Title

Responses of olive trees (cv. Chemlali) after five years of experiment to potassium mineral nutrition under rainfed condition

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Introduction

Olive tree is widely cultivated in Tunisia with more than 1.5 million hectares. Owing to water scarcity, the main limiting factor for the Tunisian agriculture, the sector is characterized by significant disparities between regions and growers. Olive tree orchards vary from very low density (17 trees/ ha in the center and south of the country) to super high density with more than 1250 T/ha, the difference depending mainly on water availability for irrigation.

Mineral nutrition is one of the major tools to optimize fruit yield and quality (Tagliavini and Marangoni, 2002). Potassium is known not only to play an important role in olive yield and quality but also in water-use efficiency (Arquero et al., 2006), which indicates its importance for the Tunisian olive sector where more than 95% of the orchards have been traditionally grown on calcareous soils under rainfed conditions.

Nutrient uptake depends on nutrient supply to the root system i.e. nutrient availability and the nutrient requirement level and the uptake period (Chapin, 1991). Fine textured soils are characteristically K+ fixing soils. Under these conditions soil-surface application is almost without effect (Mengel, 2002). Fertigation relative to broadcast application has been shown to increase K mobility in the soil (Nielsen et al. 1999; Uriu et al., 1980; Southwick et al. 1996). Weinbaum et al. (1994) suggested that this effect of K fertigation in significantly improving K uptake resulted from increasing rhizosphere soil solution K concentration. However, limitation in tree capacity to take up K during the high demand period can present a problem (Weinbaum et al. 2002), especially in K+ fixing soils.

Foliar application of nutrients is in general helpful to satisfy plant requirement and has a high efficiency (Inglese et al. 2002). Potassium is particularly well adapted to this form of fertilization because soon after foliar spraying takes place it is rapidly translocated from the leaves (Mengel, 2002). Foliar application is thus an attractive means of K application to trees especially in arid zones where a lack of water under low rainfall conditions in summer drastically depresses absorption of soil nutrients. Considering the essential role of potassium for a crop, a long term trial of the effect of K mineral nutrition given as foliar spray or soil spreading on tree K status, yield and oil quality was established.

Materials and methods

This experiment was carried out over a period of five years from 2003 to 2007 at the Olive Institute experimental farm which is located 26 km North of Sfax in the Center of Tunisia. The zone is characterized by a semi arid climate with an annual precipitation of 200 mm. A commercial olive orchard of Chemlali cultivar (the most important olive oil cultivar in Tunisia) was used for this experiment. The tree 24 * 24 m apart were grown using standard cultural practices of the Sfax region, i.e. under strict rainfall condition and without any fertilization. The soil has a sandy clay texture with 24.5 % of clay, 8.5% of loam and 67% of sand. It is also characterized by very low percent of organic matter and potassium content (Table 1).

Table 1. Olive orchard analysis

	Sampling soil depth (cm)			
	0-20	**20-40**	**40-60**	**60-80**
Organic matter (%)	0.82	0.83	0.50	0.72
PH	8.06	8.17	8.14	8.12
Soluble salts (ECe) (mhos/cm)	0.54	0.59	0.83	0.67
Total Nitrogen (ppm)	293.30	278.68	258.30	253.05
Phosphorus (ppm)	15.60	18.53	16.58	17.68
Potassium (ppm)	129.00	71.40	52.20	51.2

At the beginning of the season, an evaluation of potassium requirement was made based on the removal of nutrients contained in the yield (200 kg/tree) and the pruned wood. The total tree removal was estimated to 26.71 kg K_2O /ha (1.57 kg K_2O/ tree). Potassium was applied by two different methods and on two levels as indicated in Table 2. The same procedure was carried out annually from 2003 to 2007. Potassium was applied as potassium sulfate (K_2SO_4).

Table 2. The different potassium treatments

Treatments	Method	Potassium quantity (kg K_2O /ha)	Quantity
Control		0	
F50	Foliar spray	13.35	50% of tree removal
F100	Foliar spray	26.71	100% of tree removal
S100	Soil spreading	26.71	100% of tree removal
S200	Soil spreading	53.38	200% of tree removal

For the soil spreading treatments, the total quantity of potassium was incorporated in one application during the flower bud swell. It was applied around the trunk under the top tree projection. The foliar fertilization treatments were applied using a 100 l/tree sprayer, with a maximum K concentration of 3% as follows:

1. 30% of K total tree removal during the flower bud swelling
2. 40% of K total tree removal during the second fruit development stage
3. 30% of K total tree removal just at the beginning of the fruit color change.

Four single tree replications were used for each treatment.

Yield and olive quality

At the harvest period, the yield was determined for each tree. Thereafter a sample of 3 Kg per tree was collected and used for pomological and oil analysis. Fruit weight and flesh to pit ratio were determined on three replications of 50 fruits per tree.

Three kg of olive samples were used to extract oil using an oil mill, and then filtered and analyzed.

Oil analysis

Fatty acid composition was determined by adding 4ml of hexane and 400 µl of a methanol solution of 2M KOH to 0.3g of oil. After vigorous shaking for 1min the hexane phase containing methylated fatty acids was separated according to the method of Patumi et al. (1999). Briefly, this phase was then analyzed by gas chromatograph (ATI UNICAM 610) using a capillary column (15m of length and 0.25mm of diameter). The column, the injector and the detector temperatures were fixed respectively at 180, 220 and 250°C. Fatty acids were identified by comparing retention times with standard compound. Six fatty acids were considered in this study: palmitic (16:0), palmitoleic (16:1), stearic (18:0), oleic (18:1), linoleic (18:2) and linolenic (18:3).

Polyphenol content was analyzed using the Folin-Ciocalteau reagent and absorbance measurement at 727 nm. The results were expressed as ppm of caffeic acid (Folin-Denis, 1991). The chlorophyll fraction at 630, 670 and 710 nm were evaluated with a spectrophotometer of each olive oil sample (7.5 g) dissolved in cyclohexane (25 ml).

Mineral analysis

Each year, leaf potassium concentrations were determined. One hundred mature leaves per treatment were removed from the middle of nonbearing, current season shoot during late July as indicated for mineral analysis (Freeman and al., 1994). Potassium analysis was performed on dried samples using flame photometer (JENWAY).

Statistical analysis

Data from all experiments were subjected to analyses of variance and treatment means were separated by Duncan's multiple range tests (5% level) using SPSS software program.

Results and discussion

Fruit growth

The pattern of fruit growth was not influenced by the potassium treatments (Fig. 1). Although fruit growth was higher during stage 3 for the 100% foliar treatment, this increase was not statistical significant. Similar results were observed by Inglese et al (2002) on K nutrition effect on olive growth.

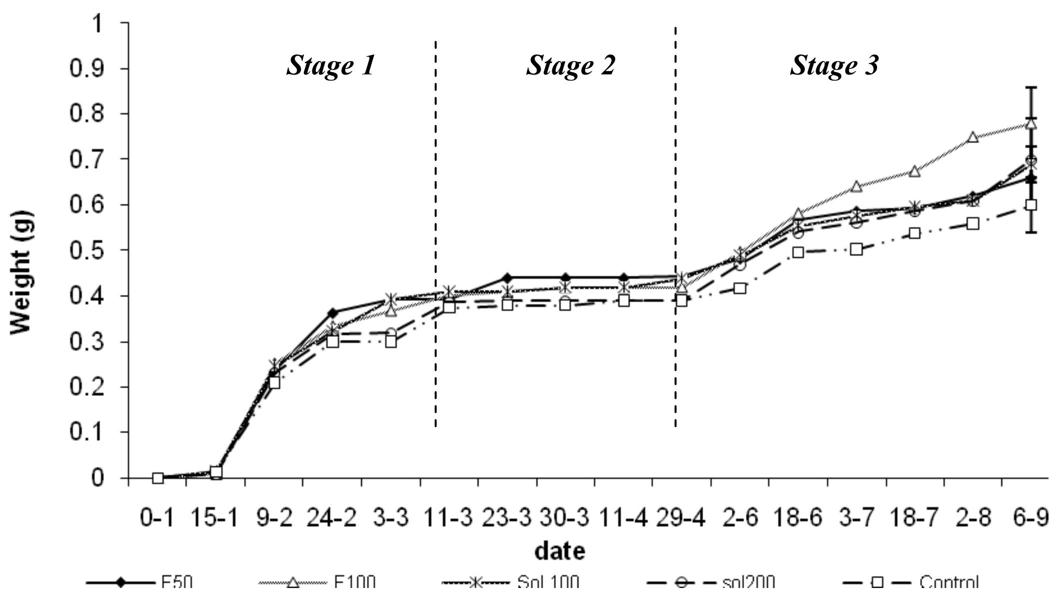

Fig. 1. The fruit growth (g) for the different potassium fertilization treatments in 2003

Yield and quality

After five year of experiments, potassium applied either as foliar or in soil has increased yields of olives. A significant difference in the cumulated yield was observed between foliar spray at 100% (F100) and the control (Table 3). The increase in yield is higher than 200 kg/tree, representing an excellent additional yield for this cultivar. In other work, Restrepo-Diaz et al. (2008) did not observe any effect of potassium foliar fertilization on olive under rainfed conditions. However they stopped their experiments after only three years.

The olive tree is naturally characterised by alternate bearing. The degree of alternation is highly affected by the environmental conditions and horticultural techniques applied

(Patumi and al., 2002, Lavee and Wonder, 2004). Chemlali is known to be an alternate bearing cultivar with no yield after a good year which explains the absence of production in 2004 after the excellent 2003 yield. The smaller yields in 2005 and 2006 comparing to 2003 and 2007 were explained by the drought observed during sensitive period for olive in these two years.

Table 3. Average and cumulated yield in kg/tree during the period between 2003 and 2007. Different letters indicated statistical differences among means by Duncan's Multiple Range Test (p≤0.05).

	Average yield					**Cumulated yield****
Treatments	**2003**	**2004**	**2005**	**2006**	**2007**	
Control	143.75a	0.00	34.25 a	56.25 a	84.75 a	319.00 a
F50	161.25 a	0.00	47.50 a	48.75 a	200.50 ab	458.00 ab
F100	183.25 a	0.00	71.25 b	36.25a	237.00 b	527.75 b
S100	145.25 a	0.00	45.00 a	38.75 a	112.00 ab	341.00 a
S200	156.25 a	0.00	71.25 b	42.50 a	109.00 ab	379.00 ab

Potassium application in soil and as foliar significantly increased fruit weight and Flesh to Pit Ratio (Table 4). Foliar application of K (F100) consistently yielded the higher fruit weight and Flesh to Pit Ratio. This result could be a consequence of the fact that the K foliar spray during the three critical phases of the fruit development filled the K tree requirement. Weinbaum et al. (1994) showed that K take part in the control and the mobilization of reserves in carbohydrates of fruits, all along their maturation. These results confirm those obtained by Inglese et al. (2002) that foliar application of KNO_3, during the second and the third phase of olive growth improved the fresh weight and the flesh to pit ratio.

The fruit size varied between the different years of the study. The higher size observed in 2006 and 2007 was explained by important rain during the beginning of the autumn which induced an important fruit growth during the third stage.

Table 4. Yield and fruit pomological characteristics under potassium treatments. Different letters indicated statistical differences among means by Duncan's Multiple Range Test (p≤0.05).

	Year	**Treatments**				
		T0	**F50**	**F100**	**S100**	**S200**
Fresh weight (g)	2003	0.61 a	0.66 b	0.81 d	0.70 c	0.69 bc
	2005	0.50 a	0.48 a	0.64 b	0.50 a	0.55 a
	2006	1.39 a	1.48 ab	1.62 b	1.34 a	1.43 a
	2007	1.38 ab	1.21 a	1.35 ab	1.31 a	1.42 b
Flesh to Pit ratio	2003	2.94 a	3.19 b	3.65 c	3.25 bc	3.10 b
	2005	1.64 a	1.59 a	2.28 b	1.77 a	1.83 a
	2006	3.78 a	4.00 a	4.87 b	4.24 a	4.00 a
	2007	4.52 ab	4.08 ab	4.00 ab	4.68 b	3.96 a

Oil quality

Chlorophyll pigments are responsible for the colour of olive oil. The highest chlorophyll content (2.67 ppm) was observed for the untreated trees (Table 5), although these

pigments are not required by the oil norm merchandising (C.O.I., 1998). All the oil acidity was lower to 0.5% which classed all the olive oil obtained from the different treatment as virgin olive oils of extra category (El Antari et al., 2000).
Oil polyphenols play an important role in biochemical and pharmaceutical effects (Visioli and Galli, 1998). Analysis of the chromatographic traces showed no clear differences in quantity of polyphenols between K fertilizer treatments.

Table 5. Effects of potassium application on oil qualitative characteristics. Different letters indicated statistical differences among means by Duncan's Multiple Range Test ($p \leq 0.05$).

Treatment	Chlorophyll content (ppm)	Acidity (%)	Polyphenols content(ppm)
Control	2.67 a	0.28 a	29.59 a
F50	1.63 a	0.35 a	37.55 a
F100	2.48 a	0.30 a	34.86 a
S100	2.46 a	0.35 a	31.70 a
S200	2.59 a	0.29 a	36.46 a

On the other hand, the oil chromatographic analysis permitted identification of many fatty acids, varying from C16 to C20 as known for olive oil. Fatty acids play a very important role in the determination of the olive oil quality. All studied samples were rich in oleic acid (C18:1). The content of this acid varied relatively little according to K treatments. Results show no effect of the K fertilization treatment on the fatty acid composition (Table 6) as reported previously by Simeos et al. (2002) working on nitrogen and potassium fertilization effect on the qualitative profile of the oil.

Table 6. The different potassium treatments effect on olive oil acidic composition. Different letters indicated statistical differences among means by Duncan's Multiple Range Test ($p \leq 0.05$).

Treatment	Oil fatty acid composition (%)					
	Palmitic acid	Palmitoleic acid	Stearic acid	Oleic acid	Linoleic acid	Linolenic acid
Control	18.46 a	1.97 a	2.55 a	59.52 a	15.76 a	0.92 a
F50	18.34 a	1.97 a	2.52 a	59.80 a	15.67 a	0.97 a
F100	19.01 a	2.02 a	2.47 a	58.20 a	16.80 a	0.76 a
S100	18.54 a	1.96 a	2.60 a	59.36 a	15.94 a	0.84 a
S200	18.52 a	1.96 a	2.55 a	59.40 a	15.92 a	0.87 a

Leaf Analysis

For four years the leaf concentration of K was higher for foliar treatments at F100 than the control (Figure 2). However, concentration varied between 'on' and 'off' years for all the treatments: the values were higher during the off year and were above the sufficiency threshold of 0.8% for olive (Freeman et al., 1994) and vice versa. These yearly variation may be associated to the presence of fruits sinks (or the crop load) and tree potassium storage. As a consequence, the highest leaf K content was detected during the year without production. Fernandez-Escobar et al. (1999) observed the same variation between years. They concluded that the high leaf K accumulation following the `off' year and the rapid decline after March of the `on' year suggest a large K demand by the reproductive structures of olive.

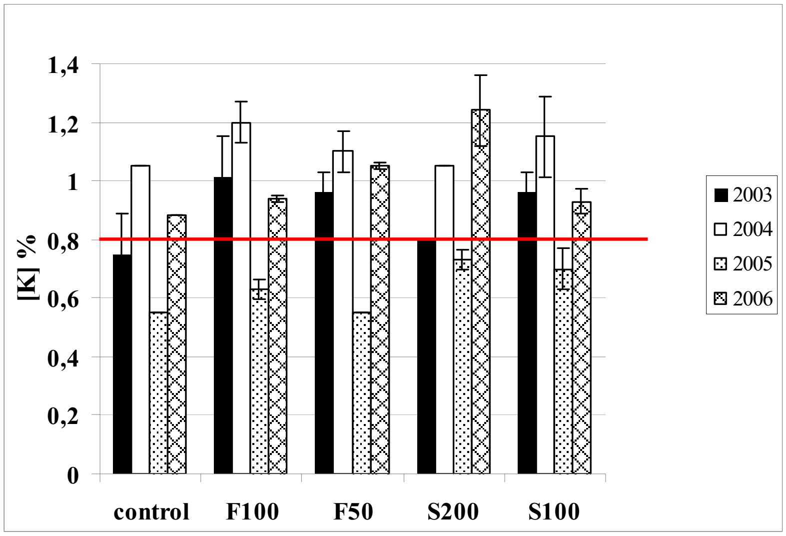

Figure 2. The effect of fertilization treatments on K leaf concentration of Chemlali olive cultivar for the years 2003, 2004, 2005 and 2006.

Conclusions

This study shows the importance of potassium nutrition in increasing the yield and oil yield of rainfed olive. The effect of split foliar application of potassium was superior to soil application which implies that this technology is preferable. Restrepo-Diaz et al. (2008) recommended foliar application in orchards growing under rainfed conditions because the lack of moisture in the soil during the growing period could limit K uptake by the roots, which is the case of the majority of Tunisian olive orchards. Our calculations for potassium application rates based on removal of K in fruit and tree buds seem to be in agreement. More work is still required in order to assess whether this balance is sustainable and profitable over longer periods. The results of this experiment demonstrate the need for a long term approach in such conditions, as both the fruit type (olive) and the climatic conditions pose a challenge in the analysis of data from field experiments.

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