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INVESTIGATING EFFECTS OF OVER-IRRIGATION AND DEFICIT IRRIGATION ON YIELD AND FRUIT QUALITY IN PINK LADY™ ‘ROSY GLOW’ APPLE

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ABSTRACT

Fruit production has to be adapted to climate change that is often associated with heat and water deficit episodes. To develop efficient strategies on how to manage commercial orchards under deficit water supply, we need to know the effects of water-stress on crop production. However, when the water supply is abundant apple growers often think that over-irrigation gives higher marketable fruit yield than potential evapotranspiration-based or sensor-based (e.g. tensiometer, dendrometer) irrigation. We therefore aimed to evaluate the effects of three water regimes, namely well-watered (100% of crop evapotranspiration – ETC, WW), 25% of ETC water deficit over the season (water-stressed, WS), and twofold of WW (200% of ETC, 2xWW), on midday stem water potential (SWP), crop yield and fruit quality of Pink Lady™ ‘Rosy Glow’ apples. As expected, SWP was lower in WS than in the others, but both WS and 2xWW decreased fruit yield, although 2xWW tended to increase yield in the >70% color class and ensured quite a constant amount of yield at each picking time. Soluble solid content (SSC) in fruit was higher in WS. As a whole, our results suggest that over-irrigation that is sometimes recommended to keep a safety margin should be considered with caution. Rather, a mild water-stress, between WS and WW in our experiment, may represent a good compromise for a good quality yield.

Key words: color index, drought, *Malus × domestica*, picking time, tree water status

INTRODUCTION

Today’s agricultural sector consumes more than two-thirds of the world’s total useful water, and the allocated water quantity for agriculture has decreased because of increasing human population and climate change [Chai et al. 2015]. In parallel with the increase in human population, freshwater and food demand will be severely increased almost everywhere [Jenkins 2003]. We need more knowledge about how to maintain crop production under deficit water supply conditions [Akhtar and Nazir 2013]. The interest in optimizing irrigation scheduling has been continuously grow-

ing in recent years, especially towards decreasing implementation rates. However, apple growers often want to add a safety factor to avoid tree water-stress [Naor 2006]. Despite numerous studies of the physiological responses of fruit trees to abiotic stress conditions (i.e. water-stress and water-logging), we lack practical references of apple tree-water relations under the conditions of over-irrigation and deficit irrigation. We hypothesized that over-irrigation that can be proposed through the concept of safety factor could also have a negative effect on total yield and fruit quality.

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We also wanted to assess that these negative effects could also be evidenced on a late apple cultivar which has a great part of fruit ripening in autumn. The objectives of the study were to determine (1) tree water status, (2) yield and (3) fruit quality in response to two extreme water regimes, water stress and over-irrigation, compared to a fully-irrigated control on Pink Lady™ ‘Rosy Glow’ apple, referred to as ‘Rosy Glow’ here, a highly colored strain of ‘Cripps Pink’, discovered in Australia.

MATERIALS AND METHODS

Experimental site and plant materials. This study was conducted in a commercial apple orchard in France (latitude 43°42'N, longitude 5°05'E – altitude 120 m) over two years (2013 and 2014). Soil with a pH of ~7.5–8.5 at the orchard is silt but well-drained and well-structured characteristics. The orchard was planted in 2000 with 4 × 1 m inter-row and intra-row spacing, respectively, in a north-south orientation using a ‘Fuji’/M.9 cultivar/rootstock combination. The cultivar was changed to ‘Rosy Glow’ by top-working in 2010. Trees had been trained since grafting as centrifugal training system [Lauri et al. 2004]. They were chemically thinned with Floristar® (1% ammonium thiosulphate – ATS) applied at 15 g L⁻¹, 2 and 6 days after full bloom in both trial years. The full bloom date was recorded

as 15th of April in the two years. The crop load was homogenized with hand-thinning after the physiological drop to reach a crop load of 7.5 fruits per cm² of branch cross-sectional area. Weeds were controlled. All trees received the same local crop husbandry practices in the orchard.

Water regimes. Before this experiment, all trees in the orchard received full irrigation (i.e. well-watered). Because soil at the orchard was homogeneous in texture, water regimes were blocked to reduce the amount of irrigation pipe needed for the study. The water regimes were replicated five times including three uniform trees in each plot (i.e. 5 × 3 = 15 trees in total per water regime) with a block design. The plots were separated from each other by ten guards. Irrigation was begun in April and finished just before the fall rains, at the beginning of September, i.e. two months before harvest. Trees were irrigated on a daily basis (4 pulses per day) by drip irrigation system. The discharge of the system was 1.6 l·h⁻¹ with a dripper spacing of 0.5 m. ET_c was calculated using the FAO standardized Penman-Monteith equation [Allen et al. 1998]. Climate data were obtained from a nearby weather station (<http://www.agrometeo.fr/>) (fig. 1). Trees were assigned to three water regimes over the whole-season: Control, i.e. well-watered (100% of ET_c, WW), 25% of ET_c water deficit (water-stressed, WS), and over-irrigation, twofold of WW (200% of ET_c, 2xWW).

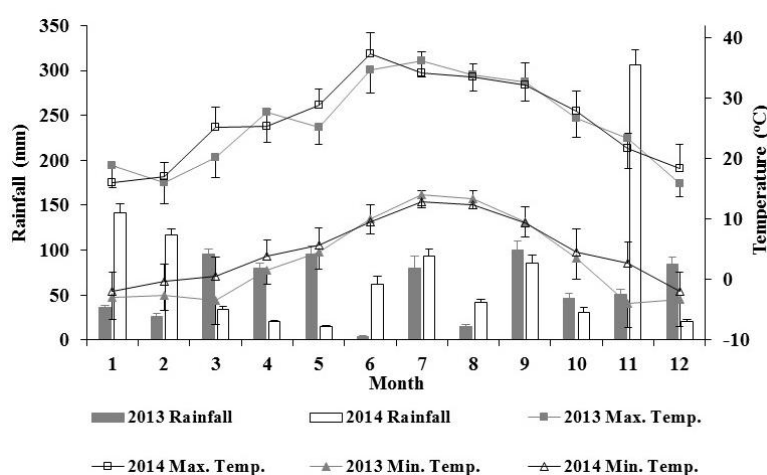


Fig. 1. Climate data at the research area over two years (2013 and 2014). The values shown (bars or symbols) are means ± standard deviation (SD)

Data collection. SWP was measured at solar noon with a pressure chamber (Arimad-3000; Plant Water Potential Measurement Device for Agricultural, Israel) from leaves located in the inner part of the tree canopy. To ensure water equilibrium between leaf and stem, selected leaves were inserted into a plastic bag covered with aluminum foil at least 1 hour before measurement [Naor et al. 2008]. SWP was preferred to determine water deficit effect instead of soil moisture measurements. Fruit yield ($\text{t}\cdot\text{ha}^{-1}$) per tree was recorded at harvest, during November in the two years. Yield efficiency ($\text{kg}\cdot\text{cm}^{-2}$) was calculated as the ratio of fruit yield (kg) to tree size (using the proxy of trunk cross-sectional area, TCSA; cm^2). Selective picking was carried out three times separated by 10 to 15 days. The differences in yield among water regimes at each harvest time were calculated. At each harvest, all fruits per tree were graded in terms of equatorial diameter (mm) and percentage of pink color (%) using an automatic fruit sorting machine (Calibreuse Pomone II 1L, <http://www.mafroda.com>). Fruit firmness ($\text{kg}\cdot\text{cm}^{-2}$), SSC (%), titratable acidity (%) and juiciness (ratio of the juice to dry matter) were measured on a sample of 30 fruits per water regime taken randomly, at first and second harvest times, using a computer-controlled quality control machine (Setop Giraud Technologie, Pimprenelle, France, www.setop.fr).

Data analysis. Statistical analysis was performed using SAS-JMP software version 7.0 (<http://www.jmp.com/software/>). Due to the TCSA of trees at the onset of trial was significant, it was used as covariate for yield efficiency. When differences were considered as significant at $P < 0.05$, means were separated by different letters using Fisher's Least Significant Difference (LSD) multiple comparison test. We figured the associated P values in the paper.

RESULTS AND DISCUSSION

As a whole, SWP indicated a higher water-stress in WS than in the other water regimes confirming the established observation of SWP as a relevant and reliable water deficit indicator in fruit trees [McCutchan and Shackel 1992, Naor et al. 2008,

Sadras et al. 2011]. SWP can provide information physiologists need to decide whether the plant is in water stress or not. Thus, according to our previous experiences in the Mediterranean climatic conditions (hot and dry summers), roots begin to absorb water from soil immediately after irrigation, which leads to overestimating when soil moisture measurements are used to schedule irrigation. The other two water regimes, 2xWW, and WW showed similar responses for SWP on average (tab. 1). This result indicated that over-irrigation did not entail water-logging in our experiment, likely due to the relatively well-drained soil characteristics.

Greater cumulative yield over the two years was determined in WW ($138.06 \pm 15.05 \text{ t}\cdot\text{ha}^{-1}$) which was significantly higher than 2xWW ($127.52 \pm 18.82 \text{ t}\cdot\text{ha}^{-1}$) and WS ($119.96 \pm 9.79 \text{ t}\cdot\text{ha}^{-1}$), respectively (fig. 2). The decrease of yield under WS can be related with more negative SWP [Naor 2006, Naor et al. 2008, Stewart et al. 2011]. On the other hand, 2xWW may cause oxygen deficiency in a soil which may adversely affect crop yield [Sun et al. 1995, Akhtar and Nazir 2013] without altering SWP, at least within our range of values. However, considering the positive relationship between total yield and the absolute value of SWP [Naor et al. 2008], an alternative hypothesis would be that apple trees maintain a quite constant SWP (tab. 1) at the expense of a higher total yield under over-irrigation (fig. 2).

As for cumulative yield, yield efficiency was greater in WW ($0.82 \pm 0.28 \text{ kg}\cdot\text{cm}^{-2} \text{ TCSA}$) than in the other two water regimes (fig. 3). At tree level, the effect of an abiotic stress factor is closely associated with the decrease of the fruitfulness of a plant [Yordanov et al. 2000, Jaleel et al. 2009, Stewart et al. 2011].

There were significant differences in yield between water regimes for each picking time. Yield in 2xWW at each picking time was quite constant which would facilitate the organization of harvest for growers. At first pick, yield was lower in WW than in the other two water regimes, but at third pick, the results were opposite (fig. 4). These results indicated that WS and 2xWW both increase precocity compared to WW, which could be well explained by the lower total yield.

Table 1. Mean midday stem water potentials (SWP, MPa) in response to water regime in 2013

Date	n	WW	WS	2xWW	P-value
June 27	5	-1.35 ±0.12 ab	-1.52 ±0.21 a	-1.23 ±0.06 b	0.0277
July 3	5	-0.67 ±0.08 b	-0.93 ±0.16 a	-0.67 ±0.03 b	0.0440
July 9	5	-1.58 ±0.11 b	-1.80 ±0.15 a	-1.97 ±0.22 a	0.0079
July 18	5	-0.91 ±0.24	-1.16 ±0.23	-1.08 ±0.30	0.4114
July 23	5	-1.84 ±0.18 ab	-2.03 ±0.07 a	-1.77 ±0.12 b	0.0405
Aug. 1	5	-1.54 ±0.05 b	-1.76 ±0.11 ab	-1.93 ±0.20 a	0.0395
Aug. 6	5	-1.79 ±0.19	-1.89 ±0.07	-1.68 ±0.19	0.1973
Aug. 14	5	-1.47 ±0.17 b	-1.84 ±0.21 a	-1.52 ±0.08 b	0.0025
Aug. 21	5	-1.69 ±0.19 a	-1.83 ±0.20 a	-1.52 ±0.09 b	0.0059
Aug. 27	5	-1.66 ±0.15 b	-1.83 ±0.09 a	-1.93 ±0.12 a	0.0170
Sept. 5	5	-1.96 ±0.15	-1.99 ±0.13	-1.91 ±0.08	0.6088
Sept. 10	5	-1.36 ±0.14 b	-1.76 ±0.17 a	-1.42 ±0.12 b	0.0057
Sept. 18	5	-1.17 ±0.26 b	-1.45 ±0.20 a	-1.04 ±0.11 b	0.0093
Sept. 24	5	-1.33 ±0.37	-1.36 ±0.20	-1.13 ±0.14	0.2931
Oct. 2	5	-1.23 ±0.16	-1.14 ±0.22	-0.92 ±0.08	0.0591
Oct. 9	5	-0.89 ±0.19	-0.95 ±0.12	-0.85 ±0.12	0.5980
Oct. 15	5	-0.56 ±0.05	-0.61 ±0.08	-0.48 ±0.06	0.0503
Oct. 23	5	-0.91 ±0.05	-0.99 ±0.15	-0.85 ±0.09	0.2203
Whole-season	90	-1.30 ±0.48 b	-1.47 ±0.49 a	-1.23 ±0.59 b	0.0063

Within each measurement date, different letters indicate significant differences at $P < 0.05$. The values shown are means \pm SD

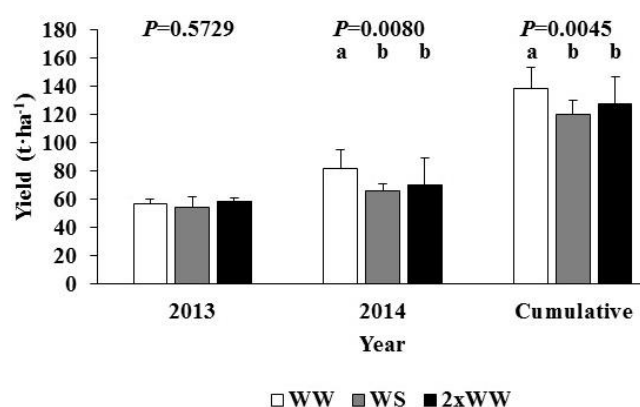


Fig. 2. Effect of water regimes on yield of ‘Rosy Glow’ apple in 2013 and 2014. Within each year, different letters indicate significant differences at $P < 0.05$. The values shown are means \pm SD

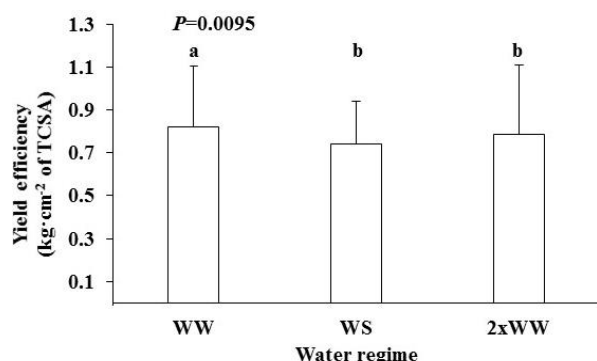


Fig. 3. Effect of water regimes on yield efficiency of ‘Rosy Glow’ apple in 2014. Different letters indicate significant differences at $P < 0.05$. The values shown are means \pm SD

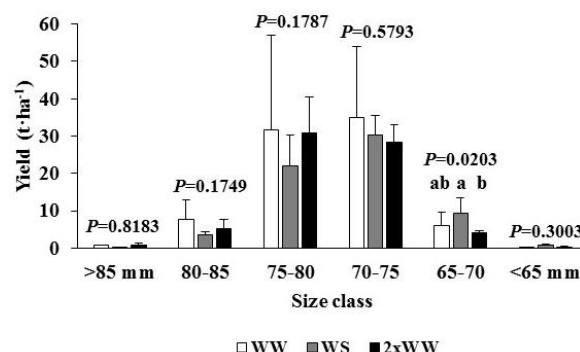


Fig. 5. Effect of water regimes on yield of ‘Rosy Glow’ apple per size class in 2014. Within each size class, different letters indicate significant differences at $P < 0.05$. The values shown are means \pm SD

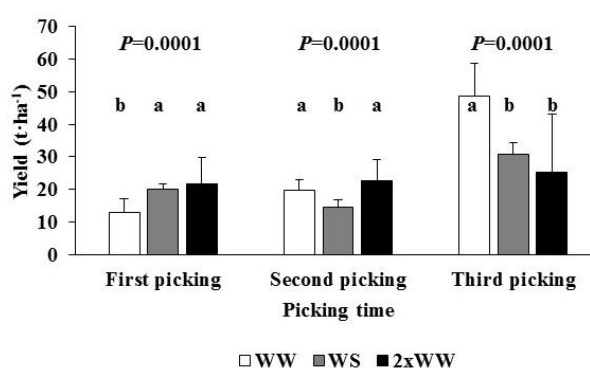


Fig. 4. Effect of water regimes on yield of ‘Rosy Glow’ apple at each picking time in 2014. Within each picking time, different letters indicate significant differences at $P < 0.05$. The values shown are means \pm SD

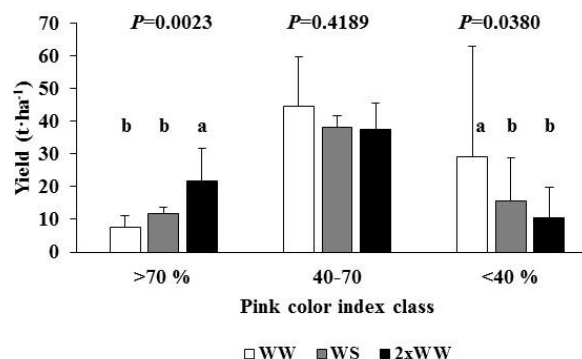


Fig. 6. Effect of water regimes on yield of ‘Rosy Glow’ apple per pink color index class in 2014. Within each pink color index class, different letters indicate significant differences at $P < 0.05$. The values shown are means \pm SD

There were no statistical differences between water regimes for the amount of fruits in the 75–80 mm and the 70–75 mm size classes, the biggest part of the total yield in 2014. There was only a slightly higher number of fruit in the 65–70 mm size class for WS (fig. 5). Yield in the 40–70% pink color index class that covers the greatest part of total yield in 2014 was not significantly different between water regimes. WW trees had higher yield in <40% pink color index class whereas 2xWW had higher yield in >70% pink color index class (fig. 6). Our results thus showed that the water regime affected fruit color. Although not measured here, a vi-

sual assessment of shoot growth indicated that there was a reduced vegetative growth in WS and 2xWW, which in turn would have increased light penetration within the tree.

There were no significant differences between water regimes for fruit quality traits, except for SSC which was higher in WS ($13.69 \pm 0.59\%$) (tab. 2). A higher SSC can be achieved by water deficit that reduces total vegetative growth thus maintaining light penetration [Crisosto et al. 1995], but also reduces fruit growth (see the higher amount of fruit in the 70–75 class for WS; fig. 5) thus increasing the relative amount of soluble matter.

Table 2. Effect of water regimes on SSC, firmness, acidity and juiciness in 2014. Data are means of first and second picking times

Water regime	SSC (%)	Firmness (kg·cm ⁻²)	Acidity (%)	Juiciness
WW	13.29 ±0.67 b	6.62 ±0.52	5.18 ±0.26	25.80 ±0.86
WS	13.69 ±0.59 a	6.63 ±0.46	5.62 ±0.60	25.60 ±1.03
2xWW	13.13 ±0.53 b	6.69 ±0.49	5.40 ±0.37	25.85 ±1.15
<i>P</i> -value	<0.0001	0.6390	0.3149	0.7325

Within columns, different letters indicate significant differences at $P < 0.05$. The values shown are means ± SD

CONCLUSIONS

To conclude, SWP, a direct physiological measure of tree water status, showed higher absolute values in the water deficit regime, WS, than in the others. Fruit SSC was greater in WS. Both extreme water regimes, WS and over-irrigation, 2xWW, decreased fruit yield. The number of fruit in the most represented fruit size (70–75 mm and 75–80 mm) and color (40–70%) classes were not altered by water regimes. Our results suggest that growers should avoid over-irrigation even to keep a safety margin. A mild water-stress, likely between WS as done here and WW, may represent a good compromise to keep a good yield maintaining high fruit quality and color.

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