. This pattern changed at around -1.8MPa when the maximum MDS was

275   reached. Then, there was also a clear trend for MDS to decrease with Ψ values lower

276   than -2MPa. The lowest Ψ Control values were in the range of 600-800μm, similar

277   values to those from RDI treatments and close to the maximum MDS measured.

278   The data of Figure 2 were grouped in the same Ψ intervals as in the previous

279   Figure. An MDS signal equal to 1 represents a theoretical value of conditions with full

280   irrigation. Figure 4 shows a confidence interval of around 10%, therefore MDS signal

281   values from 0.9 to 1.1 could be included in the group with full irrigation. All the Control

282   data are within the interval 1-1.1 of the MDS signal, though the water potential changed

283   from near -1.4MPa to slightly under -1.8MPa. There is also a clear differentiation

284   between data for 2011 and the rest of seasons. Most of the MDS signal data in this

285   season are above 1.1, even in the Control group, though Ψ values were near -1.4MPa

286   (Figure 4). On the other hand, all of the RDI data from -1.6 to -2MPa clearly presented

287   an MDS signal higher than 1.1, with maximum average values around 1.4. When the

288   Ψ values were lower than -2MPa, MDS signals were under 1.1 (Figure 4).

289   *Relationship between trunk growth rate (TGR) and environment*

290   The best relationship between TGR and meteorological data for each season is

291   presented at Table 3. Most of the relationships calculated were not significant (data not

292   shown). The ones presented here are only the best four for each season and orchard in

293   order to improve the clarity of results. None of the regressions that included absolute

294   value of the meteorological data and the daily value of TGR were significant (data not

295   shown). When TGR values were related with the increment of each meteorological

296   variable in some years the regression was significant, but they were still very poor (data

297   not shown). Only when these increments were related with the TCT of the next day the

298   signification was improved. The data of the best relationships between previous

299   meteorological data and TGR for each year are presented at Table 3, only data of the

300   year 2008 is not presented. Average daily relative humidity ((Δ-1)RHav), temperature

301   (average or maximum) and daily average vapour pressure deficit ((Δ-1)VPDav) were

302   the best relationship with TGR. Only (Δ-1)VPDav and (Δ-1)RHav were one of the best

303   in all the years considered (Table 3). Determination coefficient in these variables

304   changed from 0.34 to 0.61 in (Δ-1)VPDav and from 0.2 to 0,52 in (Δ-1)RHav (Table 3).

305   None of the other variables or any multivariable equations improved the results of these

306   two. In all the relationships of Table 3, TGR decreased with an increase of the

307   evaporative demand. The slope in the (Δ-1)VPDav vs TGR relationship was the greatest

308   in all the seasons considered (between -48.6 to -65.5 $\mu m día^{-1} KPa^{-1}$, while in the others

309   from 3.0 in (Δ-1) RHav to -18.8 (Δ-1)Tav (increment of the day before in average

310   temperature).

311   Similar relationships were obtained when data from a different near orchard was

312   considered (orchard 7*7; 2012 season, Table 3). Accuracy of the equation was

313   improved in this orchard, but (Δ-1)VPDav was again the best variable. This equation

314   explained the 75% of the data variability and the slope was 4 times greater than the rest

315   of the equations (Table 3). The equation of this orchard was significantly different from

316   the ones of the 7*5 orchard.

317   Although the (Δ-1)VPDav vs TGR relationships presented different slopes

318   between years (Table 3), such differences were not significant (Fig. 5) for the 7*5

319   orchard. The equation that considered the pool data presented a R^2 around 0.45. The

320   slope of this equation suggests an important effect of the VPD in the TGR (around 55

321      $\mu m\ día^{-1}$ per KPa). This equation was significantly different from the ones obtained in

322   7*7 orchard. However, in the interval ±1 KPa of VPD, where most of the data are

323   presented, both equations are very similar (Fig. 5).

324   The accuracy of the equations in the 7*5 orchard was very different between

325 seasons (Table 3). When R^2 is related with the fruit yield of each season, a clear trend to

326 lower influence of VPD with an increase of fruit load is obtained (Fig. 6). Fig. 6

327 suggests that R^2 in the equations, and therefore the VPD influence on TGR, decreased

328 sharply from around 13 MT ha^{-1}.

329

330 **Discussion**

331 *MDS baseline usefulness*

332 The relationship between the MDS signal and the midday stem water potential (Ψ) was

333 similar to that described in the literature (olives, Moriana et al 2000; other fruit trees,

334 Ortuño et al 2010). When there was no water stress, the values for the relationship

335 between the MDS signal and the water potential (around -1.4MPa) were grouped around

336 1, while in the MDS vs. Ψ relationship, these values showed a greater scattering. Such

337 results suggest that the MDS signal reduced the environmental noise which is common

338 in MDS values in the range near -1.4MPa.

339   The fruit load was a factor likely to affect the MDS signal vs. Ψ relationship.

340 Conditions of full irrigation or very low water stress (Ψ higher than -1.6MPa) in a low

341 fruit load season presented greater values than expected (Figure 4, higher than 1). The

342 fruit load is a factor that affects MDS values. In olive trees, Moriana et al (2011)

343 reported a significantly different lower slope in the baseline for the low fruit load than

344 for the high fruit load. Goldhamer and Fereres (2001) suggested that an active trunk

345 growth decreases the MDS in fruit trees. However, lower values for the MDS vs. Ψ

346 relationship were not found in low fruit load conditions in the present work (Figures 1

347 and 3). Since the MDS signal is a ratio, such response would be related to an estimation

348 of values lower than expected in conditions of full irrigation (the denominator in the

349 ratio). Therefore, the estimation of the MDS baseline at the beginning of a low fruit load

350 season, according to the Corell et al (2013) methodology, could underestimate the value

351 with full irrigation and then, produce a significant increase in the MDS signal during the

352 pit hardening.

353   The relationship between MDS signal and Ψ showed a clear increase in the

354 MDS signal from -1.6MPa to -2MPa (Figure 4). Such increase was also observed in the

355 MDS vs. Ψ relationship, although the variations were narrow and similar to some values

356 of the Control trees (Figure 3). In both relationships, values below -2MPa were similar

357 to the ones obtained with a Ψ higher than -1.4MPa. This pattern of increase and

358 decrease has been observed in olive (Moriana et al., 2000) and other fruit trees (Ortuño

359 et al., 2010) and has limited the usefulness of MDS in olive trees (Moriana and Fereres,

360 2002; Moriana et al 2003; Moriana et al., 2010; Fernández et al 2011). Although the

361 MDS signal also presented this pattern, MDS signal values greater than 1.1 always

362 indicated moderate water stress conditions. However, MDS signal values do not display

363 a linear increase because the decrease of MDS signal starts in this interval of water

364 potential. Therefore, in the interval 1.1-1.4, a higher MDS signal will not be necessarily

365 imply a lower Ψ. Then, although there is still an uncertain zone in the range between -

366 1.4MPa and -2MPa, at least conditions of water stress could be identified.

367

368 *Relationship between trunk growth rate (TGR) and environment*

369 TGR is poor related with environment in the literature and in the present work.

370 Predicted models of the daily TDF has reported no clear results for the overlap effect of

371 growth and water status (Deslauriers et al, 2007). Only in young olives trees, when

372 trunk growth is continuous during all the irrigation season because of the absence of

373 fruit development, significant relationships have been reported (Pérez-López et al.,

15

374 2008; Cocozza et al., 2012). Deslauriers et al (2007) suggested in several species that

375 the relationship between TGR and temperature is strongly related with the rehydration

376 phase of the daily curve of trunk diameter variations. In the present work, no

377 relationships with any of the Deslauriers' phases have been obtained. Fernández et al

378 (2011) in the same olive orchard did not obtain either any relationship. This lack of

379 results was likely related with the greater number of species and meteorological

380 conditions in the Deslauriers work than in Fernández and the present works. According

381 with the data of the present work, the influence of VPD was very important but strongly

382 affected for the yield. Both results are not new in olive literature. Evaporative demand

383 affects the daily cycle of leaf conductance (Xiloyannis et al., 1988) and the relationship

384 between leaf conductance and water potential (Moriana et al., 2002). Water relations are

385 strongly affected for fruit development (Rallo and Suárez, 1989; Martín-Vertedor et al.,

386 2011). TGR in olive trees is very different in low than in high fruit load conditions

387 (Moriana et al., 2003), but, according to the present work, excessive fruit yield will also

388 affect. Moriana et al (2013) reported in two of the data set used in the present work

389 (2008 and 2010 seasons) a continuous decrease in the TGR values in full irrigated

390 conditions. Finally, the influence of VPD in TGR values was delayed in one day and the

391 increase in VPD affect the TGR of the next day. Such result suggests that TGR

392 variations could be controlled with chemical or hydraulic changes in the trunk tissues as

393 in the root signal, described also in olive trees (Fernández et al., 2006).

394

395   **Conclusions**

396 The patterns of the relationships MDS signal vs. Ψ and MDS vs. Ψ were similar.

397 However, the MDS signal estimated according to Corell et al (2013) resulted in a

398 reduced scattering in conditions of full irrigation and clearly identified water stress

399 conditions in the range of -1.4MPa to -2MPa. This range of Ψ corresponded to MDS

400 signal values between 1.1 and 1.4. However, since the decrease in MDS signal starts

401 within this range, higher values do not indicate more severe water stress conditions.

402 Ψ values lower than -2MPa produced values of MDS signal around 1, therefore, they

403 cannot be used for detecting water stress conditions. Conditions of low fruit load could

404 limit the usefulness of this approach. Significant relationship between TGR and

405 environmental variables were obtained only when a 1 day delayed was considered. TGR

406 values during pit hardening were strongly affected for the increase in the average VPD

407 of the day before when the fruit load was not excessive.

408

409 **Acknowledge**

413

414 **References**

415 Allen, R.G., Pereira, L.S., Raes, D., Smith. M., 1998. Crop evaportranspiration.

416   Guideline for computing crop water requirements. FAO irrigation and drainage

417   paper nº 56. Roma. FAO

418 Cocozza, C., Giovannelli, A., Lasserre, B., Cantini, C., Lombardi, F., Tognetti, R. 2012.

419   A novel mathematical procedure to interpret the stem radius variation in olive

420   tres. Agric. Forest Meteorol. 161,80-93.

421 Corell, M., Girón, I.F., Moriana, A., Dell'Amico, J., Morales, D., Moreno, F. 2013.

422   Extrapolating base-line trunk shrinkage reference equations across olive

423   orchards. Agric. Water Manage. 126,1-8.

424   Cuevas, M.V., Torres-Ruiz, J,M., Álvarez, R,, Jiménez, M.D., Cuerva, J., Fernández,

425   J.E. 2010. Usefulness of trunk diameter variations for irrigation scheduling in a

426   mature olive tree orchard. Agric. Water Manage. 97, 1293–1302.

427   Deslauriers, A., Anfodillo, T., Rossi, S., Carraro, V. 2007. Using simple causal

428   modeling to understand how water and temperature affect daily stem variation in

429   trees. Tree Physiol. 27, 1125-1136.

430   Fernández, J.E. and Cuevas, M.V., 2010. Irrigation scheduling from stem diameter

431   variations: a review. Agric. Forest Meteorol. 150, 135–151.

432   Fernández, J.E., Moreno, F., Girón, I.F., Blázquez, O.M., 1997. Stomatal control of

433   water use in olive tree leaves. Plant Soil 190, 179-192.

434   Fernández, JE., Díaz-Espejo, A., Infante, J.M., Durán, P., Martín-Palomo, MJ.,

435   Chamorro, V., Girón I.F., Villagarcía, L. 2006. Water relations and gas

436   exchange in olive trees under regulated deficit irrigation and partial rootzone

437   drying. Plant Soil 284, 273-291.

438   Fernández, J.E., Torres-Ruiz, J.M., Díaz-Espejo, A., Montero, A., Alvárez, R., Jiménez,

439   M.D., Cuerva, J., Cuevas, M.V. 2011a. Use of maximum trunk diameter

440   measurements to detect water stress in mature Arbequina olive trees under

441   deficit irrigation. Agric. Water Manage. 98, 1813-1821.

442   Fernádez, JE., Moreno, F., Martín-Palomo, MJ., Cuevas, MV., Torres-Ruiz, JM,

443   Moriana, A. 2011b. Combining sap flow and trunk diameter measurements to

444   assess water needs in mature olive orchards. Environ. Exp. Bot. 72, 330-338.

445   Goldhamer, D.A. and Fereres, E., 2001. Irrigation scheduling protocols using

446   continuously recorded trunk diameter measurements. Irrig. Sci. 20, 115-125.

447 Goldhamer, D.A., Fereres, E., Mata, M., Girona, J., Cohen, M., 1999. Sensitivity of
448   continuous and discrete plant and soil water status monitoring in peach tress
449   subjected to deficit irrigation. J. Amer. Soc. Hort. Sci. 124, 437-444.

450 Herzog, K.M., Hüsler, R., Thum, R., 1995. Diurnal changes in the radius of a subalpine
451   Norway spruce stem: their relation to the sap flow and their use to estimate
452   transpiration. Trees 10, 94-101.

453 Katerji, N., Tardieu, F., Bethenod, O., Quetin, P., 1994. Behavior of Maize stem
454   diameter during drying cycles: comparison of two methods for detecting water
455   stress. Crop Sci. 34, 165-169.

456 Klepper, B., Browing, V.D., Taylor, H.M., 1971. Stem diameter in relation to plant water
457   status. Plant Physiol. 48, 683-685.

458 Martín-Vertedor, A.I., Pérez-Rodríguez, J.M., Prieto, H., Fereres, E., 2011. Interactive
459   responses to water deficits and crop load in olive (Olea europaea L., cv.
460   Morisca).Water use, fruit and oil yield. Agric. Water Manage. 98, 941–949.

461 Moriana, A. and Fereres, E., 2002. Plant Indicators for Scheduling Irrigation for Young
462   Olive Trees. Irrig. Sci. 21, 83-90

463 Moriana, A., Fereres, E., Orgaz, F., Castro, J., Humanes, M.D., Pastor, M., 2000. The
464   relations between trunk diameter fluctuations and tree water status in olive tree
465   (Olea europea L). Acta Hortic. 537, 293-297.

466 Moriana, A., Orgaz, F., Fereres, E., Pastor, M., 2003. Yield responses of a mature olive
467   orchard to water deficits. J. Amer. Soc. Hort. Sci. 128,425-431.

468 Moriana, A., Girón, I., Martín-Palomo, M.J., Conejero, W., Ortuño, M.F., Torrecillas,
469   A., Moreno, F., 2010. New approach for olive trees irrigation scheduling using
470   trunk diameter sensors. Agric. Water Manage 97,1822-1828.

471 Moriana, A., Moreno, F., Girón, I., Conejero, W., Ortuño, M.F., Morales, D., Corell,

472   M., Torrecillas, A., 2011. Seasonal changes of maximum daily shrinkage

473   reference equations for irrigation scheduling in olive trees: influence of fruit

474   load. Agric. Water Manage. 99, 121-127.

475 Moriana, A., Pérez-López, D., Prieto, M.H., Ramírez-Santa-Pau, M., Pérez-Rodriguez,

476   J.M. 2012. Midday stem water potential as a useful tool for estimating irrigation

477   requirements in olive trees. Agric. Water Manage. 112:43-54.

478 Moriana, A., Corell, M., Girón, I.F., Conejero, W., Morales, D., Torrecillas, A.,

479   Moreno, F. 2013. Regulated deficit irrigation based on threshold values of trunk

480   diameter fluctuation indicators in table olive trees. Sci Hort 164, 102-111.

481 Ortuño, M.F., Conejero, W., Moreno, F., Moriana, A., Intrigliolo, D.S., Biel, C.,

482   Mellisho, C.D., Pérez-Pastor, A., Domingo, R., Ruiz-Sánchez, M.C., Casadesus,

483   J., Bonany, J., Torrecillas, A., 2010. Could trunk diameter sensors be used in

484   woody crops for irrigation scheduling?. A review of current knowledge and

485   future perspectives. Agric. Wat. Management 97,1-11.

486 Pérez-López, D.; Moriana, A.; Rapoport, H; Olmedilla, N.; Ribas, F. (2008) New

487   approach for using trunk growth rate and endocarp development in the irrigation

488   scheduling of young olive orchards. Scientia Hort. 155, 244-251

489 Pérez-López, D., Pérez-Rodríguez, J.M., Moreno, M.M., Prieto, M.H., Ramírez-Santa-

490   Pau, M., Gijón, C., Guerrero, J., Moriana, A. 2013. Influence of different

491   cultivars-locations on maximum daily shrinkage indicators: Limits to the

492   reference baseline approach. Agric. Water Manage. 127, 31-39.

493 Rallo, L. and Suarez, M.P. 1989. Seasonal distribution of dry matter within the olive

494   fruit-bearing limb. Adv. Hort. Sci. 3, 55-59.

495   Rapoport, H.F., Pérez-López, D., Hammami, S.B.M., Aguera, J., Moriana, A. 2013.

496   Fruit pit hardening: physical measurements during olive growth. Ann. Appl.

497   Biol. 163, 200-208.

498   Scholander, P.F., Hammel, H.T., Bradstreest, E.A., Hemmingsen, E.A., 1965. Sap

499   pressure in vascular plant. Science 148, 339-346.

500   Xiloyannis,C; Pezzarossa,B; Jorba,J; Angelini,P (1988): Effects of soil water content on

501   gas exchange in olive trees. Adv. Hort. Sci. 2, 58-63.

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Figure Captions

521 Fig. 1. Relationship between Midday stem water potential vs Maximum daily shrinkage

522 during the three seasons. Each symbol is the average of 6 measurements. The period of

523 measurement was from the beginning of pit hardening until harvest. Symbols: 2011

524 season, triangles; up and empty Control trees, down and empty RDI 2, up and black

525 RDI 12. 2012 season, square; empty Control trees, mid-filled RDI 2; black RDI 12.

526 2013 season, circle; empty Control trees, mid filled RDI 2; black RDI 12. Vertical dash

527 line indicated the reference value of stem water potential (-1.4 MPa).

528

529 Fig. 2. Relationship between Midday stem water potential vs Maximum daily shrinkage

530 signal (MDS signal) during the three seasons. Each symbol is the average of 6

531 measurements. The period of measurement was from the beginning of pit hardening

532 until harvest. Symbols: 2011 season, triangles; up and empty Control trees, down and

533 empty RDI 2, up and black RDI 12. 2012 season, square; empty Control trees, mid-

534 filled RDI 2; black RDI 12. 2013 season, circle; empty Control trees, mid filled RDI 2;

535 black RDI 12. Vertical dash line indicated the reference value of stem water potential (-

536 1.4 MPa). Horizontal dash line indicated the reference value of MDS signal (1).

537

538 Fig. 3. Relationship between Midday stem water potential vs Maximum daily shrinkage

539 during the three seasons. Each point is the average of all the data of Figure 1 grouped

540 according to water potential intervals: values higher than -1.4 MPa, between -1.4 until -

541 1.75 MPa, between -1.75 until -2 MPa and lower than -2 MPa. Vertical and horizontal

542 bars at the symbol represent the standard error in MDS and water potential respectively.

543 Vertical dash line shows the reference of stem water potential (-1.4 MPa). Symbols:

544 2011 season, triangles; up and empty Control trees, down and empty RDI 2, up and

545   black RDI 12. 2012 season, square; empty Control trees, mid-filled RDI 2; black RDI

546   12. 2013 season, circle; empty Control trees, mid filled RDI 2; black RDI 12.

547

548   Fig. 4. Relationship between Midday stem water potential vs Maximum daily shrinkage

549   signal (MDS signal) during the three seasons. Each point is the average of all the data of

550   Figure 2 according to the water potential interval of: values higher than -1.4 MPa,

551   between -1.4 until -1.75 MPa, between -1.75 until -2 MPa and lower than -2 MPa.

552   Vertical and horizontal bars at the symbol represent the standard error in MDS signal

553   and stem water potential respectively. Vertical dash line shows the reference of stem

554   water potential (-1.4 MPa). Horizontal dash lines represent the reference of MDS signal

555   (1) and an interval of ±10%. Symbols: 2011 season, triangles; up and empty Control

556   trees, down and empty RDI 2, up and black RDI 12. 2012 season, square; empty

557   Control trees, mid-filled RDI 2; black RDI 12. 2013 season, circle; empty Control trees,

558   mid filled RDI 2; black RDI 12.

559

560   Fig. 5. Relationship between trunk growth rate (TGR) and increment of the vapour

561   pressure deficit the day before ((Δ-1)VPD). Black square and solid line represent all the

562   data of the 7*5 m orchard (Table 3, n=257, TGR=-54.15 (Δ-1)VPD, R^2=0.46***,

563   Error=31.0 μm día^{-1}). White square and dash line represent data from 7*7 orchard

564   (Table 3, n=60, TGR=-79.39 (Δ-1)VPD, R^2=0.75***, Error=27.8 μm día^{-1}).

565

566   Fig. 6. Relationship between the determination coefficient (R^2) of the regressions

567   between increment of the vapour pressure deficit the day before ((Δ-1)VPD) and TGR

568   (Table 3) vs the yield. The highest yield and lowest R^2 correspond to the regression

569   obtained in the 2008 season (data not shown).

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571

	2011	2012	2013
Control	-0.84±0.03	-1.00±0.02	-0.89±0.07
RDI 2	-0.92±0.04	-1.04±0.03	-0.84±0.07
RDI 12	-0.98±0.03	-1.05±0.03	-0.86±0.06

Table 1. Midday stem water potential (MPa) during the three seasons of the MDS experiment. The values presented are the average of the period previous to pit hardening. Measurements were performed in 5 different dates (2011, from April to June), in 12 different dates (2012, from March to June) and in 11 different dates (2013, from March to June).

577

578

Seasons	DOY Ph II	ETo Ph II	Rain Ph II	Yield	AW		
					Control	RDI 2	RDI 12
2008	172-246		11.1	18.3±0.3	619		
2010	166-235		15.6	15.0±1.7	710		
2011	157-235	519	1.8	2.5±0.5	285	132	100
2012	173-232	368	0.0	6.6±0.7	412	130	111
2013	176-233	361	0.0	9.0±1.1	369	207	106
2014	168-236	390	6.1	14.7±1.6	279		

Table 2. Features of the experimental seasons used in the present work. In all the seasons is presented: the length of the pit hardening phase (DOY PH II, beginning and end date), reference evapotranspiration in the pit hardening phase (ETo PhII, mm), rainfall in the pit hardening phase (Rain Ph II, mm), yield in Control treatments (MT ha^{-1}), seasonal applied water in the treatments used in each season (AW, mm).

584

Variable	n	R^2	Standar Error	Equation
		2010	**Orchard 7*5**	**DOY 166-235**
$(\Delta-1)$ VPDav	70	0.34***	42.4 μm	TGR=-48.6$(\Delta-1)$DPVmed
$(\Delta-1)$ Tav	70	0.40***	40.1 μm	TGR=-18.8$(\Delta-1)$Tmed
$(\Delta-1)$ Tmax	70	0.27***	44.7 μm	TGR=-9.2$(\Delta-1)$Tmax
$(\Delta-1)$ RHav	70	0.20**	46.7 μm	TGR=2.1$(\Delta-1)$HRmed
		2012	**Orchard 7*5**	**DOY 173-232**
$(\Delta-1)$ VPDav	60	0.61***	24.8 μm	TGR=-50.8$(\Delta-1)$DPVmed
$(\Delta-1)$ RHav	60	0.52***	27.3 μm	TGR=3.0$(\Delta-1)$HRmed
$(\Delta-1)$ RHmin	60	0.36***	31.6 μm	TGR=2.2$(\Delta-1)$HRmin
$(\Delta-1)$ Tmax	60	0.31***	32.8 μm	TGR=-8.0$(\Delta-1)$Tmax
		2013	**Orchard 7*5**	**DOY 176-233**
$(\Delta-1)$ VPDav	58	0.61***	21.8 μm	TGR=-65.5$(\Delta-1)$DPVmed
$(\Delta-1)$ Tav	58	0.29***	28.8 μm	TGR=18.7-13.5$(\Delta-1)$Tmed
$(\Delta-1)$ RHav	58	0.27***	29.3 μm	TGR=18.0+2.3$(\Delta-1)$HRmed
Δ RHav	58	0.24***	30.0 μm	TGR=17.9+2.14ΔHRmed
		2014	**Orchard 7*5**	**DOY 168-236**
$(\Delta-1)$ VPDav	69	0.47***	28.5 μm	TGR=-63.1$(\Delta-1)$DPVmed
$(\Delta-1)$ RHav	69	0.39***	30.5 μm	TGR=2.8$(\Delta-1)$HRmed
$(\Delta-1)$ Tav	69	0.38***	31.0 μm	TGR=-15.2$(\Delta-1)$Tmed
$(\Delta-1)$ Tmax	69	0.36***	31.4 μm	TGR=-9.1$(\Delta-1)$Tmax
		2012	**Orchard 7*7**	**DOY 173-232**
$(\Delta-1)$ VPDav	60	0.75***	28.0 μm	TGR=-79.2$(\Delta-1)$DPVmed
$(\Delta-1)$ RHav	60	0.53***	38.0 μm	TGR=4.3$(\Delta-1)$HRmed
$(\Delta-1)$ Tav	60	0.48***	39.9 μm	TGR=-20.3$(\Delta-1)$Tmed
$(\Delta-1)$ Tmax	60	0.47***	40.5 μm	TGR=-13.7$(\Delta-1)$Tmax

Table 3. Results in the different seasons of the relationship between several meteorological variables and trunk growth rate (TGR) of full irrigated trees. In all the seasons the orchard is the same, only in 2012 data from a next orchard is included. In each season the four best results are presented. In all of them **(Δ-1)VPDav** (increment of the daily average vapour pressure deficit the day before) was one of the best and is presented in first position, the rest are organised according to the determination coefficient (R^2). **($\Delta-1$) Tav**, increment of daily average temperature the day before; **($\Delta-1$) Tmax**, increment of daily maximum temperature the day before; **($\Delta-1$) RHav**, increment of daily average relative humidity the day before; **($\Delta-1$) RHmin**, increment of dailiy minimum relative humidity the day before; **Δ RHav** increment of daily average relative humidity
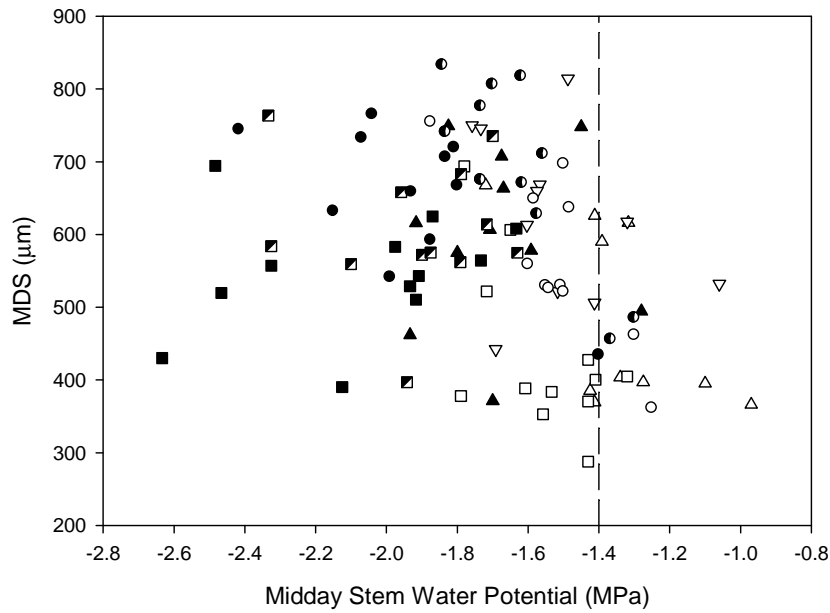
Figure 1
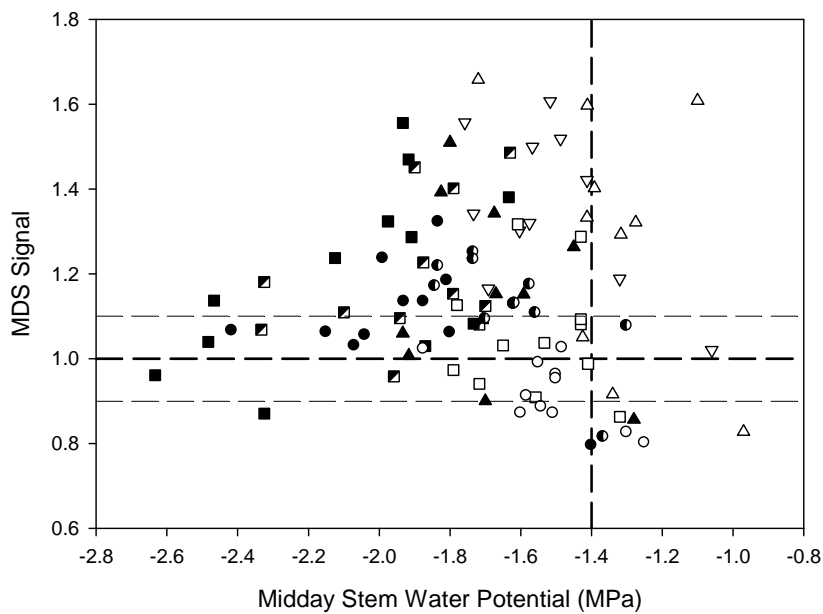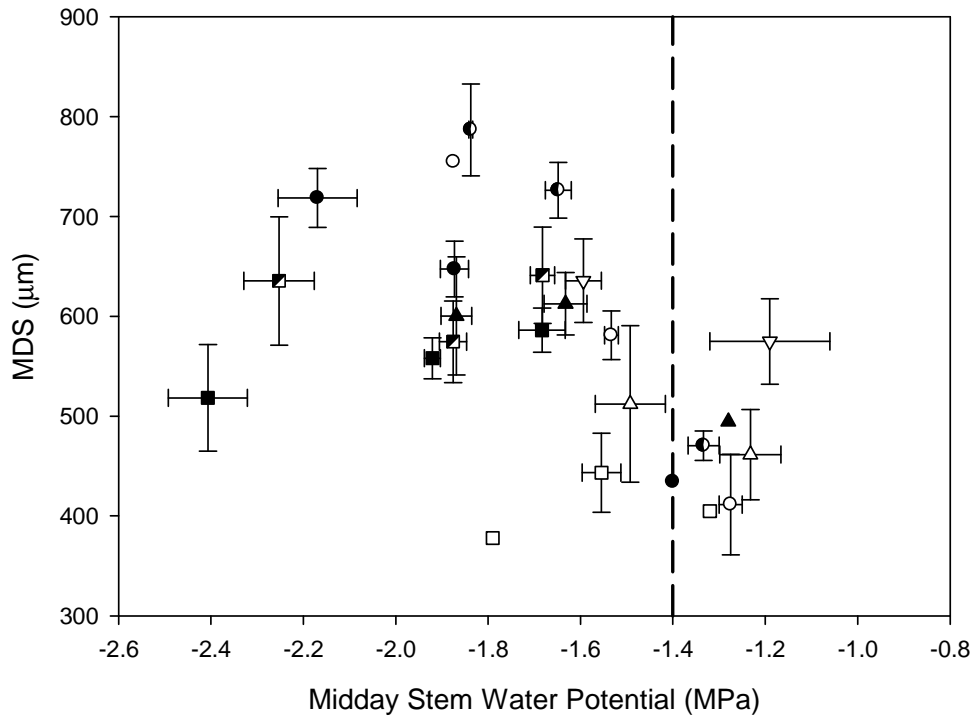

Figure 1. Relationship between Midday stem water potential vs Maximum daily shrinkage during the three seasons. Each symbol is the average of 6 measurements. The period of measurement was from the beginning of pit hardening until harvest. Symbols: 2011 season, triangles; up and empty Control trees, down and empty RDI 2, up and black RDI 12. 2012 season, square; empty Control trees, mid-filled RDI 2; black RDI 12. 2013 season, circle; empty Control trees, mid filled RDI 2; black RDI 12. Vertical dash line indicated the reference value of stem water potential (-1.4 MPa).

Figure 2

Figure 2. Relationship between Midday stem water potential vs Maximum daily shrinkage signal (MDS signal) during the three seasons. Each symbol is the average of 6 measurements. The period of measurement was from the beginning of pit hardening until harvest. Symbols: 2011 season, triangles; up and empty Control trees, down and empty RDI 2, up and black RDI 12. 2012 season, square; empty Control trees, mid-filled RDI 2; black RDI 12. 2013 season, circle; empty Control trees, mid filled RDI 2; black RDI 12. Vertical dash line indicated the reference value of stem water potential (-1.4 MPa). Horizontal dash line indicated the reference value of MDS signal (1).

Figure 3

Figure 3. Relationship between Midday stem water potential vs Maximum daily shrinkage during the three seasons. Each point is the average of all the data of Figure 1 grouped according to water potential intervals: values higher than -1.4 MPa, between -1.4 until -1.75 MPa, between -1.75 until -2 MPa and lower than -2 MPa. Vertical and horizontal bars at the symbol represent the standard error in MDS and water potential respectively. Vertical dash line shows the reference of stem water potential (-1.4 MPa). Symbols: 2011 season, triangles; up and empty Control trees, down and empty RDI 2, up and black RDI 12. 2012 season, square; empty Control trees, mid-filled RDI 2; black RDI 12. 2013 season, circle; empty Control trees, mid filled RDI 2; black RDI 12.
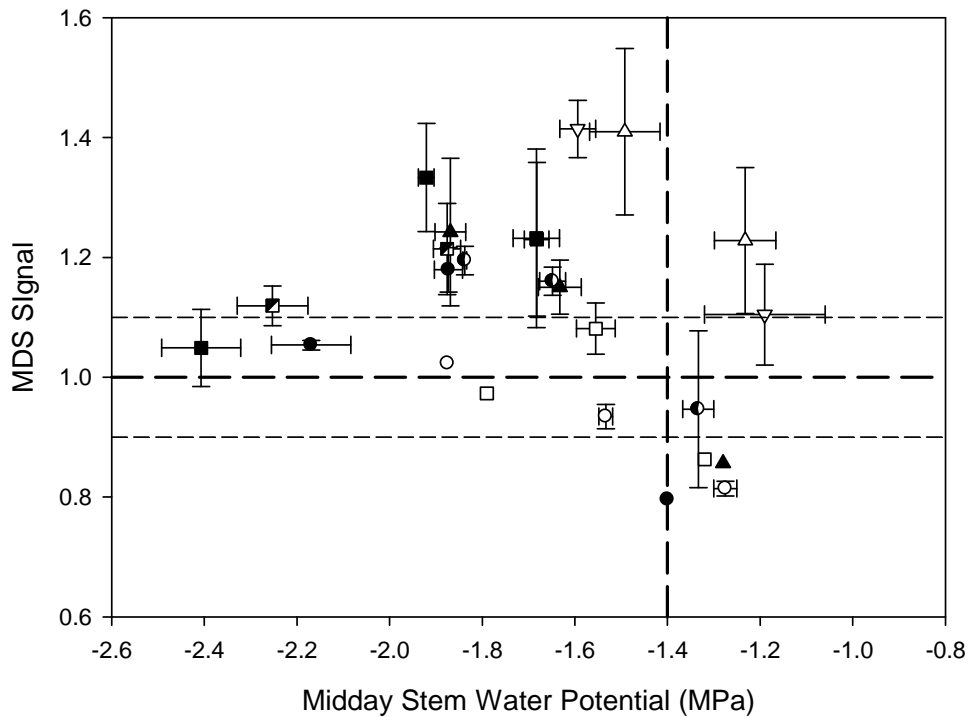
Figure 4

Figure 4. Relationship between Midday stem water potential vs Maximum daily shrinkage signal (MDS signal) during the three seasons. Each point is the average of all the data of Figure 2 according to the water potential interval of: values higher than -1.4 MPa, between -1.4 until -1.75 MPa, between -1.75 until -2 MPa and lower than -2 MPa. Vertical and horizontal bars at the symbol represent the standard error in MDS signal and stem water potential respectively. Vertical dash line shows the reference of stem water potential (-1.4 MPa). Horizontal dash lines represent the reference of MDS signal (1) and an interval of ±10%. Symbols: 2011 season, triangles; up and empty Control trees, down and empty RDI 2, up and black RDI 12. 2012 season, square; empty Control trees, mid-filled RDI 2; black RDI 12. 2013 season, circle; empty Control trees, mid filled RDI 2; black RDI 12.
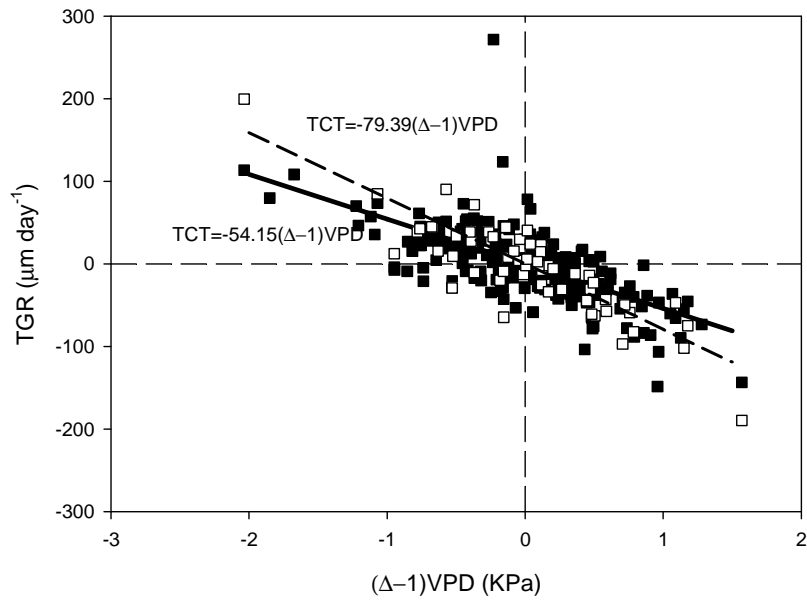
Figure 5

Fig. 5. Relationship between trunk growth rate (TGR) and increment of the vapour pressure deficit the day before ((Δ-1)VPD). Black square and solid line represent all the data of the 7*5 m orchard (Table 3, n=257, TGR=-54.15 (Δ-1)VPD, R^2=0.46***, Error=31.0 µm día^{-1}). White square and dash line represent data from 7*7 orchard (Table 3, n=60, TGR=-79.39 (Δ-1)VPD, R^2=0.75***, Error=27.8 µm día^{-1})
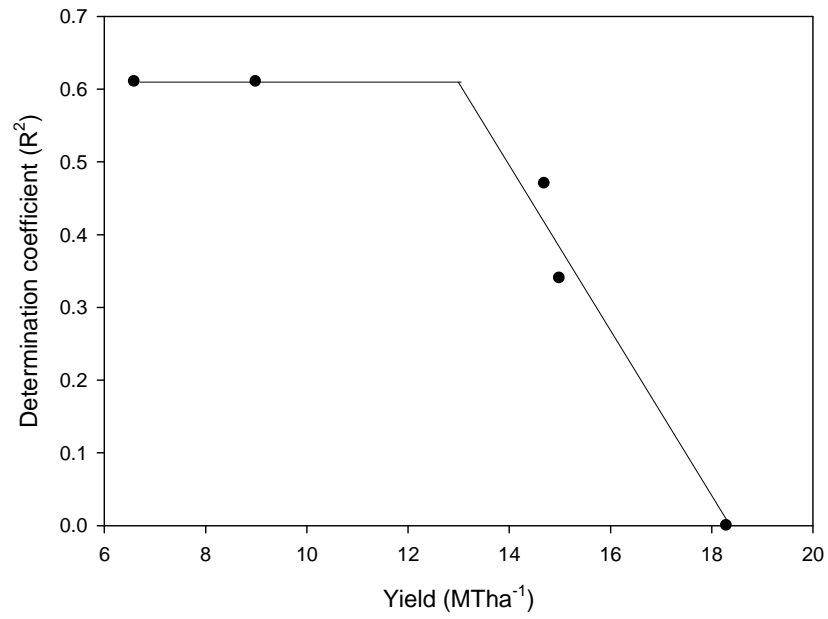
Figure 6

Fig. 6. Relationship between the determination coefficient (R^2) of the regressions between increment of the vapour pressure deficit the day before ((Δ-1)VPD) and TGR (Table 3) vs the yield. The highest yield and lowest R^2 correspond to the regression obtained in the 2008 season (data not shown).