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Improving yield and fruit quality of peach cv. 'Flordastar' by potassium foliar spray associated to regulated deficit irrigation

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Abstract - The importance of potassium leaf application was highlighted in this study. A field experiment was carried out in a commercial orchard of early peach cultivar 'Flordastar'. Trees were subjected to combination of two irrigation regimes (FI and DI were respectively full and deficit irrigation) and foliar potassium spray (K+) and no potassium supply (K-). Four treatments were consequently considered such as FI/K+, FI/K-, DI/K+ and DI/K-. Yield, fruit quality and vegetative growth were measured for each treatment. Results showed differences between treatments. At harvest, the highest yield was observed in trees which received potassium application especially with FI. For both treatments FI/K+ and DI/K+ fruit diameter and total soluble solids were increased however firmness was reduced. Measurements of vegetative growth showed slight differences between treatments except FI/K+ which increased shoot length. Potassium leaf content was high in K+ treatments.

Keywords: potassium, irrigation, yield, quality, peach.

1. Introduction

Presently the scenario of climate change predicts an increase in aridity especially a decrease in precipitation and a rise in average temperature. The Mediterranean climate is concerned by these fluctuations (IPCC 2007). As a consequence the fruit tree production is affected (Ghrab et al. 2008). Some fruit cultivars will certainly show different behavior and fruit quality will be influenced. The chilling and the heat requirement have a significant effect on tree productivity (Ghrab et al, 2016). In Tunisia, peach crop presents an important economic value. As a consequence various cultivars were introduced leading to cover a large ripening period from April to September (Ghrab et al, 2016). 'Flordastar' have a considerable interest for its earliest ripening date. In spite of the improvement of orchard training and trees tend to be very vigorous and reach full bearing potential rapidly (Dejong et al, 1994), some fruit characteristics remain mediocre. Particularly the technological characteristics of fruits such as sugar concentration and acidity and sometimes firmness were poor. Previously, various alternatives were researched for improving fruit quality. The mineral nutrition was usually modified and it is one of the major tools to optimize fruit yield and quality (Tagliavini and Marangoni, 2002). Seen that, potassium element was classified as a quality key of fruits some experimentations were done. In peach tree, Ben Mimoun et al (2009) indicated that the use of potassium foliar fertilization increased peach weight at harvest. Some aspects of fruit quality were also improved. For olive tree it was shown the importance of potassium fertilization in increasing the yield and oil yield (Ben Mimoun et al, 2008, Elloumi et al, 2009). Previously, it was highlighted the importance of potassium during the fruit growth period as there is an intense mobilization of potassium from leaf to fruit (Weinbaum et al. 1994). Likewise potassium is involved in some physiological process in plant adaptation to conferring abiotic and biotic stress. Benlloch-Gonzalez et al. (2008) affirmed that potassium starvation inhibited water-stress-induced stomatal closure. In olive trees, potassium starvation favored stomatal conductance and transpiration continue, as well as inhibiting shoot growth. Stomatal resistance is therefore decreased, and CO_2 assimilation is enhanced by high potassium supply under environmental conditions that promote stomtal opening (Kwak et al. 2001). In another hand, the use of regulated deficit irrigation was adopted for saving water and ultimately ameliorated fruit characteristics. In peach tree, water restriction during some stages of fruit development was recommended (Ben Mechlia et al. 2002; Li et al. 1989). It was usually applied in the stone hardening phase of the fruit development because in this phase the fruit growth is very slow and the shoots grow very fast. That's why the deficit irrigation in this period controls vegetative growth (Chalmers et al. 1981; Li et al. 1989; Girona et al. 1993) and improving fruit quality (Li et al. 1989). In early-maturing cultivars, the interest of regulated deficit irrigation practices should be continued to postharvest water-saving strategies. Both the limitation of shoot growth and the reserve gain for the trunk during this period does not affect the productivity in the next year (Mounzer et al. 2008). The idea of the combination of deficit irrigation with potassium foliar spray is proposed for improvement of the fruit yield and quality at the same time reducing the amount of irrigation water. The establishment of the present experimental design considered previous results which reported that foliar fertilizer applications showed irregular effects on fruit trees (Ferreira et al. 1986; Smith et al. 1987; Khemira et al. 1999). In fact, various factors were underlined such as: leaf age, salt degree, foliar application frequency and hydraulic status of trees (Swietlik and Faust 1984). Restrepo-Diaz et al. (2008) affirmed that potassium foliar application on olive trees should be carried out in Spring under rainfed conditions, when trees present a good water status and there are many younger leaves, since foliar applications seems to be more effective. This work aimed the improvement of 'Flordastar' peach quality and the water use efficiency using the combination of deficit irrigation and potassium foliar spray.

2. Material and Methods

2.1. Experimental site

The experiment was applied in a ten year old early season peach cultivar (Prunus persica (L.) cv 'Flordastar') drip irrigated orchard located in 'Sidi Khélifa' (36.26°, 10.37°) in the central region of Tunisia. The cultivar was grafted on 'Garnem' rootstock. Trees were planted at a spacing of 6 m by 4 m. The soil of the plot has an average depth of 1.5 m and is a sandy-loam soil and with low content of potassium (Table 1). The peach orchard was managed according to the normal cultural practices in the region: irrigations were applied daily with an automated drip system. Two laterals row were located on both sides from trees at 0.5 m from the trunk. Self compensating emitters of 4 L h^{-1} were placed depending on irrigation treatment. Soluble fertilizers were applied with the drip irrigation system along the season (phosphoric acid at the beginning of growth cycle, ammonium nitrate on three applications (after flowering, after fruiting, after harvest) and Iron (Sequestrene) was also used as 40-150g per tree). Fruits were thinned in early Mars by hand.

Table 1: Soil analysis of the experimental orchard in ppm

Depth (cm)	Phosphore (P)	Potassium (K)	Calcium (Ca)	Sodium (Na)
0-30	32±0.60	17±2	35.33±0.73	136±7.81
30-60	26±1.10	16.5±1.32	33.03±0.95	135.66±25.14
60-90	24.3±1	19.93±1.10	36.43±0.75	121.33±23.96

2.2. Treatments

The experiment design was a complete randomized block with five replicates and four treatments which consist on combinations between water regime and foliar potassium application. Two irrigation treatments such as control or fully irrigated (*FI*) treatment with 100% of the irrigation requirements estimated by the own farmer according to the FAO methodology (Allen et al. 1998) and regulated deficit irrigation (*RDI*) like the control except during the first and the second stages of fruit growth trees received only 50% of the amount of required water. The two stages correspond respectively to the fruit cell division and stone hardening phase of fruit development. Basing on results of Ben Mechlia et al (2002) which affirmed that the greatest decrease of yield was observed for water reduction during the final stage of fruit growth these irrigation treatments were defined. The length of the period of water restriction was around two months and started after fruit set. Each block consisted of a row of 20 trees. In the full treatment each tree was irrigated with four emitters of 4 L h^{-1} whereas in the (*RDI*) treatment the 4 L h^{-1}emitters were removed and substituted by emitters of 2 L h^{-1}. Irrigations were applied daily and the two water regimes were applied simultaneously and with the same duration. Irrigation scheduling was depending on the crop coefficient which started from bud break to post harvest period. The two water regimes were associated with two potassium treatments such as: +*K* treatment with potassium foliar application at 100% of tree needs (430g of K_2O) divided on three times and –*K* treatment without potassium (0g of K_2O). The requirement for potassium was estimated for 'flordastar' peach tree as from the calculation based on the K contents of the expected yields and the pruning wood. The fertilizer used is the sulphate of potash (52%K_2O). Potassium applications were done using a mechanical sprayer of 10 liters starting in fruiting period. In brief four combined treatments were carried out: *FI/K*$^+$, *FI/K*$^-$, *RDI/K*$^+$, *RDI/K*$^-$. The amount water of FI was 650mm and 450mm for the DI treatment.

2.3. Measurements

Yield and fruit quality

The fruits of each tree of the different treatments were individually harvested. All the fruits of each tree were weighted. The average yield was determined from these data. Productivity of irrigation water or the water use efficiency (WUE) in the different treatments was calculated as the fruit yield divided by the amount of applied water (kg mm^{-1}). To control quality parameters a subsample of 10 fruits per tree was processed in the laboratory and different measurements were done: fruit weight, diameter, visual skin color, firmness, total soluble solids content and total acidity. The firmness was measured using a penetrometer (Effegi) after removing approximately a 2.5 cm diameter slice of peel with a standard peeler on the two opposite sides of each fruit. The fleshy part was mixed by a kitchen juicer and the juice was used for the following analysis:

The total soluble solids content (TSSC) expressed in °Brix measured by digital refractometer. The total acidity (TA) was based on the neutralisation of the acids present in the fruit juice with a basic solution (NaOH 0.1 N). It was expressed as the quantity of malic acid in the juice (g/l). The sugar-to-acid ratio (TSSC/TA) was also calculated from recorded data to assess the influence of the different treatments in this maturity index. TSSC/TA is the fruit quality parameter that is ultimately most closely related with consumer acceptance of peaches (Crisosto et al. 2006).

Vegetative growth and mineral leaf analysis

Measurements of five shoots per direction for each tree were done during the growth cycle. To evaluate the leaf nutrient concentration of different element, leaves from each treatment were collected every week. A dozen of leaf samples picked from each direction were cleaned, dried and mixed. The leaf Potassium content (K) was using 100 mg of dry leaves sample ashed in a muffle furnace at 700 ◦C and mineralized with HNO3. The potassium content was determined by spectrophotometry.

2.4. Statistical analysis

Statistical analyses were performed adopting analysis of variance (ANOVA) of the SPSS software (Statistics 20). Comparisons among treatments were performed using Duncan test at $P = 0.05$.

3. Results and discussion

3.1. Yield and fruit quality

Significant effects of treatments in fruit production (Kg tree^{-1}) were noted (Table 2). The fruit production was significantly higher in the FI/K+ (84.83 Kg tree^{-1}) than in the DI/K+ (70.66), FI/K- (45.9 Kg tree^{-1}) and DI/K- (51.73 Kg tree^{-1}) treatments. Similarly for two irrigation regimes potassium application increased yield. Also the water use efficiency clearly showed differences between treatments (Table 2). In fact, FI/K+ and DI/K+ reached the highest value and the DI/K- treatment was not statistically different. Both treatments (potassium application and deficit irrigation) increased the WUE. These results showed the importance role of potassium in yield and water use efficiency (WUE). These results are in total agreement with the previous researches about benefits of potassium application especially in the case of abiotic stress particularly in the drought conditions. Fallahi et al. (2010) and Rowley (2013) affirmed that the application of potassium respectively in apple and cherry trees increased yield. For Clementine mandarin, Hammami et al. (2010) affirmed that fruit yield was positively associated with nitrogen (r2 = 0.91) and potassium (r2 = 0.84) rates. Also, Alva et al. (2006) affirmed that citrus yield increased with the increase of potassium foliar spray (2 sprays) compared to those unsprayed. Our experiment tested not only the potassium application but the association to deficit irrigation. Results were important seen that a notable improvement of WUE was observed. Previous studies on deficit irrigation showed the reduction of the amount of applied water improved the WUE in olive (Dbara et al. 2011), in almonds (Egea et al. 2010) and in citrus (Pérez-Pérez at al, 2010) orchards. For peach specie Abrisqueta et al (2010) and Ghrab et al (2013) revealed that the water productivity (WP) was strongly influenced by the irrigation water supply. It increased with the reduction of water application. In this case, the reduction of water amount associated with potassium supply given interest results.

Table 2: Water use efficiency (WUE) for FI/K^-, FI/K^+, DI/K^- and DI/K^+ treatments (Kg m^{-3})

Treatments	Yield (Kg $tree^{-1}$)	WUE (Kg m^{-3})
FI/K^-	51.73 ±1.61 *a*	3.31 *a*
FI/K^+	84.83 ±0.61 *c*	5.44 *b*
DI/K^-	45.90 ±1.45 *a*	4.25 *ab*
DI/K^+	70.66 ±1.30 *b*	6.54 *b*

Values in the same column followed by the same letter are not significantly different at 0.05.

Concerning fruits, significant differences between treatments in the quality parameters were found. The average diameter and the average weight of the fruit were strongly affected by treatments (Figure 1). The FI/K+ treatment increased fruit diameter and weight comparatively to other treatments. Even with deficit irrigation regime, the potassium application increased these parameters. Treatments without potassium supply showed that the best values were observed in full irrigated trees. Figure 3 presents the results of pulp and dry matter fractions in different treatments. No significant differences were obtained for the first parameter (more than 90%) however the second was affected by treatments. So, the important values were noted in DI treatments (from 41 to 66%) comparatively to FI (25 to 35). It is clearly that potassium application increased this parameter for both irrigation regimes. The measurements of firmness presented in the figure 4 showed that potassium supply decreased it for the two irrigation regime which also affected it. In fact fruits harvested from full irrigated trees presented lowest values comparatively to fruits from deficit irrigated trees for the same potassium treatment. The table 3 illustrates the average values of juice total soluble solids content (TSSC, in °Brix), juice total acidity (TA in g/l) and TSSC/TA ratio for all treatments. Results showed that potassium application increased TSSC for both irrigation regimes whereas the total acidity was unaffected. As a consequence, the TSSC/TA ratio follows the same TSSC response.

Table 3: Average values of juice total soluble solids content (TSSC, in °Brix), juice total acidity (TA in g/l) and TSSC/TA ratio in FI/K-, FI/K+, DI/K- and DI/K+ treatments

Treatments	TSSC (°Brix)	TA (g/l)	TSSC/TA
FI/K^-	7.11±0.37	1.41±0.066	5.04
FI/K^+	8.44±0.23	1.31±0.067	6.44
DI/K^-	7.46±0.13	1.38±0.065	5.40
DI/K^+	8.55±0.42	1.23±0.109	6.95

Values in the same column followed by the same letter are not significantly different at 0.05.

In this work fruit characteristics highlight the importance of applied treatments and confirm the majority of previous studies. Potassium supply increased fruit size (Fallahi et al. 2010; Stiles 1994) in spite that deficit irrigation had negative effects in this parameter (Ben Mechlia et al. 2002). Ben Mimoun et al (2008) affirmed that potassium foliar spray treatment increased peach weight. Also, Ruiz (2006) related the higher weight observed on nectarine to the greater flux of potassium to the fruit. For cherry and pear trees, it was affirmed that potassium is important for the final fruit quality at harvest (Dekers and schoofts 2002). Moreover, it is seen that insufficient potassium supply decrease photosynthesis of leaves; which in turn, lowers sugar concentrations (Faust 1989). It is for this reason, treatments with potassium (FI/K+ and DI/K+) given fruits with higher TSSC. However Ruiz (2006) found no significant difference both in TSSC and in firmness. For TA, results showed no significant differences between treatments contrary to those of Hansen (1980), Fallahi et al. (2010) and Stiles (1994).

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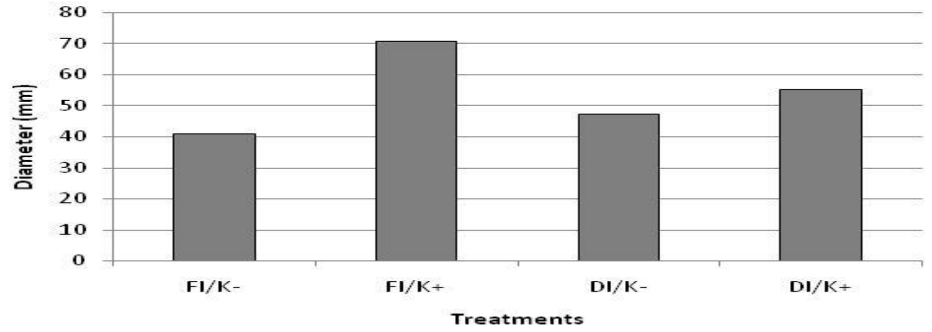

Figure 1: Average fruit diameter (mm) measured at harvest in Full (FI) and deficit (DI) irrigated trees with (K+) and nor (K-) potassium foliar application. Each value is the average of 15 measurements. The length of the vertical lines in each data value indicates twice the standard error.

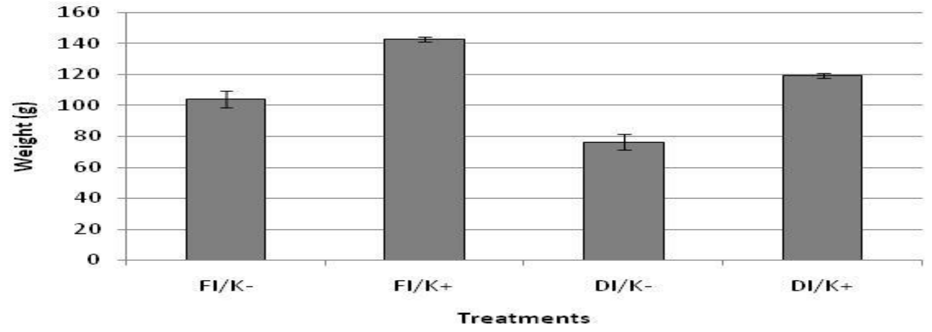

Figure 2: Average fruit weight (g) measured at harvest in Full (FI) and deficit (DI) irrigated trees with (K+) and nor (K-) potassium foliar application. Each value is the average of 15 measurements. The length of the vertical lines in each data value indicates twice the standard error.

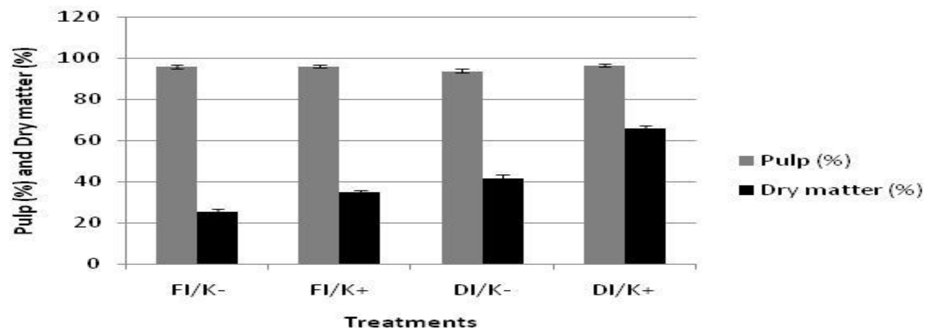

Figure 3: Average pulp and dry matter fractions of fruits measured at harvest in Full (FI) and deficit (DI) irrigated trees with (K+) and nor (K-) potassium foliar application. Each value is the average of 15 measurements. The length of the vertical lines in each data value indicates twice the standard error.

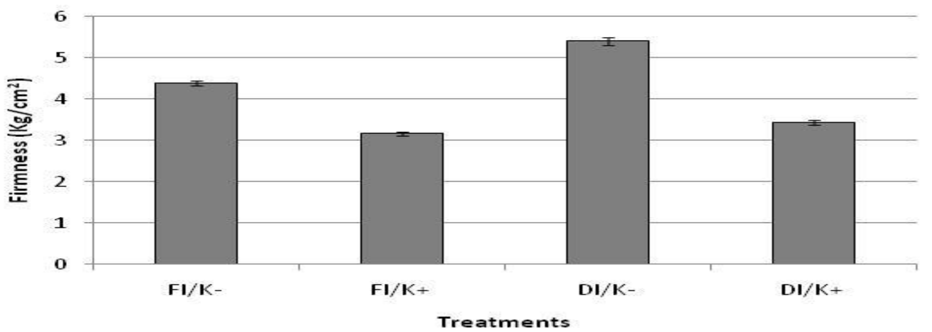

Figure 4: Average fruit firmness (Kg/0.5cm2) measured at harvest in Full (FI) and deficit (DI) irrigated trees with (K+) and nor (K-) potassium foliar application. Each value is the average of 15 measurements. The length of the vertical lines in each data value indicates twice the standard error.

3.2. Vegetative growth and leaf mineral analysis

The measurement of shoot length showed differences between treatments (Figure 5). The FI/K+ treatment accelerated the shoot growth in contrast to DI/K- treatment which presented short shoots. The FI/K- and DI/K+ presented intermediate values. Results are in accordance with those of Ben Mimoun et al (2008) which affirmed that potassium fertilization didn't affected vegetative growth. This can be explained by the fact that the fruit is the major sink for carbohydrate especially during the final stage of fruit growth. Also it was said that the vegetative growth was controlled by deficit irrigation regimes as quoted by several authors (Chalmers et al. 1981; Li et al. 1989). However, the effect of potassium application results was different depending on the experiment. Restrepo-Diaz et al. (2008) affirmed that shoot length in olive plants cultivated with low K and treated with any potassium fertilizer had a greater shoot growth than control. Also, Saykhul et al. (2013) said that the potassium concentration affected the plant growth of 'Kalamon' and 'Arbequina' olive plants. Whereas, some works showed that potassium deficiency negatively affected tree light interception and photosynthetic capacity in almonds tree (Basile et al. 2003).

Concerning the potassium leaf element content, results are illustrated in the table 4. It was noted slight differences between treatments during first days after treatments. Significant differences were noted at 30DAT, the highest level was noted in both treatments FI/K^+ and DI/K^+. This result is in accordance with those of Ben Mimoun et al (2008), Restrepo-Diaz et al. (2008) and Elloumi et al (2009) which presented that the potassium concentration was higher for foliar treatment than control (untreated).

Table 4: Mineral leaf analysis: Potassium (K) content in percentage of dry matter (%DM) in FI/K-, FI/K+, DI/K- and DI/K+ treatments at different dates (DAT: day after treatment). Values in the same column followed by the same letter are not significantly different at 0.05.

	0DAT	15DAT	30DAT	45DAT
K (%DM)				
FI/K^-	0.86 *a*	2.03 *a*	2.26 *a*	1.47 *a*
FI/K^+	0.86 *a*	1.98 *a*	3.14 *b*	2.08 *b*
DI/K^-	0.86 *a*	2.01 *a*	2.18 *a*	2.02 *b*
DI/K^+	0.86 *a*	2.29 *b*	3.92 *b*	1.89 *b*

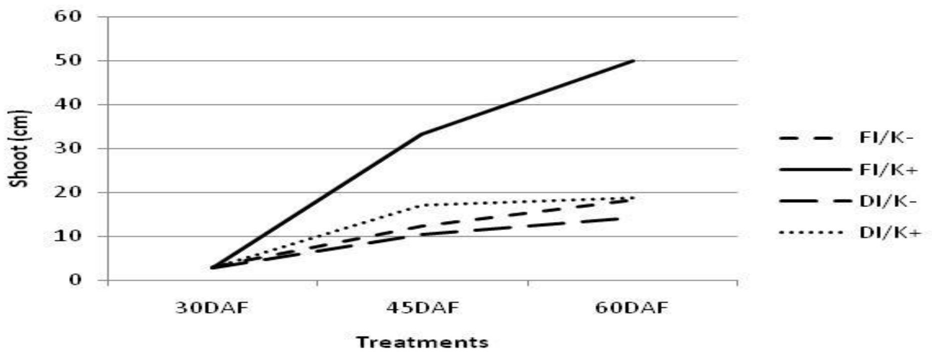

Figure 5: Evolution of shoot length (cm) after treatments in Full (FI) and deficit (DI) irrigated trees with (K+) and nor (K-) potassium foliar application. Each value is the average of 15 measurements.

4. Conclusion

The experiment showed interest results which could be useful to confronting water shortage for the coming decades. The adoption of potassium application with reducing the amount of irrigation water slightly reduced yield and improved fruit quality especially the TSSC and firmness.

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