

1 **Comparison of the water potential baseline in different locations. Usefulness for**
2 **irrigation scheduling of olive orchards.**

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24

25 **Abstract**

26 Deficit irrigation scheduling needs accurate indicators and in recent decades, continuous
27 plant indicators have been developed. However, threshold values that could be useful in
28 commercial orchards are not commonly reported. The water potential is a discontinuous
29 measurement commonly used as a reference in the description of water stress level. In some
30 fruit trees, such as olive trees, there are several works suggesting threshold values in fully
31 irrigated conditions, but the influence of the evaporative demand is not taken into account.
32 The aim of this work is to compare the values of the fully irrigated water potential in different
33 locations in order to study the estimation of a common baseline. Three mature olive orchards
34 were selected, two in Seville (South Spain) and one in Ciudad Real (Central Spain). There
35 were clear differences between the three orchards during the 2015 season. Orchards in Seville
36 (S-1 and S-2) were close (10 km apart) and had the same cultivar (table olive, cv Manzanilla)
37 but they were different in terms of the fruit load (almost no fruit in S-1, medium fruit load in
38 S-2) and distribution of water (single drip line in S-1, double drip line in S-2). The orchard
39 in Ciudad Real (CR) was very different with regards to the olive cultivar (cv Cornicabra) and
40 the location, as it was in a borderline zone for olives growing with very low temperatures
41 that delay the phenological development. In all the orchards, the best baseline was obtained
42 with different climatic measurements, even in S-1 and S-2. When all the data were
43 considered, the best fit was obtained with the average vapour pressure deficit (VPD_{av}).
44 Influence of the location was significant in the interception term of the equations when
45 Temperature was used but not with VPD. This source of variation was related with the level
46 of fruit load. Slope of the equations was not affected for the location. The equation obtained
47 was validated with water potential data from previous seasons of S-1 and CR orchards.

48 Maximum temperature presented the best validation results. The usefulness of this baseline
49 is discussed.

50

51 **Keywords: Plant water status measurements, oil olive, table olive, water relations.**

52

53 **1. INTRODUCTION**

54 Water for agricultural uses progressively decreases in arid zones because of the scarcity of
55 natural resources and the increase in water demand for other social uses (Fererres and Soriano,
56 2007). The climate change models estimate that in these zones rainfall will decrease and
57 temperature will increase, consequently the evaporative demand will rise. (IPCC, 2015). In
58 addition, traditional rainfed fruit crops in these zones, such as olive trees, are converted into
59 more dense, irrigated orchards. These species are usually drought resistant and farmers
60 receive less irrigation water than the real needs of the orchard. Olive trees are a good example,
61 with more than 400,000Ha on irrigated land in Spain (MAGRAMA, 2016) where most of the
62 surface experiences deficit irrigation conditions.

63 Nowadays there is a wide variety of soil and plant sensors available, even for
64 commercial orchards, and they could be used to schedule deficit irrigation conditions (i.e.,
65 zim probe, dendrometry, canopy temperature). However, to our knowledge, little is known
66 about the water stress threshold level of these tools. Thus, at least in olive orchards, the
67 technology related to the design of new sensors is ahead of the sensor management in the
68 field, understood as the knowledge about the stress threshold values that the plants can be
69 subjected to. Although midday stem water potential is not the earliest indicator of water stress
70 in olive trees (Moriana and Fereres, 2002), it is used as the standard comparison for most of
71 the new sensors. Moriana et al (2012) suggested using -1.2 and -1.4MPa of midday stem
72 water potential as the threshold for fully irrigated olive trees. However, according to
73 literature, values below -1.4MPa are common, mainly in mid-summer or in high fruit load
74 seasons in fully irrigated treatments (i.e. Martín-Vertedor et al, 2011).

75 Plant measurements have been considered very efficient tools for irrigation
76 scheduling (Turner, 1990) although they were not traditionally used due to their close

77 relationship with evaporative demand (Hsiao, 1990). Shackel et al (1997) was one of the first
78 works that suggested irrigation scheduling for fruit trees based on the water potential.
79 Nevertheless, the influence of evaporative demand when suggesting water potential threshold
80 values is not commonly considered in the literature (i.e. plum, Lampinen et al, 2001; citrus,
81 Ballester et al, 2013; pecan, Othman et al., 2014; olive, Moriana et al., 2012, Rosecrance et
82 al., 2015, Girón et al., 2015). For continuous indicators, such as dendrometry, it is very
83 common to estimate the baseline (Ortuño et al., 2010). Because these methodologies have a
84 great amount of data, baseline estimations at the beginning of the season are easier to obtain
85 than in water potential measurements. The great sensitivity of plant measurements to the tree
86 physiology also increases the difficulty of obtaining a strong baseline, especially when
87 different cultivars or environments are considered. Thus, few works have been published
88 about the comparison of thresholds or approaches between significantly different locations.
89 The aim of this work is to compare the seasonal baseline of the water potential in different
90 olive orchards in order to verify if a unique estimation would be comparable and useful.

91

92 **2. MATERIAL AND METHODS**

93 *Orchards locations*

94 Three experimental orchards were considered for the comparison of baselines:

- 95 1. **Seville 1 (S-1)**. This orchard is located in La Hampa, the experimental farm of the
96 Instituto de Recursos Naturales y Agrobiología (IRNAS-CSIC) in Coria del Río, near
97 Seville (Spain) (37°17'N, 6°3'W, 30 m altitude). The sandy loam soil (about 2 m
98 deep) of the experimental site was characterized by a volumetric water content of
99 $0.33\text{ m}^3\text{ m}^{-3}$ at the saturation point, $0.21\text{ m}^3\text{ m}^{-3}$ at field capacity and $0.1\text{ m}^3\text{ m}^{-3}$ at the
100 permanent wilting point, and a bulk density of 1.30 (0-10cm) and 1.50 (10-120cm) g

101 cm⁻³. The experiment was performed on 44-year-old table olive trees (*Olea europaea*
102 L cv Manzanillo) during the 2015 season. Tree spacing followed a 7m x 5m square
103 pattern. Irrigation was carried out during the night by drip, using one lateral pipe per
104 row of trees and five emitters per plant, delivering 8L h⁻¹ each.

105 2. **Seville 2 (S-2)**. This orchard is located in Doña Ana, a private farm in Dos Hermanas,
106 near Seville (Spain) (37° 25' N, 5° 95' W). The loam soil (deeper than 1m) of the
107 experimental site was characterized by a volumetric water content of 0.31 m³ m⁻³ at
108 field capacity and 0.14 m³ m⁻³ at the permanent wilting point, and a bulk density of
109 1.4 (0-30cm) and 1.35 (30-90cm) g cm⁻³. The experiment was performed on 30-year-
110 old table olive trees (*Olea europaea* L cv Manzanillo) during the 2015 season. Tree
111 spacing followed a 7m x 4m square pattern. Irrigation was carried out during the night
112 by drip, using two lateral pipes per row of trees and twenty-six emitters per plant,
113 divided between the two rows, delivering 2L h⁻¹ each.

114 3. **Ciudad Real (CR)**. This orchard is located in “El Chaparrillo”, the experimental farm
115 of Consejería de Agricultura (Junta de Castilla La Mancha) in Ciudad Real, Central
116 Spain, (39° 02' N, 3° 94' W, altitude 640m above sea level). The soil is a shallow clay-
117 loam (Petrocalcic Palexeralfs) 0,75m deep and a discontinuous petrocalcic horizon
118 between 0.75-0.85m. The volumetric water content was for was 26.0 % after field
119 capacity and 13.1% at wilting point. The experiment was performed on 17-years-old
120 olive trees (*Olea europaea* L cv Cornicabra) during the 2015 season. Tree spacing
121 followed a 7m x 4.76m square pattern. Irrigation was carried out during the night by
122 drip, using one lateral pipe per row of trees and four emitters per plant, delivering 8L
123 h⁻¹ each.

124

125 *Climatic description*

126 The climatic conditions of the orchards located in Seville are almost equal because the
127 distance between them is only around 10Km and both of them are at the same level in the
128 Guadalquivir Valley. The distance between Ciudad Real and Seville is around 330Km and
129 there are a great differences in altitude (640m vs 30m above sea level) and in the distribution
130 of rains and temperatures. Figure 1 presents the seasonal pattern of reference
131 evapotranspiration (ET_o), rain and temperature in both locations during the 2015 season.
132 Winter minimum temperatures are clearly different between both locations. While Seville is
133 slightly below 0°C, some data of Ciudad Real are in the region of -10°C. These minimum
134 temperatures indicate that Seville is a traditional olive zone while Ciudad Real is in the
135 borderline where this fruit tree can be cultivated. Although summer temperatures are similar
136 in both locations, the delay in the recovery of spring temperatures causes a shorter growing
137 season in Ciudad Real than in Seville and the date of flowering is very different: around mid-
138 April in Seville and early-June in Ciudad Real. During 2015, seasonal rains were slightly
139 lower in Seville than in Ciudad Real (Fig. 1b). In both locations, late-spring and summer are
140 dry periods and evaporative demand is extremely high.

141 Table 1 summarizes the fruit load of the three orchards considered during the 2015
142 season in comparison with the historical average. The CR orchard has a lower average yield
143 than the S-1 and S-2 orchards due to the important problems with low winter temperatures.
144 The current yield, the one obtained in the 2015 season, was clearly different between
145 locations. The CR orchard presents a record yield in comparison with the historical average
146 (two fold more than the average). On the other hand, S-1 and S-2 were lower than the average
147 with almost no fruit load in the S-1 orchard.

148

149 *Irrigation regimes and measurements*

150 All the measurements were made on six to eight trees (depending on the orchard)
151 located in a plot with adjacent guard rows. The water status of the trees for each treatment
152 was characterised by the midday stem water potential (Ψ) and maximum leaf conductance.
153 The leaves near the main trunk were covered in aluminium foil at least one hour before
154 measurements were taken. The water potential was measured at midday in one leaf per tree,
155 using the pressure chamber technique (Scholander et al., 1965) every 7-10 days. Leaf
156 conductance was measured with permanent porometer (S1 and S2 orchards, Decagon) and
157 with an IRGA (CR orchard, CIRAS-1, pp system). Problems with the IRGA limited the
158 period of measurements to only the beginning of the season. Leaf conductance daily cycle in
159 olive tree presents a maximum during the morning and a minimum during midday
160 (Xiloyannis et al., 1988). Moriana et al (2002) reported that maximum leaf conductance was
161 more sensitive to water stress than minimum values. According to this result, values of
162 maximum leaf conductance were estimated in S1 and S2 orchards. Because the IRGA
163 measurements spend more time than porometer and leaf conductance values are dynamics,
164 minimum leaf conductance was measured in CR orchard.

165 Trees were irrigated with more than 100% of crop evapotranspiration (ET_c) in order
166 to maintain the midday stem water potential values higher than -1.4MPa (according to the
167 value suggested in Moriana et al., 2012). Because midday stem water potential values were
168 lower than this threshold in the CR and S-1 orchards during some periods, the applied water
169 was greater (four fold) than in S-2 (Table 1).

170 Micrometeorological 30 min data, namely air temperature, solar radiation, relative
171 humidity of air and wind speed at 2m above the soil surface, were collected by an automatic

172 weather station located some 40m from the experimental site in the S-1 orchard and around
173 100m in the CR orchard. The daily reference evapotranspiration (ET_o) was calculated using
174 the Penman-Monteith equation (Allen et al., 1998). The mean daily vapour pressure deficit
175 (VPD) was calculated from the mean daily vapour pressure and relative humidity. The
176 maximum daily vapour pressure deficit (VPD) was calculated from the minimum daily
177 vapour pressure and relative humidity. The climatic variables considered were: minimum
178 and average VPD, maximum, minimum and average temperature, minimum and average
179 relative humidity and ET_o. Climatic data measured at the S-1 orchard were used in the
180 relationships between S-1 and S-2 orchards.

181 The soil moisture was measured with a portable FDR sensor (HH2, Delta-T, U.K. in
182 Seville orchards and Diviner, 2000, Sentek Pty. Ltd., Australia in Ciudad Real orchard) with
183 a calibration obtained in previous works. The measurements were made in three to four plots
184 per orchard. The access tubes for the FDR sensor were placed in the irrigation line at about
185 30cm from an emitter, which is the distance where root activity is higher (Fernández et al.,
186 1991). The data were obtained at 1m depth with 10cm intervals.

187 A linear regression analysis was carried out to explore the relationships between
188 variables (midday stem water potential and climatic variables) in each location and
189 considered all the three orchards with 2015 season data. Adjusted coefficient of
190 determination (R^2) was considered only in multi-variable models, otherwise coefficient of
191 determination as used. Differences between regression lines were determined with a T-test
192 of the slope and y-intercept (Statistic SX 8.0). The random effect due to the locations were
193 analysed with mixed model using the library “nlme” in R program (R 3.3.1; R Core team,
194 2016). Random effects in the interception and slope terms were considered. The selection of
195 the best model was based on the results obtained in the lineal (MSE and R^2) and mixed

196 models (AIC). Data from different seasons (2014 in the S-1 orchard and 2012 and 2013 in
197 the CR orchard) were used to validate the relationships obtained. Values of relative humidity
198 (in %) were transformed with arcsin function to avoid heterocedasticity.

199

200 **3. RESULTS**

201 The soil water content (θ) is presented in Figure 2 for the three locations of the experiment.
202 The seasonal pattern of θ was very similar for all locations. At the beginning of the season
203 values were low because irrigation had not started. However, even these minimum values
204 were not limiting in any of the locations considered. The irrigation increased θ but measured
205 values were almost constant and commonly lower than field capacity in all the locations.
206 Only S-1 values were higher than field capacity during most of the summer. In the other two
207 locations, CR and S-2, θ values were no limiting, if 70% of the available water is considered
208 as the threshold value (Goldhamer and Fereres, 1990).

209 The seasonal pattern of midday stem water potential and leaf conductance for the
210 three orchards are presented at Fig. 3. Water potential values varied from near -0.5 MPa to
211 slightly below of -2 MPa (Fig. 3a). In S-1 and S-2, measurements began before than CR
212 orchard and in these dates (end of winter/beginning of spring) maximum values were
213 obtained. Most of values were around -1.4 MPa, the threshold selected, but in S-1 and CR
214 locations around DOY (day of the year) 188 until DOY 237, water potential decreased until
215 minimum values. In this period, on the contrary, S-2 orchard presented almost constant
216 values arund -1.4 MPa. Leaf conductance measurements in CR locations were not much
217 because of the problem with the equipment. The values obtained in this site are near of the
218 ones reported in the literature for full irrigated trees using the same methodology (Moriana

219 et al 2002). In S-1 and S-2 orchards, leaf conductance values were similar at the beginning
220 of the season, but from DOY 204 until the end of the experiment, values measured at S-1
221 was clearly higher than the one obtained at S-2.

222 Table 2 summarises the results of the regressions at the CR orchard. In this location,
223 the multi-variable model was not better than the ones presented in Table 2. All the climatic
224 measurements considered were closely related to the midday stem water potential (Ψ). In this
225 location, temperature measurements presented the best agreement with Ψ (around 0.75 of
226 R^2), while relative humidity indicators were clearly the worse (values R^2 around 0.35). All
227 the climatic measurements considered values that implied a greater evaporative demand and
228 reduced Ψ . The greater slope of the regression was obtained for the transformed relative
229 humidity (HR_{av} 1.13MPa %⁻¹, HR_{min} 2.24 MPa %⁻¹) while the lower was in temperature
230 (between T_{max} -0.04 MPa °C⁻¹ and T_{min} -0.05MPa °C⁻¹). The best agreement was obtained
231 with minimum temperatures.

232 The regression results of the S-1 orchard are presented in Table 3. In this location the
233 multi-variable approach that includes average VPD (VPD_{av}) and the reference
234 evapotranspiration (ET_o) were better than any of the single models. All the climatic variables
235 considered were closely related to Ψ . In this location, the relative humidity indicators also
236 presented some weak agreements with Ψ but, in this case, the minimum temperature was the
237 worst ($R^2= 0.2$). On the contrary, ET_o and VPD_{av} , as a single model, showed the best
238 agreement with R^2 values around 0.75. This latter result was significantly improved when
239 both were combined in a multi-variable model (adjusted $R^2=0.82$). As in the previous
240 location (CR), Ψ was reduced when all the climatic indicators implied an increase in the
241 evaporative demand. Also as in the previous location, transformed relative humidity

242 presented the greater slope in the regression equation (HR_{av} 1.42MPa %⁻¹, HR_{min} 1.67 MPa
243 %⁻¹). The minimum slope was estimated again in the regression equations for temperature
244 (between T_{min} -0.03MPa °C⁻¹ and T_{max} -0.06 MPa °C⁻¹) similar to the ones obtained in the
245 previous location (Table 2).

246 Table 4 shows the results of the regression equations in the S-2 orchard. As in the CR
247 orchard, any multi-variable model was not significantly better than the single ones presented
248 in the Table. All the climatic variables considered were closely related to Ψ . In this location,
249 as in the previous one, the relative humidity shows the weakest relationship ($R^2=0.31$)
250 although minimum temperature ($R^2=0.46$), as in the S-1 orchard (Table 3), and average VPD
251 ($R^2=0.51$) are also clearly worse than the rest. As in the previous locations, Ψ was reduced
252 when all the climatic indicators implied an increase in the evaporative demand. Transformed
253 relative humidity was also the equation that presented the greatest slope (HR_{av} , 0.95MPa %⁻¹
254 ¹, HR_{min} 1.04 MPa %⁻¹), while temperature variables were the lowest (between T_{max} -
255 0.047 MPa °C⁻¹ and T_{av} -0.059 MPa °C⁻¹). In this location, the maximum temperature clearly
256 showed the best equation.

257 The results of the pool data of the three locations is presented in Table 5. The multi-
258 variable equations containing data of average temperature and average relative humidity were
259 similar to the best single regression ($R^2=0.68$, in the single equation vs $R^2=0.67$ in the multi-
260 variable). All the climatic variables considered were closely related to Ψ . The agreement of
261 the regressions was more similar when all the data were considered than for separate
262 locations and only minimum temperatures presented a very low R^2 (0.14) in comparison with
263 the rest (between 0.46 and 0.68). Although relative humidity showed again one of the worse
264 agreements, the pool data were better than at isolated locations. Transformed HR were, again,

265 the ones that presented the greatest slope in the equations (HRav, 1.11 MPa %⁻¹, HRmin,
266 1.52MPa %⁻¹) but VPDav and VPDmax showed the best agreements when single models
267 were considered. AIC (Akaike information criterion) is the parameter uses in mixed models
268 for selected the best approach. As low is the AIC, better is considered the predictions of the
269 model. In Table 5, AIC showed the similar results as R² and MSE; multi-variable fit, VPDav
270 and VPDmax were, in this order, according to this parameter the best models. On the other
271 hand, Tmin, both HR and Tav were the worst using the AIC (Table 5).

272 The Figure 4 compares the relationship of Ψ vs the two most extreme climatic
273 variables according to their results in the regressions obtained (Table 5), VPDav (Figure 4a)
274 and Tmin (Figure 4b). Regressions equations between VDPav and Ψ were more similar
275 between locations than the ones related with Tmin. Such differences occurred even though
276 the values of VPD measured in Seville were slightly higher than the ones in Ciudad Real,
277 while the minimum temperature range was almost the same.

278 Figure 4 shows, using the two extreme models as an example, that there could be an
279 effect of the location depending of the climatic measured considered. Mixed models
280 evaluated the effect of the different locations. Results of mixed models consider only random
281 effects in the interception term is shown at Table 6. In this kind of analysis, the standard
282 deviation due to location is estimated (σ_a) and is compared with the one of the error term (σ)
283 using the p-ratio (percentage of σ_a^2 in the total variance) . According to the p-ratio, there are
284 two clear groups, one in which the influence of the location is very small (VDPav, VPDmax,
285 HRav, HRmin and the multi-variable model). Other group where locations affect the
286 agreement of the model and no unique model could be considered (ETo, but mainly Tmax,
287 Tav, Tmin).

288 The influence of the locations could affect also to the slope term. Therefore,
289 considering one climatic measured, slope could be different in different locations. This effect
290 is also analysed with mixed models at Table 7. Not all the climatic measurements are
291 presented at Table 7 because there were not enough interactions to obtain a result using this
292 approach. In all the climatic measured considered, the percentage of the variance explained
293 for changes in the slope (p-ratio) are very low. Such results suggest that slopes are not
294 affected for the location. Otherwise, there are starting conditions which is the main effect of
295 the location in this variable (p-ratios between 40 to 88% of the total variance).

296

297 All the equations of Table 5, using the whole set of data, were validated with data
298 from different seasons. The best validations are presented at Fig. 5, VPDav (Fig. 5a) and
299 Tmax using single (Fig. 5b) and mixed models (Fig. 5c and 5d). The equations using in Tmax
300 that include the random effect of interception are presented at Table 8. There were significant
301 differences between all the fits and the equation 1:1. Slopes of equations were significantly
302 different of 1, though estimations with Tmax were nearer than the ones of VPDav. Equations
303 based on mixed models in Tmax did not improve the validation obtained with single model
304 when the interception coefficients are considered according to the location of the orchard
305 (Fig. 5c, equations of Table 8). Fig 5d equations of Table 8 was selected according to fruit
306 load instead of location. Table 8 equation for CR was used in the validation of S-1 (yield
307 efficiency 1.40 Kg m^{-3}) and CR 2013 season (yield efficiency 1.49 Kg m^{-3}), while equation
308 for S-1 was used in the validation of CR 2012 season (yield efficiency 0.05 Kg m^{-3}). These
309 changes improved the validation in comparison to Fig. 5c, though was similar to Fig 5b. Data
310 from the CR orchard in the both seasons considered were nearer to a 1:1 relationship (slopes

311 0.72, VPD_{av}, 0.74, T_{max} and 0.7 and 0.66 T_{max} mixed models) that the ones of S-1 (slope
312 0.34, VPD_{av}, 0.54, T_{max}, and 0.53, in both T_{max} mixed models).

313

314 **4. DISCUSSION**

315 Midday stem water potential (Ψ) was always related in the same way in all the locations
316 considered, the increase of evaporative demand (higher temperature, low humidity and so
317 on) reduced the Ψ values. However, each location presented a different optimum climatic
318 measured for a full irrigated model, even the two orchards with the same cultivar and
319 relatively near, such as S-1 and S-2 (around 10 Km away). Although climate could be
320 considered the same in the S-1 and S-2 orchards, such differences in water relations were
321 likely affected by the irrigation system. In the S-2 orchard there were more drips than in the
322 S-1 and this could increase the fraction of roots in wet conditions. Torres-Ruiz et al (2013)
323 reported differences in the leaf conductance between trees with different fraction of roots in
324 wet conditions, even when they received the same amount of water. In addition, the great
325 differences of water applied in both orchards (Table 1) to obtain a similar water status also
326 behave in this way. Such differences could affect the water potential values and the
327 relationship with climatic measurements. Fernández et al (2014) suggest that in fully irrigated
328 conditions, the water potential is regulated for leaf conductance and this could reduce the
329 decrease caused by the environmental changes. On the other hand, Ciudad Real is a cooler
330 location than Seville. The wider variations in minimum temperature experienced mainly this
331 season in Ciudad Real could be the reason for a better fit of this climatic measurement.
332 Differences in the best climatic measured to predict water status plant indicator have been
333 found commonly such as maximum daily shrinkage (MDS). In olive trees, mean temperature,

334 VPD and maximum temperature have been reported as possible predictors of a fully irrigated
335 baseline of MDS (Moriana and Fereres, 2004; Moreno et al, 2006; Moriana et al., 2011).

336 The selection of the best baseline predictor should be based in several results when
337 the pool data is used in order to generalize the relationship to other orchards different for the
338 ones where the experiment was performed. Coefficient of determination (R^2) and MSE at
339 Table 5 show that the best agreements are VPDav and VPDmax. Multi-variable equation was
340 almost equal to VPDav, but it should not be considered because the improving does not
341 justify the use of one climatic measured more. The study of the variance in the mixed models
342 shows that, in addition, VPDav had an almost null effect of the locations while VPDmax and
343 mainly Tmax have a great influence of the orchard (Table 6). On the contrary, the analysis
344 of the random effect of the slope showed that there were no differences due to locations
345 (Table 7). Mixed models have not improved the AIC of the single models in VPDav (Table
346 5 vs Table 6). Therefore, VPDav using the single lineal model was the best fit and the best
347 candidate for obtained a general equation. VPDmax and Tmax could be also interesting
348 approaches but primarily Tmax would have an important source of variations between
349 orchards. Mixed model that considered the random effect in the interception presented the
350 highest AIC in Tmax (Table 5 vs Table 6 and 7) and should be considered if this parameter is
351 used (Table 8).

352 One of the possible sources of error between locations could be fruit load. Data from
353 Fig. 4 showed that equations were closer for a medium/high fruit load (S-2 and CR) than for
354 a low fruit load season (S-1). In Table 8, yield efficiency of each orchard is showed. The
355 lowest values of yield efficiency were associated with the higher intercept values in Tmax
356 equation (Table 8). Moreover, the validation using mixed models with Tmax was improved
357 when fruit load instead of locations itself were used. Low fruit load conditions reduced the

358 leaf conductance and increased the water potential (Martín-Vertedor et al., 2011). The lack
359 of influence of fruit load in the VPDs relationships is likely related with the great response
360 of olive trees water relation to this parameter. Olive trees are very sensitive to VPD variations
361 and adjust the daily cycle of gas exchange to the VPD daily patterns (Xiloyannis et al, 1988).
362 Fernández and Moreno (1999) suggested that VPD and radiation are the main drivers for
363 stomata closure. Moriana et al (2002) reported a lineal relationship between minimum leaf
364 conductance and VPD which changed with water status of the trees. Therefore, VPD could
365 be an easy measurement indicator in commercial orchards, strongly related with tree
366 physiology and probably, with similar relationships even in different locations. On the other
367 hand, interception values for T_{max} equations provide in Table 8 are likely useful, according
368 to the validation results, considering only low, medium or high fruit load and not yield
369 efficiency which is a difficult parameter to estimate in commercial orchards at the beginning
370 of the season.

371 Water status indicators are strongly affected by the environment and this questions
372 their usefulness as irrigation scheduling tools. Baselines from climatic measurements have
373 been widely used, mainly for continuous indicators such as maximum daily shrinkage.
374 However, from our knowledge, comparisons between different orchards with very different
375 conditions are not reported in the literature. This lack of information limits the commercial
376 applications of these techniques. The results of the present work suggest that a unique
377 equation could be useful enough to determine the effect of the evaporative demand, at least,
378 in commercial conditions. This is very important because the water potential is a
379 discontinuous plant indicator and the number of data available is considerably low in
380 comparison to, for instance, MDS. In most fruit trees, using the first data obtained in the
381 season has been suggested to calculate the estimation of the MDS baseline (Goldhamer and

382 Fereres, 2004; Egea et al., 2009; Corell et al., 2013). Although a similar estimation could be
383 done with water potential, using the first data for the current season, the needs of going to
384 the field and the narrower variations in water potential than in MDS make this an unsuitable
385 strategy, especially in commercial conditions.

386 The range of Ψ values measured were great, though full irrigated conditions were
387 performed. Although values lower than -2.0 MPa were not the most common (the average of
388 the data pool was -1.34MPa), some measurements were clearly lower than the ones suggested
389 by Moriana et al (2012) after pit hardening (-1.4MPa). Irrigation scheduling approaches
390 based on a constant value of water potential consider negligible the influence of evaporative
391 demand (for instance Moriana et al (2012) in olives or Lampinen et al (2001) in prunes).
392 According to the present data, such suggestions will not reduce yield but will over-estimate
393 water needs. In addition, not using a baseline in the determination of threshold values could
394 distort the conclusions, because the effect of the environment could be confused with drought
395 resistance.

396

397 **5. CONCLUSIONS**

398 Each orchard location presented differences in the best climatic measurements to fit a
399 baseline. The effect of the location was significant in some equations, mainly the ones related
400 with Temperature, while as almost negligible in others such as VPDs. There were no effects
401 of the location in the slope of the equations considered. VPDav was the best fit when all the
402 data were considered and, according to the present work, could be used as general equation
403 in different locations. Tmax presented the best validation, although it was not the best fit
404 when the whole data is considered. The random effect in the interception of Tmax equation

405 was related with fruit load. Good validation according to fruit load was obtained using the
406 interception values provided in the present work. These baselines (based on VPDav and
407 Tmax), which consider all data, presented a reasonably good fit when validated with data
408 from other seasons and they could be considered as a valid tool, at least in commercial
409 orchards. Maximum temperature could be the most interesting because of the great validation
410 results and because it is the easiest climatic measurement to obtain. The usefulness of these
411 baselines is very high in indicators such as water potential, for whom the number of data is
412 limited. The use of these baselines will provide a more accurate estimation of the water needs.

413

414 **Acknowledge**

415 This research was supported by the Spanish Ministerio de Ciencia e Innovación (MICINN),
416 (AGL2013-45922-C2-1-R).

417

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Location	Type of product	Average yield	% Soil Cover	Current yield	Applied Water
S-1	Table olive	8 MT ha ⁻¹	56%	0.2 MT ha ⁻¹	452 mm
S-2	Table olive	9 MT ha ⁻¹	32%	3.6 MT ha ⁻¹	158 mm
CR	Oil olive	4.5 MT ha ⁻¹	33%	8.2 MT ha ⁻¹	420 mm

522 Table 1. Main features of the experimental orchard. The type of products and the historical
523 average of the yield for each orchard are included. In addition, the fruit yield, percentage of
524 soil cover and applied water during the experimental season is presented.

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	Constant	Slope	R ²	N	MSE
VPD_{av}	-1.0855****	-0.2689****	0.6854***	16	0.0232
VPD_{max}	-0.9813****	-0.1398****	0.7247***	16	0.0203
ET_o	-0.9265***	-0.1062**	0.4837**	16	0.0381
HR_{av}¹	-2.0579****	1.1328*	0.3456*	16	0.0483
HR_{min}¹	-1.9922****	2.2458*	0.3566*	16	0.0475
T_{max}	-0.3738 ^{ns}	-0.0368****	0.7106****	16	0.0214
T_{av}	-0.5762*	-0.0427****	0.7405****	16	0.0192
T_{min}	-0.9014****	-0.0524****	0.7619****	16	0.0176

543 Table 2. Regression analysis of the climatic variable and water potential data at CR orchard.
544 The best fit is marked in bold. R² . Determination Coefficient. N. Number of data. MSE.
545 Mean Square of Errors. ns. No significative. *. p≤0.05. **. p≤0.01. ***. p≤0.001. ****.
546 p≤0.0001. ¹arcosin transformation was made to avoid heterocedasticity.

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	Constant	Slope 1	Slope 2	R²	N	MSE
VPD_{av}	-0.7401****	-0.437****		0.7437****	21	0.0292
VPD_{max}	-0.6058***	-0.220****		0.6495****	21	0.0399
E_{To}	-0.2286^{ns}	-0.209****		0.7491****	21	0.0286
HR_{av}¹	-2.3601****	1.4220**		0.5394***	21	0.0525
HR_{min}¹	-1.9041****	1.6661**		0.3849**	21	0.0701
T_{max}	0.6834 ^{ns}	-0.064****		0.6700****	21	0.0376
T_{av}	0.0772 ^{ns}	-0.0598***		0.5661***	21	0.0494
T_{min}	-0.8544**	-0.0331*		0.1964*	21	0.0916
VPD_{av}, E_{To}	-0.3850*	-0.2382*	-0.1175**	0.8064****	21	0.0209

561 Table 3. Regression analysis of the climatic variable and water potential data at S-1 orchard.
562 R² . Determination Coefficient. N. Number of data. MSE. Mean Square of Errors. ns. No
563 significative. *. p≤0.05. **. p≤0.01. ***. p≤0.001. ****. p≤0.0001. ¹arcosin transformation
564 was made to avoid heterocedasticity.

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	Constant	Slope	R²	N	MSE
VPD_{av}	-0.7918****	-0.3529***	0.5084***	24	0.0434
VPD_{max}	-0.6535****	-0.1709****	0.6396****	24	0.0318
ET_o	-0.2336 ^{ns}	-0.1803****	0.6131****	24	0.0341
HR_{av}¹	-1.9285****	0.9476**	0.3149**	24	0.0605
HR_{min}¹	-1.5706****	1.0441**	0.3270**	24	0.0594
T_{max}	0.2944^{ns}	-0.0474****	0.7785****	24	0.0195
T_{av}	0.1759 ^{ns}	-0.0585****	0.7344****	24	0.0234
T_{min}	-0.3421 ^{ns}	-0.0512***	0.4585***	24	0.0478

578 Table 4. Regression analysis of the climatic variable and water potential data at S-2 orchard.
579 R² . Determination Coefficient. N. Number of data. MSE. Mean Square of Errors. ns. No
580 significative. *. p≤0.05. **. p≤0.01. ***. p≤0.001. ****. p≤0.0001. ¹arcosin transformation
581 was made to avoid heterocedasticity.

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	Constant	Slope 1	Slope 2	R ²	MSE	AIC
VPD_{av}	-0.82****	-0.38****		0.68****	0.036	-24.95
VPD_{max}	-0.68***	-0.19****		0.67****	0.038	-23.15
ET_o	-0.37*	-0.18****		0.59****	0.047	-9.47
HR_{av}¹	-2.09****	1.11****		0.52****	0.054	-0.53
HR_{min}¹	-1.82****	1.52****		0.46****	0.061	9.77
T_{max}	0.25 ^{ns}	-0.05****		0.61****	0.045	-12.56
T_{av}	0.10 ^{ns}	-0.05****		0.51****	0.055	0.63
T_{min}	-0.91****	-0.029**		0.14**	0.097	35.01
HR_{av}¹,T_{av}	-1.01****	-0.187^{ns}	-0.34****	0.67****	0.037	-36.90

596 Table 5. Regression analysis of the climatic variable and water potential data using the pool
597 data of the three locations. In all the relationship n=61. R². Determination Coefficient. N.
598 MSE. Mean Square of Errors. AIC. Akaike information criterion. ns. No significative. *,
599 p≤0.05. **, p≤0.01. ***, p≤0.001. ****. p≤0.0001. ¹arcosin transformation was made to
600 avoid heterocedasticity.

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	AIC	σ_a	σ	p-ratio (%)
VPD_{av}	-13.61	0.0034	0.0345	0.95
VPD_{max}	-14.37	0.0082	0.0325	5.93
ET_o	-6.91	0.0167	0.0361	17.51
HR_{av}¹	7.99	1.714E-10	0.0544	9.93E-16
HR_{min}¹	15.99	0.0030	0.0627	0.23
T_{max}	-18.03	0.0260	0.0280	46.23
T_{av}	-10.94	0.0376	0.0315	58.72
T_{min}	21.72	0.0732	0.0547	64.13
HR_{av}¹, T_{av}	-21.08	0.0078	0.0267	7.94

615 Table 6. Results of the analysis of pool data using mixed models only in the interception
616 coefficient (a). AIC Akaike information criterion. σ_a Standard deviation of the random effect
617 in the interception term. σ Standard deviation of the error term. P-ratio. Ratio between
618 variance of the random effect and the total variance ($\sigma_a^2 / (\sigma_a^2 + \sigma^2) * 100$).

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		Variance	P ratio (%)	AIC
Tmin	σ_a	0.2706	57.2	25.72093
	σ_b	1.985e -06	0	
	σ	0.2340	42.8	
Tmax	σ_a	0.4457	88	-16.04042
	σ_b	0.0102	0.4	
	σ	0.1623	11.6	
ETo	σ_a	0.3696	79	-6.395355
	σ_b	0.0452	1.2	
	σ	0.1825	19.8	
VDPmax	σ_a	0.1478	40.3	-10.726
	σ_b	0.0193	0.7	
	σ	0.1788	59	

634 Table 7. Results of the analysis of pool data using mixed models in the interception (a) and
635 slope (b) coefficients. AIC Akaike information criterion. σ_a Standard deviation of the random
636 effect in the interception term. σ_b Standard deviation of the random effect in the slope
637 term. σ Standard deviation of the error term. P-ratio. Ratio between variance of the random
638 effect and the total variance.

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T max	Single model	Random components	Final Equations	Yield efficiency (Kg m ⁻³)
CR		-0.165	$\Psi=-0.019-0.046T_{max}$	1.63
S-1	$\Psi=0.146-0.046T_{max}$	0.017	$\Psi=0.163-0.046T_{max}$	0.02
S-2		0.148	$\Psi=0.294-0.046T_{max}$	0.31

652 Table 8. Regression equations obtained with Tmax. Lineal model which considered only all
653 term as fixed (single model). The random components of intercept term in each zones and
654 final equations with mixed models. Yield efficiency calculated as the ratio between the yield
655 and tree volume in each location.

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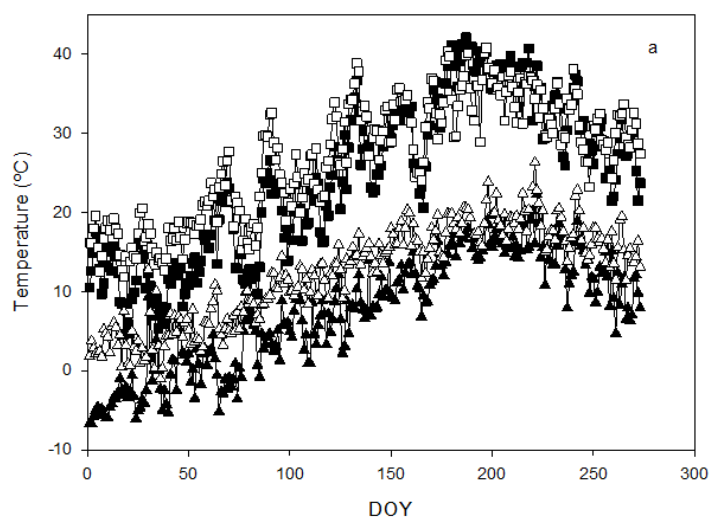
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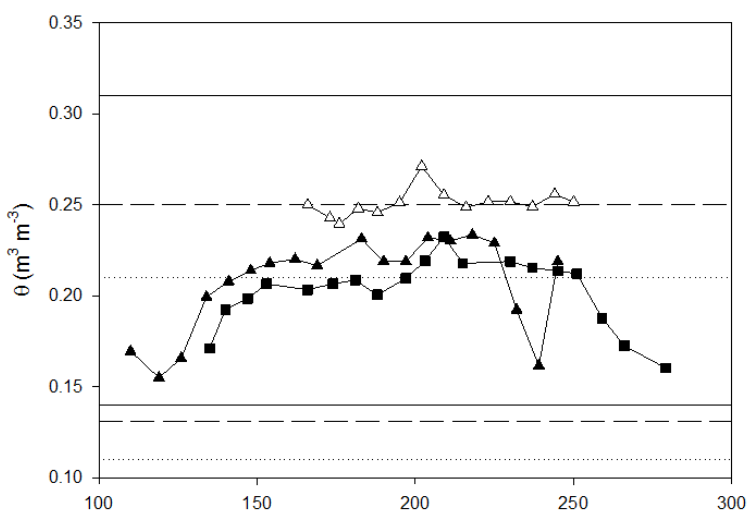
662 Figures



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664 Figure 1. Seasonal pattern of the climatic variables in Seville (empty symbols) and Ciudad
665 Real (full symbols). (a) Maximum and minimum temperatures (b) Reference
666 evapotranspiration (ET_o) and rain. All the data were obtained from automatic weather station
667 near (around 100 m) to the experimental orchards named as CR and S1.

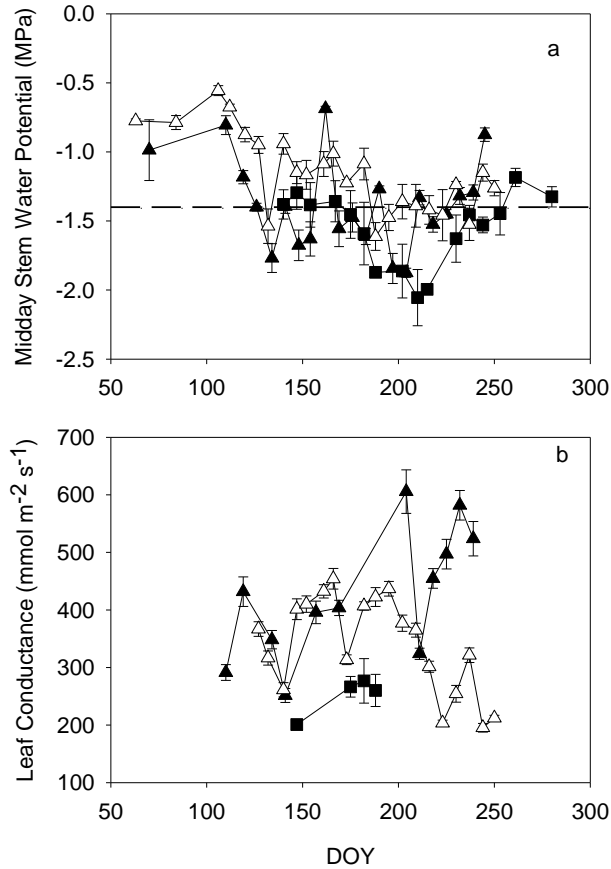
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680 Figure 2. Seasonal pattern of soil water content (θ) in the three experimental orchards. CR,
681 Full square and dash line; S-1, full triangle and dot line; S-2, empty triangle and solid line.
682 Horizontal lines represent the field capacity and permanent wilting point of the soils. Each
683 point is the average of 4 measurements in CR and S-2 orchards and 3 in S-1 orchards.

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696 Figure 3. Pattern of midday stem water potential (a) and leaf conductance (b) in the three
 697 experimental orchards. Full square, CR ; Full triangle, S1; Empty triangle S2. Each point is
 698 the average of 6 to 8 data depending of the orchard consider. Vertical bars represent standard
 699 error. Horizontal dash line in figure “a” shows the threshold value of water potential for the
 700 three orchards (-1.4 MPa).

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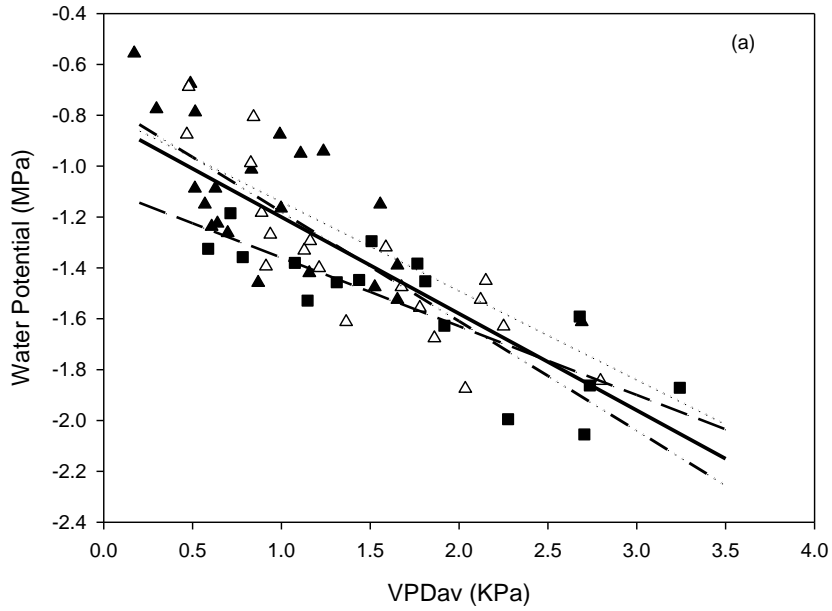
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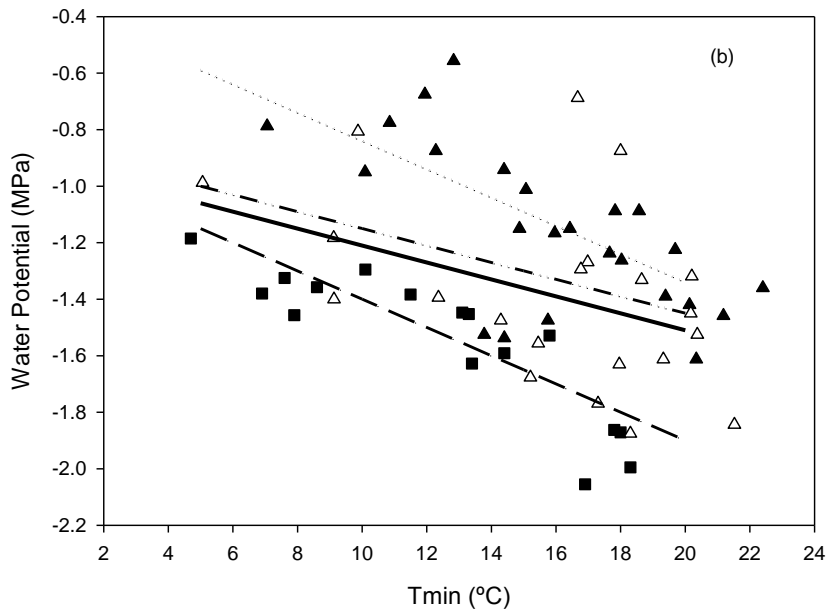
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709 Figure 4. Relationship between VPDav (a) and Tmin (b) vs midday stem water potential.

710 Square and dash line represent the data of CR orchard. Full triangle and dot lines represent

711 the data of S-1 orchard. Empty data and dot and dash line represent the data of S-2 orchard.

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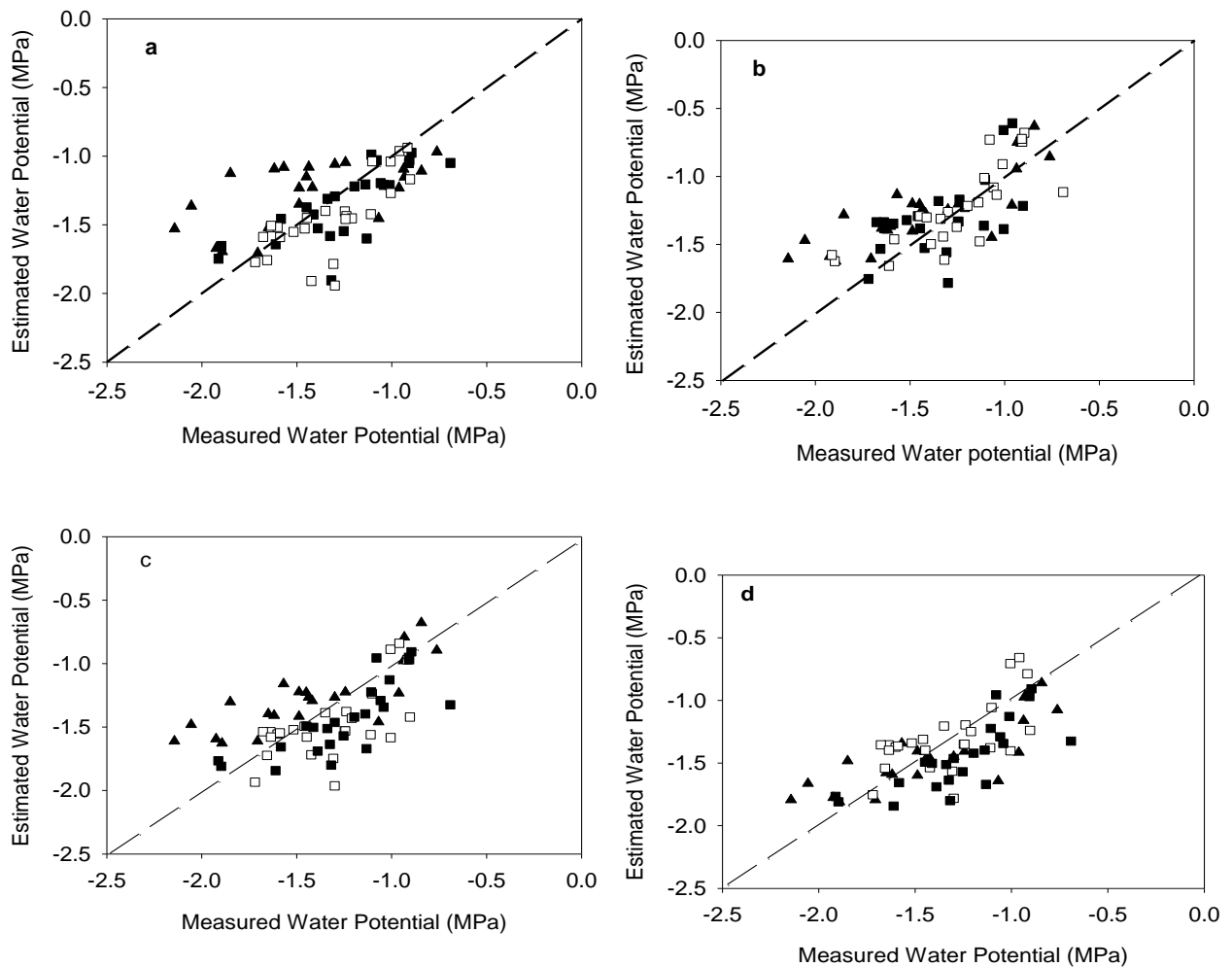


Figure 5. Relationship between measured and estimated stem water potential measured using the equation of average VPDav (a) and Tmax (b) (Table 5) and Tmax with mixed models (c) (Table 8) and Tmax with mixed models considered current fruit load (d) (see text). Dash line represents the 1:1 relationship. Data for validation include: triangle, S-1 orchard 2014 season; fill square CR orchard 2013 season; empty square, CR orchard 2012 season. Best fits for the equations were: (a) $Y=-0.72+0.47VPD_{av}$; $R^2=0.35^{***}$; (b) $Y=-0.43+0.62T_{max}$; $R^2=0.51^{***}$; (c) $Y=-0.68+0.54T_{max}$; $R^2=0.37^{***}$; (d) $Y=-0.60+0.60T_{max}^{***}$; $R^2=0.48^{***}$