Research Findings

Foliar K increases fruit yield of clementine var. *Cadoux*. Photo by the authors.

Response of Clementine Citrus var. *Cadoux* to Foliar Potassium Fertilization; Effects on Fruit Production and Quality

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Abstract

Clementine var. *Cadoux* is a citrus fruit that is well appreciated by consumers. However, this cultivar tends to produce fruits of small to medium size that are less accepted commercially. In this field study, we evaluated the effects of various rates and frequencies of foliar potassium (K) fertilization, as either potassium nitrate (KNO_3) or potassium sulfate (K_2SO_4), on fruit production (fruit size, weight and yield) and quality parameters (skin thickness, firmness, color index, maturity index, juice content, acidity and total soluble sugars). Application rates of tested foliar fertilizers were 5 percent and 8 percent KNO_3, and 2.5 percent and 4 percent for K_2SO_4, applied either two or three times during fruit growth on orchards of three planting densities (D_1: 6 x 6 m, D_2: 5 x 6 m and D_3: 6 x 3.5 m tree spacing). The levels of K in leaves of clementine var. *Cadoux* increased by up to 40 percent two weeks after the last foliar K application. Fruit weight increased with K application rate and frequency. K fertilization treatments in three foliar applications showed the best percentages of fruits of extra size class, whatever the source of K (KNO_3 or K_2SO_4) or plant density. Foliar applications of K increased fruit color, firmness and rind thickness. Fruit juice content, acidity and total soluble sugars were slightly increased by foliar K application. Raising K concentration and the number of foliar applications increased tree fruit production. In terms of efficiency of foliar K fertilizers, 4 percent K_2SO_4 in three applications resulted in a maximum gain of fruits per kg of foliar fertilizer.

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Introduction

The citrus industry plays an important role in Moroccan agriculture. Morocco is the world's fourth largest fresh citrus exporter and the third for clementine (USDA, 2010). Citrus exports amount to around 500,000 tons per year, generating annual revenue of 3 billion dirhams. An area of 85,000 ha is devoted to citrus cultivation with an annual production of 1,300,000 tons of fruit. In social terms, the citrus sector provides more than 21 million workdays and is the main source of income for 13,000 farming families.

The national average yield of citrus is 17 tons per hectare, which is considered low compared with other major citrus producing countries. The identified constraints to citrus productivity are ageing orchards, scarcity of water, management inefficiencies and losses due to pests and diseases.

Given the global market requirement for quality citrus fresh fruit in the context of globalization and the emergence of new citrus producing countries, Morocco is expected to review its citrus sector strategy to improve its competitiveness. The Morocco Green Plan agricultural strategy considers the citrus industry as a pilot sector and provides a plan for renewal of old orchards and greater utilization of drip irrigation.

Increasing citrus exports is very often restricted because fruit quality is not high enough to meet the standards imposed by foreign markets. Citrus packing stations, for example, record high reject rates of above 25 percent. Several factors are responsible for this, such as fruit damage from pests and diseases, inadequate mineral nutrition, etc. For clementines and mandarins, it is mainly small fruit size which is considered the principal reason for rejection. Several techniques are used to combat this, such as application of growth hormones, tree pruning etc. The final fruit size in a given year depends on several factors, including tree fruit load, precipitation, fertilization program, tree pruning and combination of variety/rootstock. Of all these factors, fertilization practices are probably the easiest to control. Potassium (K) fertilization, in particular, is known to greatly affect fruit quality.

Citrus fruit quality for the fresh market, in the case of Moroccan exports, is judged by fruit size and skin texture. K deficiency leads to the production of small fruits with thin skin, while an excess of K results in production of large fruit with thick skins and a coarse texture. Regarding the quality of the juice, excess K induces high acidity. K fertilization is thus an important tool to optimize the quality of citrus fruit and juice.

Until recently, fertilization practices were primarily directed towards obtaining high yields and it is only recently that interest has grown in the positive effect of fertilization on citrus fruit quality, particularly in relation to phosphorus (P) and K. Foliar fertilization with K is a practice that now offers a means of reaching these goals of high yield and improved fruit quality.

The research results presented in this article reveal the improvement of both production and fruit quality of clementine citrus var. *Cadoux* in response to foliar K fertilization by application of different rates and frequencies of potassium nitrate (KNO_3) or potassium sulfate (K_2SO_4).

Material and methods

Experimental site

The experiment was conducted in 2007 at Sidi Allal Tazi experiment station of INRA, located in the Gharb plain of Morocco. The soil type is clay and the citrus clementine variety used was *Cadoux*, grafted on *citrange Carrizo*. Healthy and homogeneous trees, aged 23 years, showing no signs of mineral deficiency were selected for this experiment. The experimental design was a split plot design with three blocks, three increasing planting densities (D_1: 6 x 6 m, D_2: 5 x 6 m and D_3: 6 x 3.5 m tree spacing) (large plots) and nine foliar K fertilization treatments (small plots).

Soil analysis indicated that the different horizons had sufficient and acceptable contents of organic matter, P and K for production of clementine (Table 1).

Table 1. Soil pH, organic matter, P and K content of the experimental site.

Soil horizon	pH (water)	Organic Matter	P_2O_5	K_2O
cm		*%*	----------*ppm*	----------
0-30	7.7	2.1	41.8	497
30-60	7.9	1.6	11.9	319
60-90	8.2	1.4	4.9	229

Experimental treatments

Experimental treatments consisted of different K fertilization rates (concentration) and a number of foliar applications (two or three times) for a given planting density (D_1, D_2 or D_3). Two sources of K (soluble mineral fertilizers) were tested: KNO_3 and K_2SO_4. Application rates of tested foliar fertilizers were 5 percent and 8 percent KNO_3, 2.5 percent and 4 percent for K_2SO_4. The control was sprayed with water alone. Concentrations of KNO_3 applications correspond to those recommended in the literature (Obreza *et al.*, 2008; Abd-Allah, 2006; Erner *et al.*, 2004; Erner and Ya'acov, 2004). The applied rates for K_2SO_4 correspond to a K content equivalent to that contained in KNO_3. The dates of foliar applications were as follows: July 16, August 3 and August 21, 2007. At a given application date, each tree was sprayed with ten liters of the foliar K fertilizer.

Measurements

The measured production parameters in this study were fruit size, weight and yield. Monitored fruit quality parameters were skin thickness, firmness, color index, maturity index, juice content, acidity and total soluble sugars. Skin thickness was measured on ten fruit skins using a caliper. Fruit firmness was measured with a penetrometer (Koehler, France). Color measurements were determined using a colorimeter (Minolta CR-400; Konica Minolta Sensing, Inc) from which maturity index was derived. Juice content was extracted from ten fruits, acidity was determined by Sodium hydroxide (NaOH) titration and total soluble sugars were measured using a digital refractometer (PAL-1, Atago Co., Japan).

Results and discussion

Effects of foliar K fertilization on mineral elements content in leaves

The levels of K in leaves of clementine var. *Cadoux* increased two weeks after the last foliar K application. This increase was observed in all treatments except in the control where a slight decrease in leaf K content was noticed (Table 2).

The increase of K concentration in the leaves of fertilized trees was independent of the source of K (KNO_3, K_2SO_4) and the number of foliar applications. The increase in K after foliar K applications reached 40 percent, while in the control that content dropped 15 percent from its level before foliar fertilizer applications.

This marked increase in K content of citrus leaves indicates the effectiveness and speed of absorption of K when applied as a foliar fertilizer to leaves (Opazo and Razeto, 2001) as compared to conventional soil application.

Levels of P and magnesium (Mg) were not affected by foliar K applications. In all treatments, Mg concentrations were below optimum before and after foliar applications of K, while calcium (Ca) content was at optimal levels.

Effects of foliar K fertilization on citrus fruit parameters

Fruit weight

The highest average weight, about 96 g per fruit, was recorded in the medium planting density (D_2: 6 x 5 m) while the lowest average weight, about 91 g, was obtained with the highest density (D_3: 6 x 3.5 m). Regardless of planting density, the control treatment had the lowest values of fruit weight (Fig. 1).

At the low density D_1, treatment with 8 percent KNO_3 in two or three foliar applications, proved most effective in improving average fruit weight. These treatments had respective weights of 98.2 and 98.6 g (Fig. 1). Two foliar applications recorded the lowest average fruit weight compared to other treatments.

In terms of efficacy, treatments with high concentrations of K (8 percentKNO_3 or 4 percent K_2SO_4) in three foliar applications are to be recommended to increase weight and size of clementine fruit.

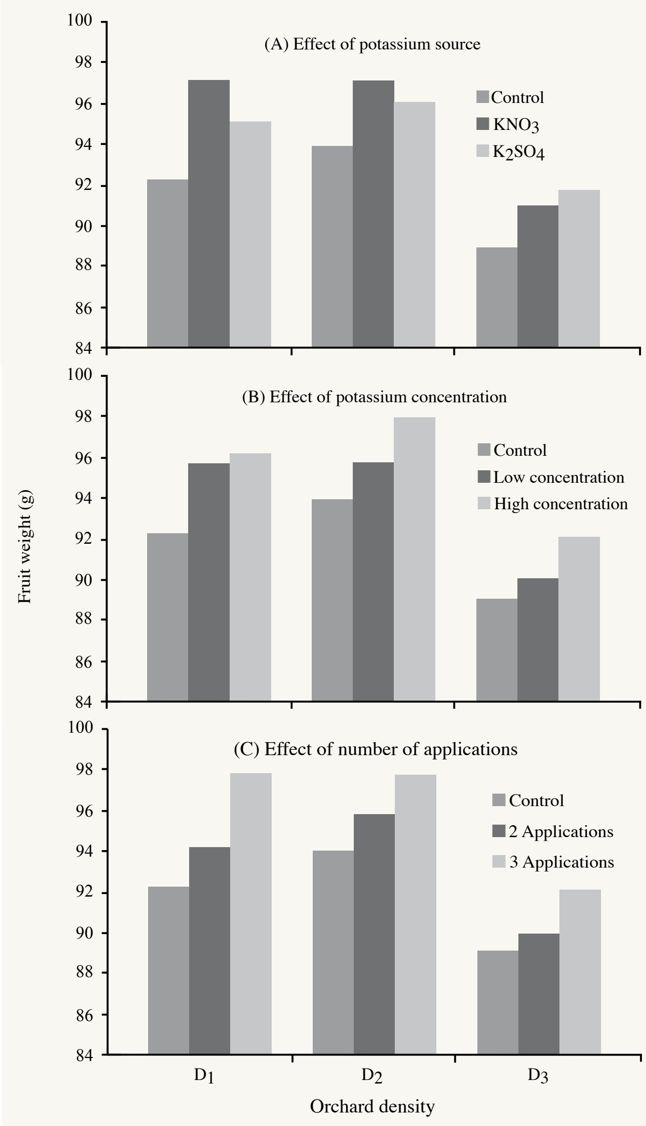

Fig. 1. Effects of foliar K fertilization on fruit weight of clementine var. *Cadoux*: (A) Effect of K source, (B) effect of application rate, and (C) effect of number of applications.

Table 2. P, K, Ca and Mg levels (percent dry matter) in leaves of clementine var. *Cadoux* before and two weeks after the last foliar K application.

Treatments	P		K		Ca		Mg	
	Before	After	Before	After	Before	After	Before	After
	---% of DM---							
Control	0.16	0.14	1.88	1.60	4.04	4.76	0.28	0.23
5%-KNO_3 x 2	0.15	0.16	1.84	2.32	4.12	4.16	0.25	0.26
5%-KNO_3 x 3	0.18	0.15	1.88	2.48	4.00	3.60	0.22	0.23
8%-KNO_3 x 2	0.13	0.16	1.76	2.20	5.32	4.24	0.27	0.26
8%-KNO_3 x 3	0.12	0.16	1.72	2.08	4.44	3.96	0.26	0.26
2.5%-K_2SO_4 x 2	0.18	0.17	1.88	2.64	3.56	3.92	0.25	0.25
2.5%-K_2SO_4 x 3	0.19	0.15	2.04	2.28	4.24	4.32	0.38	0.27
4%-K_2SO_4 x 2	0.13	0.17	1.80	2.48	4.28	3.24	0.25	0.23
4%-K_2SO_4 x 3	0.16	0.15	1.76	2.24	3.68	3.88	0.23	0.23

Table 3. Distribution of fruit number (%) of clementine by size class in response to foliar K fertilization for the low (D_1), medium (D_2) and high (D_3) planting density.

Treatments	Cal 1-3 57 to 63 mm			Cal 4 51 to 56 mm			Cal 5 44 to 50 mm			Cal 6 41 to 43 mm			Out of range <40 mm		
	D_1	D_2	D_3	D_1	D_2	D_3	D_1	D_2	D_3	D_1	D_2	D_3	D_1	D_2	D_3
	---% ---														
Control	7.8	9.2	7.6	68.9	52.8	30.5	23.3	11.5	24.2	0	15.3	24.6	0	11.2	13.2
5%-KNO_3 x 2	22.2	17.3	14.4	67.8	72.2	63.3	10.0	7.1	4.3	0	3.3	3.2	0	0	14.7
5%-KNO_3 x 3	63.3	60.8	54.2	36.7	37.4	30.2	0	1.3	3.2	0	0.5	11.5	0	0	1.0
8%-KNO_3 x 2	21.1	16.2	12.6	64.4	66.2	64.2	14.4	15.2	13.4	0	2.3	3.3	0	0	6.6
8%-KNO_3 x 3	73.3	62.9	57.3	26.7	28.4	32.6	0	7.8	7.2	0	0.8	2.8	0	0	0
2.5%-K_2SO_4 x 2	20.0	22.4	16.2	71.1	58.7	61.4	8.9	9.2	6.5	0	7.2	8.2	0	2.5	7.7
2.5%-K_2SO_4 x 3	62.2	55.3	48.7	37.8	31.5	36.6	0	5.2	7.2	0	4.3	5.3	0	3.7	2.2
4%-K_2SO_4 x 2	24.4	19.3	14.6	67.8	65.2	51.4	7.8	8.2	5.2	0	5.2	16.2	0	2.1	12.6
4%-K_2SO_4 x 3	63.4	56.2	47.5	36.7	38.7	42.2	0	3.4	5.2	0	1.7	3.2	0	0	1.9

Photo 1. Effect of foliar K fertilization on fruit size and color of citrus clementine var. *Cadoux* (densitiy D_1, 6 x 3.5 m). Photo by the authors.

Fruit size

K fertilization treatments in three foliar applications showed the best percentages of extra size class (Cal 1-3), whatever the source of K (KNO_3 or K_2SO_4) or plant density (Table 3). The treatment 8 percent KNO_3 x 3 gave the highest percentage of fruit in the extra size class in all planting densities. For the three planting densities (D_1, D_2 and D_3), the 8 percent KNO_3 x 3 treatments, respectively, produced 73, 63 and 57 percent of fruits in the larger Cal 1-3 class, compared to the 7.8, 9.2 and 7.6 percent recorded in the control.

Trees sprayed with only two foliar applications were markedly less effective in improving clementine fruit size when compared with those that received three applications (Fig. 2).

These results show the effectiveness of foliar K fertilization in improving fruit size of clementine (Photo 1).

It should be noted that an increase in planting density also induces a decrease in fruit size. It is therefore wise to choose a low planting density (D_1 = 6 x 6 m) to reach a level of profitable, commercial grade fruit (Cal 1-3 and 4).

Our results confirm those in the literature (Embleton *et al.*, 1975, Wei *et al.* 2002; Obreza *et al.*, 2008) which show that increasing the rate and frequency of foliar applications of K is accompanied by an increase in citrus fruit size.

The coloration of the fruit rind

In general, whatever the planting density, all treatments of foliar K fertilization induced a redder color of the fruit rind than the control (Photos 1 and 2).

The Color Index (CI), measured with a colorimeter (Model CR-400, Konica Minolta Sensing, Japan) and whose value reflects

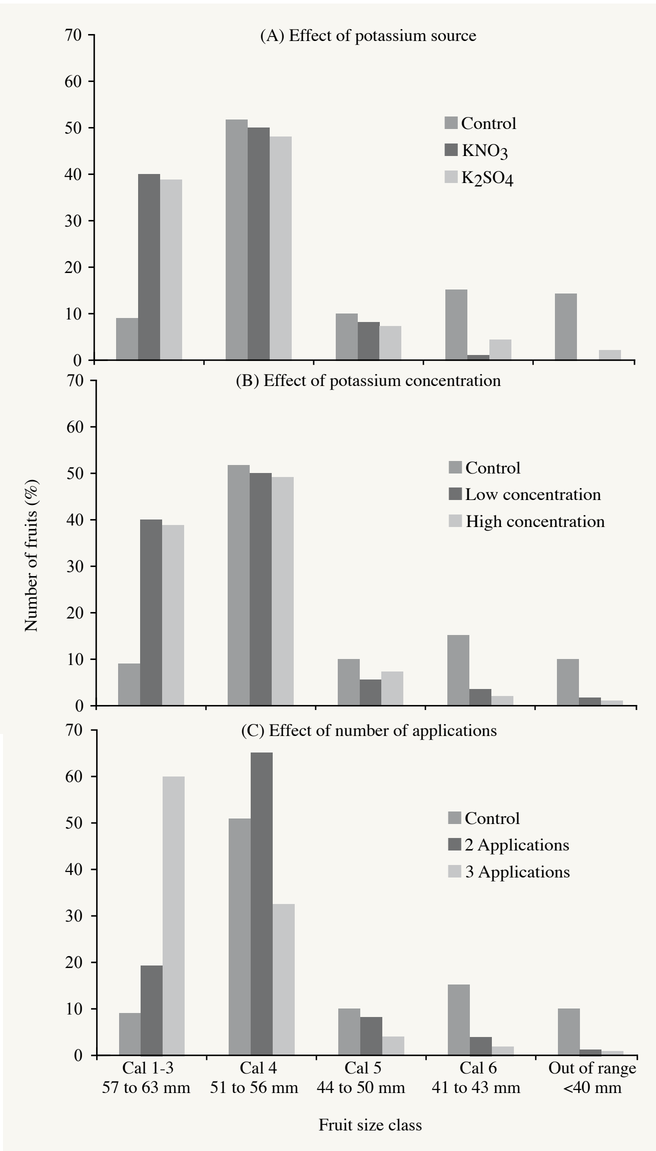

Fig. 2. Effects of foliar K fertilization on fruit size of clementine var. *Cadoux*: (A) Effect of K source, (B) effect of K concentration, and (C) effect of number of applications.

the intensity of the orange-red, was significantly reduced as plant density increases. The recorded values are respectively 5.52, 4.80 and 3.99 for D_1, D_2 and D_3.

All foliar K fertilization treatments have a greater average value of CI than that of the control, indicating that foliar applications of K had a positive impact on improving fruit color of clementine var. *Cadoux*. Generally, foliar applications of KNO_3 were more effective in improving fruit color than K_2SO_4 (Photo 1).

In the low density D_1, treatments 5 percent KNO_3 x 3 and 2.5 percent K_2SO_4 x 2 had the greatest CI values, with 6.3 and 6.4 respectively.

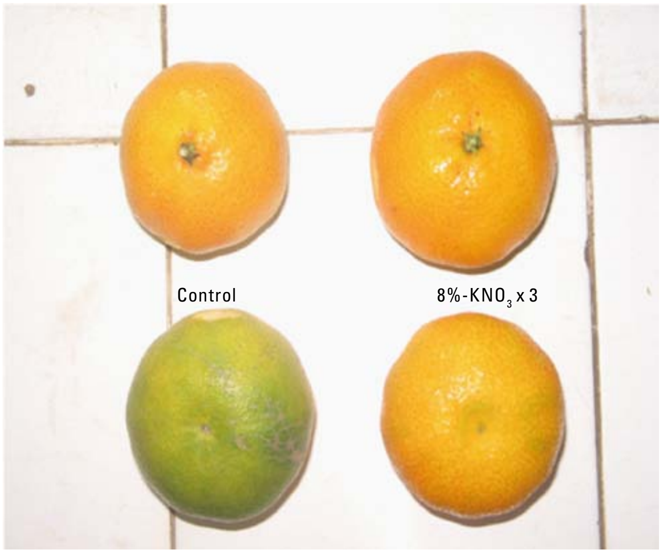

Photo 2. Improvement of fruit color by foliar K fertilization and persistence of green color in the control (left). Photo by the authors.

For the medium density D_2, treatment 8 percent KNO_3 x 2 was superior in terms of fruit color improvement when compared to other treatments. Its color index (CI = 5.5) was significantly higher than that of treatment 2.5 percent K_2SO_4 x 3 (CI = 4.2).

For the high density D_3, treatment 5 percent KNO_3 x 3 induced the highest value of color index (CI = 4.6) whereas treatments 8 percent KNO_3 x 2 and 2.5 percent K_2SO_4 x 3 had the lowest values.

A positive effect of foliar K fertilization on citrus fruit color is reported in the literature (Hellali, 2002; Erner *et al.*, 2004; Obreza *et al.*, 2008). It is also reported that high concentrations of K applied to citrus induced green fruits compared to the application of low concentrations (Koo, 1988). This latter effect was observed in the present experiment with the 4 percent K_2SO_4 treatment in two applications which gave the lowest values of color index and caused a delay in fruit coloration (Photo 1).

It can be concluded that foliar fertilization of KNO_3, at 5 and 8 percent in three foliar applications, and those based on K_2SO_4 at 2.5 and 4 percent respectively, in two and three foliar applications, are most effective in improving fruit color of clementine var. *Cadoux*.

Fruit firmness

Whatever the planting density, the control treatment had higher values of fruit firmness, with 405, 366 and 402 g/0.5 cm^2 for densities D_1, D_2 and D_3 respectively. In addition, all treatments of foliar K fertilization had acceptable fruit firmness, which varied between 300 and 415 g/0.5 cm^2.

Thickness of the fruit rind

The average fruit rind thickness of all treatments is 11.5 mm. Foliar K fertilization slightly increased rind thickness as K concentration, or the number of foliar applications, increased.

Our results are consistent with those reported in the literature, which indicate that increasing K, applied as foliar fertilization, induces an increase in the citrus fruit rind thickness (California Fertilizer Association, 1998; Obreza *et al.*, 2008).

This increase in thickness of the skin of the fruit is of importance as it provides resistance to insects.

Fruit juice content

In all treatments, the fruit juice content met the standards for export of the fruits of Moroccan clementine (a minimum of 40 percent).

In the low density D_1, the increase in the number of foliar applications, for a given concentration of either KNO_3 or K_2SO_4, is accompanied by an increase in fruit juice content. This increase was 0.5 percent between treatments 5 percent KNO_3 x 3 and 5 percent KNO_3 x 2; and 1.8 percent between 8 percent KNO_3 x 3 and 8 percent KNO_3 x 2. A slight decrease in fruit juice content of 0.92 percent is recorded between treatments 4 percent K_2SO_4 x 3 and 4 percent K_2SO_4 x 2.

For the medium density D_2, the juice content decreased with the increasing number of foliar applications for low K concentrations but increased with the number of foliar applications for high concentrations of K.

For the density D_3, the juice content is highest in the 4 percent K_2SO_4 x 2 treatments with a value of 45 percent.

Acidity (A) of the juice

The acidity of the juice of clementine var. *Cadoux* for all foliar K fertilization treatments meets the export standards of between 0.8 and 1.5 percent. In all treatments, acidity was less than 1.1 percent. Increasing the number of foliar K applications, however, causes a slight increase in acidity in the fruit juice.

These results are consistent with those of the literature which indicates that increased levels of K in leaves, due to an increase in concentration and/or number of foliar applications, induces an increase in acidity of citrus fruit (Erner *et al.*, 2004; Obreza *et al.*, 2008).

Fruit total soluble sugar content (TSS)

The export market for Moroccan clementine citrus requires a minimum content of total soluble sugars (TSS) of nine percent. In all foliar K fertilization treatments, and in the control, TSS contents were much higher than stated standards for exports of clementine.

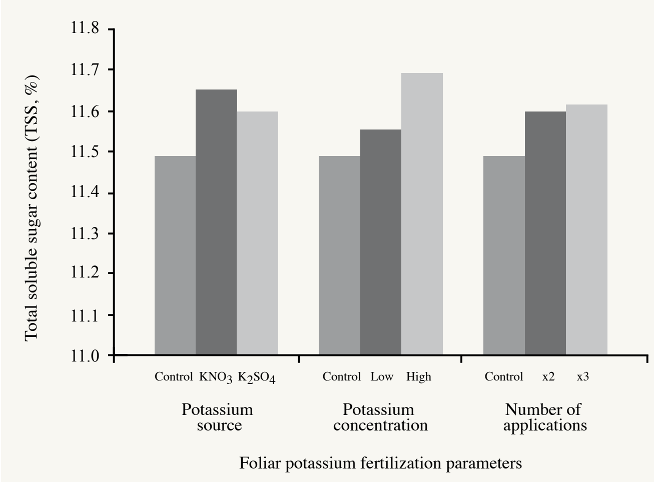

Fig. 3. Effects of foliar K fertilization on fruit TSS of clementine var. *Cadoux*: Effect of K source, concentration and number of applications.

Foliar K fertilization slightly improved total soluble sugar content of the fruit with better efficiency for KNO_3 in comparison to K_2SO_4 (Fig. 3).

Index of fruit maturity (TSS/A)

According to export standards, a minimum maturity index of 7 is required for Moroccan clementine although some importing countries require a value between 7 and 7.5.

In all foliar K fertilization treatments, the fruit maturity index exceeded 10.6. This index was lower in treatments which received KNO_3, and higher in treatments that received K_2SO_4 as a source of K for foliar application.

Effect of foliar K fertilization on fruit yield

The fruit production of the different planting densities were respectively 174, 160 and 116 kg per tree for the low (D_1), medium (D_2) and high density (D_3). In terms of fruit production per hectare, yields of densities D_1, D_2 and D_3 were 48.1, 53.7 and 55.3 mt ha^{-1} respectively.

Concerning the effect of foliar K fertilization, our results clearly indicate that raising the K concentration and the number of foliar applications increased tree fruit yield (Fig. 4B and 4C; Photo 3).

For treatments that received two foliar applications, raising K concentration did not induce any significant increase in production.

These results are consistent with the literature that indicates that increasing frequency or concentration of K foliar application on citrus, three to five weeks after the fruit size reached a diameter of 20 to 25 mm, leads to increased production (Erner *et al.*, 2004; Obreza *et al.*, 2008).

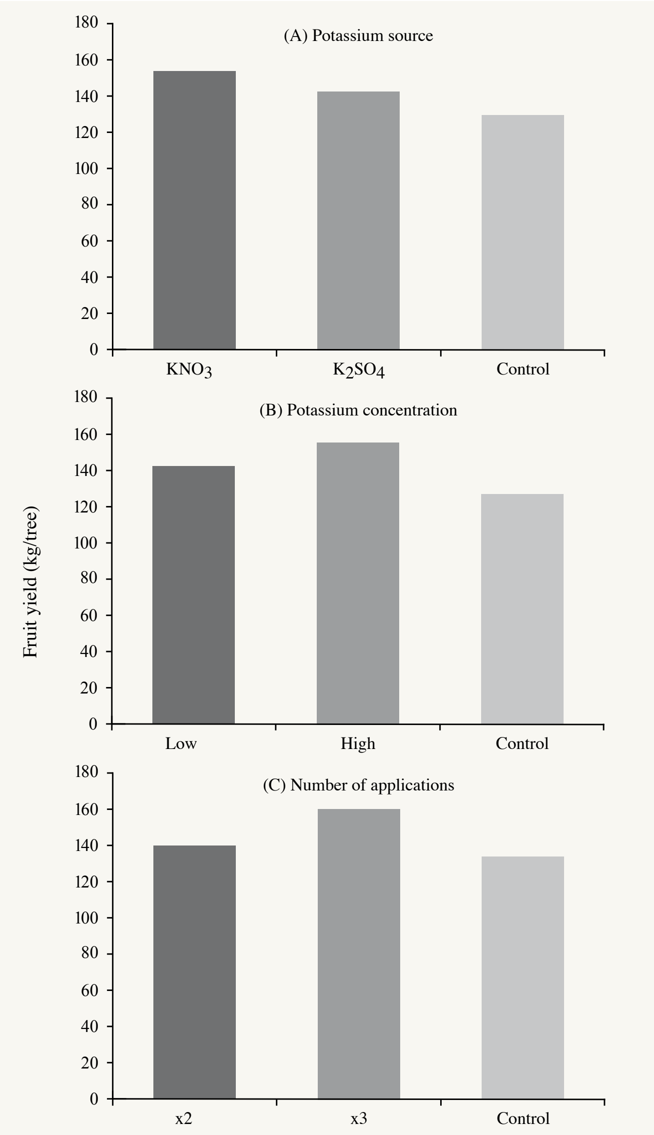

Fig. 4. Effects of foliar K fertilization on fruit yield (kg tree^{-1}) of clementine var. *Cadoux*: Effect of (A) K source, (B) K concentration, and (C) number of applications.

Within the planting densities D_1 and D_2, 8 percent KNO_3 and 4 percent K_2SO_4 treatments with three foliar applications were the most effective in improving fruit yield of clementine var. *Cadoux*. The recorded yields for these treatments in D_1 were 204 and 195 kg/tree respectively, while the control produced only 160 kg/tree. This increase in production was 21.5 percent and 17.6 percent respectively for treatments 8 percent KNO_3 x 3 and 4 percent K_2SO_4 x 3 over the control.

For the medium density D_2, the treatment 8 percent KNO_3 x 3 was the most effective as it increased fruit yield by 21.2 percent over the control (184 kg/tree versus 145 kg/tree). The 5% KNO_3 x 3 and 4 percent K_2SO_4 x 3 treatments have generated a marked production increase of 16.5 percent (173 and 175 kg/tree respectively) when compared to the control.

For the high density D_3, treatment 5 percent KNO_3, 8 percent KNO_3 and 4 percent K_2SO_4 in three foliar applications appear to be the most effective in improving fruit production of clementine var. *Cadoux*. There was no significant difference between these two treatments and the recorded average production was 130 kg/tree, an improvement of 18 percent when compared to the control.

Production gains and efficiency of KNO_3 and K_2SO_4 foliar application on clementine var. *Cadoux*

Treatments 5 percent KNO_3, 8 percent KNO_3, 2.5 percent K_2SO_4 and 4 percent K_2SO_4, with three foliar applications, were selected for an evaluation of their efficiencies because of their positive effects on fruit production and quality parameters of clementine var. *Cadoux*.

Treatment 8 percent KNO_3 with three foliar applications had an average production gain of 12-13 mt ha^{-1} over the control in the three planting densities (Table 4), while the treatment 2.5 percent K_2SO_4, with three foliar applications, gave the lowest fruit production gains.

Control — 5%-KNO_3 x 3 — 4%-K_2SO_4 x 3

Photo 3. Trees representative of the effects of foliar K fertilization on fruit yield of clementine var. *Cadoux* (density D_1, 6 x 3.5 m). Photos by the authors.

Table 4. Production gain and marginal productivity of citrus clementine var. *Cadoux* with three foliar K applications of KNO_3 and K_2SO_4.

K source and concentration	Planting density	Yield	Applied fertilizer	Production gain	Efficiency
		mt ha^{-1}	*kg ha^{-1}*	*mt ha^{-1}*	*kg fruit per kg fertilizer*
Control	D_1	44.4	-	-	-
	D_2	48.4	-	-	-
	D_3	50.5	-	-	-
5%-KNO_3 x 3	D_1	50.5	415.5	6.1	14.7
	D_2	57.7	499.5	9.4	18.7
	D_3	59.4	714.0	8.9	12.4
8%-KNO_3 x 3	D_1	56.5	664.8	12.1	18.2
	D_2	61.4	799.2	13.1	16.4
	D_3	63.6	1,142.4	13.0	11.4
2.5%-K_2SO_4 x 3	D_1	47.0	207.7	2.7	12.7
	D_2	53.2	249.7	4.8	19.3
	D_3	54.6	357.0	4.1	11.4
4%-K_2SO_4 x 3	D_1	53.9	332.4	9.5	28.6
	D_2	58.2	399.6	9.9	24.7
	D_3	60.9	571.2	104	18.2

In terms of efficiency of foliar K fertilizers, the treatment 4 percent K_2SO_4 in three applications resulted in a maximum gain of about 28 and 24 kg of fruits per kg of foliar fertilizer, respectively for densities D_1 and D_2 (Table 4).

Conclusion

Foliar application of K, either as KNO_3 or K_2SO_4, increased fruit production and quality parameters (weight, size, color, rind thickness, juice content and maturity index) of clementine citrus var. *Cadoux*.

On the basis of yield gain, fertilizer efficiency and profitability, the combination of D_1 spacing (6 x 6 m) sprayed with 4 percent K_2SO_4 three times, gave the best return and is recommended for foliar fertilization of clementine var. *Cadoux*.

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The paper "Response of Clementine-Citrus var. *Cadoux* to Foliar Potassium Fertilization: Effects on Fruit Production and Quality" also appears at:

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