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Leaf nitrogen and potassium concentrations for optimum fruit production, quality and biomass tree growth in Clementine mandarin under Mediterranean climate

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Leaf analysis is a useful tool to evaluate the nutrient status of citrus trees, but diagnosis standards for 'Clementine mandarin' are not available. Nutrition recommendations of the current fertilization practices are mainly based on the same recommended nutrient rates for orange trees. A three-year (2005 - 2007) field experiment was conducted in North Eastern Tunisia (El Gobba). This experiment was carried out using 25 years old 'Clementine mandarin' trees (Citrus reticulata Osbeck) on 'Sour orange' (Citrus aurantium Osbeck) rootstock; grown on a sandy soil; to establish leaf nutrient (N and K) concentration standards for optimum biomass tree growth, fruit production and quality. Nitrogen and potassium rates ranging from 160 to 232 and 200 to 290 kg/ha/yr, respectively, were applied in a drip irrigation system (12 fertigations events/yr). Irrigation was scheduled based on tensiometer readings at the root zone. Fruit yield was positively associated with N ($r^2 = 0.91$) and K ($r^2 = 0.84$) rates; as well as with leaf N concentration ($r^2 = 0.92$) and tree fruit load ($r^2 = 0.91$). Leaf N concentration was significantly correlated with N rates ($r^2 = 0.72$) and biomass tree growth ($r^2 = 0.52$). These findings indicate that 192 and 200 kg/ha/yr of N and K_2O (N:K = 0.9), respectively, are required to support optimal fruit yield of 43 T/ha/yr with tree fruit load of 2.4 kg/m^3 (fruit yield/tree canopy size ratio) and optimum fruit quality. At 90% of maximum relative fruit yield, leaf N and K concentrations were 27 to 29 and 10 to 12 g/kg, respectively. Leaf nutrient concentration ranging from 27 to 29 g/kg for N; and from 10 to 12 g/kg for K corresponding to a fertilizer management program of 192 kg/ha/yr and 200 kg/ha/yr, could be recommended as optimum levels of N and K for 'Clementine mandarin' grown under Mediterranean conditions.

Key words: Leaf nutritional status, optimum fruit yield, biomass tree growth, Clementine mandarin, semi arid Mediterranean climate.

INTRODUCTION

Nitrogen (N) and potassium (K) are 2 of the most important nutrients for citrus tree growth, fruit yield and fruit quality. They are needed in adequate amounts especially at critical crop growth stages, especially, fruit initiation and development (Obreza and Morgan, 2008; Alva et al., 2005). Nitrogen is the pre-requisite and most important nutrient for citrus cultivation (Embleton and Jones 1978; Dasberg et al.1984; Alva and Tucker 1999; Boman and Obreza 2002; Alva et al., 2003), especially in the sandy soil, which contains small amounts of available N (Futch and Alva, 1994; He et al., 2003). Nitrogen is essential to enhance plants biological processes (normal cell division, growth and respiration) and enables plants to use the energy of sunlight to form sugars from carbon dioxide and water (Abbas and Fares, 2008). However, excess nitrogen application enhances vegetative tree growth (Alva et al., 2003; Schumann et al., 2003) and may cause groundwater contamination if leached with excess irrigation and/or rainfall (Alva and Paramasivam, 1998; He et al., 2000; Alva et al., 2006). Potassium is

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Table 1. Chemical and physical soil proprieties of the experimental site.

Depth (cm)	pH	Soil texture			Organic carbon	EC (dS/m)	CEC (cmol/kg)	K_2O exch. (Ac.NH_4)	P_2O5 ass. (Olsen)
	In H_2O (1: 2.5)	Clay	Silt	Sand				mg/kg	
0 - 30	7.4	43	36	920	3.25	0.95	3.7	197	75
30- 60	7.3	30	50	920	1.16	1.04	2.8	185	38
60- 90	7.5	40	103	857	1.04	1.22	2.0	91	22
90 - 110	7.9	237	93	670	-	1.39	6.5	-	-
110- 120	7.6	424	210	366	-	1.15	19.5	-	-

Table 2. Treatments used with their corresponding rates for N and K.

Treatments (N_iK_j)		Nitrogen rates (kg N ha/yr) $^{(1)}$				
		$N_0 = 0$	$N_1 = 160$	$N_2 = 192$	$N_3 = 232$	$N_G = 300$
	$K_0 = 0$	N_0K_0	-	-	-	-
Potassium rates	$K_1 = 200$	-	N_1K_1	N_2K_1	N_3K_1	-
(kg K_2O ha/yr) $^{(2)}$	$K_2 = 240$	-	N_1K_2	N_2K_2	N_3K_2	-
	$K_3 = 290$	-	N_1K_3	N_2K_3	N_3K_3	-
Additional treatment	$K_G = 375$	-	-	-	-	N_GK_G

$^{(1)}$Ammonium nitrate (N = 33%); $^{(2)}$Potassium sulphate (K_2O_2 = 50%), N_GK_G: Common farming fertilization program

necessary for several basic physiological functions, such as, sugars and starch metabolism, synthesis of proteins, normal cell division and growth and neutralisation of organic acids (Abbas and Fares, 2008). It will increase fruit size, yield, vitamin C content and fruit quality (Ritenour et al., 2002). Furthermore, potassium regulates the CO_2 supply to citrus plants by controlling stomata opening and closing (Abbas and Fares, 2008). But excessive high potassium levels will result in large and coarse fruit with a rather thick and greenish peel and high juice acidity (Wutscher and Smith, 1993).

Leaf tissue testing is a useful tool to evaluate tree nutritional status with respect to most nutrients, but is particularly effective for: 1) Macronutrients, primarily nitrogen and potassium that readily move with soil water and 2) the micronutrients copper (Cu), manganese (Mn), zinc (Zn) and iron (Fe) (Obreza et al., 1992). Leaf tissue analysis is a much better indicator of the effectiveness of soil-applied fertilizer for these elements than soil analysis. The leaf mineral concentration might be compared with the critical range of concentrations that are established and previously published for particular crop based on years of experimentation (Millis and Benton-Jones, 1996). The interpretation of leaf tissue mineral analysis depends on the physiological stage of leaves that are sampled for analysis, leaf decontamination procedure and analytical methods (Hanlon et al., 1995). Although, critical leaf concentration standards for almost all nutrients are well established for citrus orange (Chapman 1960; Embleton et al., 1975; Koo et al., 1984; Paramasivam et al., 2000; Alva et al., 2005) and for grapefruit trees (Boman, 1993; He et al., 2003), nevertheless, there are few research results related to Clementine mandarin leaf chemical analysis. However, the nutrition recommendations of all current fertilization practices of this cultivar are mainly based on the same recommended nutrient rates for orange trees.

The major objectives of this paper are to evaluate the effect of rates of nitrogen and potassium fertigation, according to tree phenological stages requirements combined with improved irrigation scheduling, on tree nutritional status, biomass tree growth, fruit yield and quailty, of 25 years old of ‘Clementi grafted on ‘Sour orange’,ersemiarid Mediterraneanund conditions.

MATERIALS AND METHODS

Experimental conditions

A field experiment was carried out from 2005 to 2007 in the citrus production area of Cap-Bon (El Gobba), located in the North East of Tunisia. The soil was sandy (loamy mixed thermic mollic xerofluvent), especially at 0 - 60cm depth, and loam to clay in depth (60 - 120cm); the main chemical and physical proprieties of the soil at various depths are summarized in Table1.

The citrus trees were ‘Clementine(*Citrusrticul*m**a***ta*ndarin *Osbeck*) grafted on ‘Sour*Citrus*or**a***urantium*nge’ (*Osbeck*) rootstock, planted in 1978 at 6.0 x 4,0 m spacing with 416 trees/ha. The experimental design was a randomized complete block with ten fertilizer treatments replicated three times. In addition to control treatment and 9 treatments resulting from 3 different levels of nitrogen and potassium, N_iK_j (value i and j are corresponding rates of N and K, respectively) (Table 2), we added, the fertilization program used by the grower, as a second control treatment (N_GK_G). Every plot was composed of three adjacent disease-free trees to each other in one row, with uniform growth. Treatments were separated with sufficient buffer area within and between tree rows. Fertilizer treatments were applied through a drip irrigation system (12 fertigation events/yr). To achieve optimal tree growth, phosphate was applied to all treatments as phosphoric acid (P_2O_5 = 85%) with N: P (1:0.088). Half of annual N rates and 30% of K_2O were applied during early spring flash growth to fruit set; the remaining 50% N and 40% of the K_2O were applied between fruit setting and the end of physiological fruit drop period. The last 30% of K_2O was added during fruit growth stage.

The drip-irrigation system used consisted of two drip lines delivering approximately 0.048 m^3/h at 0.1 MPa for each tree. Water tree irrigation management was monitored with four clusters of tensiometers, each at 0.25; 0.50; 0.75 and 1.0 m depths, were installed inside the drip line under tree canopy and were read every day. The 0.25 depth tensiometer was used to evaluate soil water depletion level as a basis to schedule irrigation. According to the optimal citrus production water requirements, soil water content was maintained above 33% depletion of available soil water during flowering fruit set phase (Koo et al., 1969) and during the remaining part of the growing season, the available soil water can be allowed to deplete by 67% before replenishment of the soil water back to field capacity (Fares and Alva, 2000).

However, the watering of trees during February through June was triggered when the 0.25 m tensiometer read $10/10^3$ and $15/10^3$ MPa during July through October (Smajstrala et al., 1985; Pearsons, 1989).

Plant and fruit sampling and analysis

Six-month-old spring flush leaves from non-fruiting terminals were sampled, each for the three years, following the procedure described by Obreza et al. (1992). The leaves were washed in detergent solution followed by several rinses in distilled water (Alva and Tucker, 1997), dried at 70°C for 48 h. The dried leaves were grounded <0.4mm, and ashed in a muffle furnace at 550°C for 5 h. The ash was cooled and dissolved in 20 ml of 1M HCL (Alva et al., 2005). Leaf total N content was determined by the semi micro-Kjeldahl method (Bremner, 1995b); the concentrations of K, Ca, Mg, Na and micronutrients Iron, Copper, Manganese and Zinc contents were measured using Atomic-absorption Spectrophotometer (Perkin-Elmer, Inc., Norwalk, CT) and the concentrations of P were determined by UV-Vis spectrophotometer.

Just before fruit harvest, 30 fruits were sampled from each plot for the evaluation of the fruit weight and size, titratable acidity and total suspended solids TSS/TA ratio. The date of fruit sampling collection for quality parameters analyses were 15, 18 and 20 November, respectively, for the 3 consecutive cropping seasons (2005, 2006 and 2007). Fruits were harvested in last decade of November of each year, by manually picking from each tree of the plot. Fruit were weight and their average diameter recorded. Fruit were cut along their equatorial zone, their peel thickness was recorded and their juice extracted and weighed. Juice pH, titratable acidity (using 0.1 N NaOH titration) and total soluble solids content (using a laboratory refractometer expressing the amount of sugars in %) were determined (Wardowski (1990). The total weight of fruit in each tree as well as in each plot was measured, and the yield of trees plots was used to calculate the per-hectare yield based on tree density in the grove.

Statistical analysis

Response of fruit yield, fruit weight, fruit size, titratable acidity, total suspended solids TSS/TA ratio, canopy volume, efficient productivity and leaf nutritional status, to nitrogen and potassium fertigation, were evaluated by analyses of variance (ANOVA) and regression analysis using PROC ANOVA and PROC REG of SAS (1996). When differences among treatments means were significant, means separation was done using Least Significant Difference LSD at $p \leq 0.05$.

RESULTS

Fruit yield

Analyses of variance (Table 3) indicated that fruit yield, relative fruit yield and tree yield efficiency (expressed as tree fruit yield/tree canopy volume ratio) are dependant on treatment effects (p<0.01). These differences were generally attributed to the common farming fertilization program (N_GK_G) and the control (N_0K_0) that were significant for this facts. However, the analysis of variance did not indicate with enough evidence significant effects for all the interactions. Moreover, main effects of N and K were not significant for all traits.

Greater fruit yield and relative fruit yield were obtained for Nitrogen application ranging from N_2 (192 kg N/ha/yr) to N_3 (232 kg N/ha/yr) combined with 200, 240 and 290 kg K_2O/ha/yr rates (Table 4). The fruit yield mean values for these treatments (N_2K_1, N_3K_3 and N_2K_2) is 41.2 T/ha/yr while it represents around 91.5% of relative fruit yield. Higher fruit yield was obtained with N and K_2O rates of 192 and 200 kg /ha/yr, respectively. However, similar trend was noted for 232/290 and 192/240 kg /ha/yr rates of N and K_2O, respectively. In addition, the tree productivity evaluation indicated that N_2K_1 treatment trees was associated with the highest fruit yield and greater fruit yield efficiency (2.4 kg of fruit/m^3 of canopy). This result suggests that optimum fruit load level is achieved at N_2K_1 fertilizer application. Nevertheless, the lowest trees productivity level (0.8 kg/m^3) of the control treatment (N_0K_0) is related to the low fruit yield associated with the large tree canopy size (49.8 m^3).

The lower fruit yield efficiency obtained at N_0K_0 indicates an inadequate ratio that favours canopy growth rather than fruiting ability. Moreover, lower tree fruit load

Table 3. ANOVA of nitrogen and potassium fertigation effect on fruit yield, relative fruit yield, canopy tree size and tree yield efficiency ;(mean square of all parameters, 2005 - 2007).

Source of variation	df	Fruit yield (T/ha/yr)	Relative fruit yield (% of max.)	Canopy volume (m^3/tree)	Tree yield efficiency (kg/m^3)
Year (Y)	2	1095.556 ^{NS}	5422.709 ^{NS}	3439.135 **	9.699 *
Replicates (R)	6	400.696 ^{NS}	1981.255 ^{NS}	87.953 ^{NS}	1.569 ^{NS}
Treatments (T)	10	657.837 **	3245.273 **	58.361 ^{NS}	2.723 **
Nitrogen rates(N)	2	491.916 ^{NS}	2427.447 ^{NS}	28.224 ^{NS}	1.731 ^{NS}
Potassium rates(K)	2	198.364 ^{NS}	978.386 ^{NS}	17.641 ^{NS}	0.936 ^{NS}
N × K	4	149.784 ^{NS}	740.315 ^{NS}	57.822 ^{NS}	0.997 ^{NS}
Contrast C_1: (N_GK_G)	1	1523.712 **	7514.235 *	19.253 ^{NS}	5.449 *
Contrast C_2: (N_0K_0)	1	3074.957 **	15165.572 **	241.343 ^{NS}	12.457 **
T× Y	20	108.065 ^{NS}	533.270 ^{NS}	9.291 NS	0.363 ^{NS}
N × Y	4	58.657 ^{NS}	289.917 ^{NS}	7.915 NS	0.136 ^{NS}
K × Y	4	211.481 ^{NS}	1043.894 ^{NS}	5.548 NS	0.744 ^{NS}
N × K × Y	8	54.134 ^{NS}	267.233 ^{NS}	7.790 ^{NS}	0.257 ^{NS}
C_1 × Y	2	26.949 ^{NS}	133.079 ^{NS}	31.069 ^{NS}	0.207 ^{NS}
C_2 × Y	2	296.270 ^{NS}	1140.471 ^{NS}	3.764 NS	0.635 ^{NS}
Error	60	181.328	895.613	86.974	0.944

** Significant at $p<0.01$; * significant at $p < 0.05$; NS: Not significant at $p < 0.05$.

Table 4. Means of fruit yield, relative fruit yield, canopy volume and tree yield efficiency, 2005 - 2007; (similar letters within rows indicate no significant differences among treatments, $lsd_{0.05}$).

Treatments	N and K_2O rates (kg/ha/yr)		Fruit yield (T/ha/yr)	Relative Fruit yield (% of max.)	Canopy volume (m^3/tree)	Tree yield efficiency (kg/m^3)
N_iK_j	N	K_2O				
N_2K_1	192	200	42.6 a	94.73a	42.79ab	2.39a
N_3K_3	232	290	41.7 a	92.73a	43.75ab	2.29a
N_2K_2	192	240	39.2 a	87.05a	46.59ab	2.02ba
N_2K_3	192	290	37.7 ab	83.85ba	46.77ba	1.93bac
N_1K_1	160	200	37.7 ab	83.72ba	46.59ab	1.94bac
N_3K_1	232	200	35.5 ab	78.90ba	45.41ab	1.87bac
N_3K_2	232	240	34.1 ab	75.87ba	40.76b	2.01ba
N_1K_3	160	290	30.3 bca	67.45bac	43.56ab	1.67bac
N_1K_2	160	240	26.4 bca	58.70bdc	42.86ab	1.48bdc
N_GK_G	300	375	20.5 cd	45.70dc	43.34ab	1.13dc
N_0K_0	0	0	16.7 d	37.06d	49.79a	0.80d
LSD 0.05			12.7	28.2	8.79	0.92

with small fruit size were often noted at N_0K_0 (Table 6). This could be explained by the fact that, the major part of the residual soil nutrient resources was just used for biomass tree growth, and only a few amounts were allocated to tree flowering and fruiting (Table 4).

Over the ranges of N (160 to 232 kg/ha/yr) and K (200 to 290 kg/ha/yr) rates, the mean fruit yield response followed a quadratic relationship (Figure 1). Mean fruit yields were 39.2, 41.7 and 42.6 T/ha/yr for N_2K_2, N_3K_3 and N_2K_1 treatments, respectively. Increasing N rate from 160 to 192 kg/ha/yr translated into an increase in fruit yield, but further increases in N or K rates decreased fruit yield.

These responses demonstrated that nitrogen and potassium rates in excess of 192 and 200 kg/ha, respectively, reduced fruit yield. A 1:0.9 nitrogen to potassium ratio seems to be the most adequate rat mandarin' under these Mediterranean c estimation of the nutrient requirement per unit weight of fruit production expressed as kg of nutrient per 1 ton of

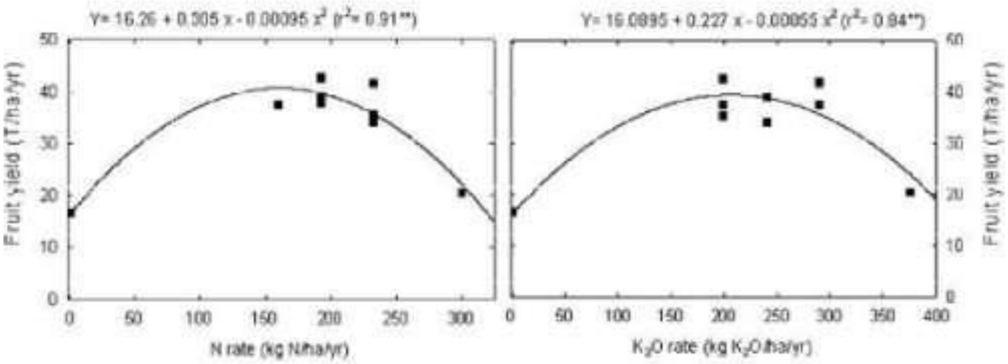


Figure 1. Effect of N and K_2O rates on Clementine mandarin Fruit yield, 2005 - 2007.

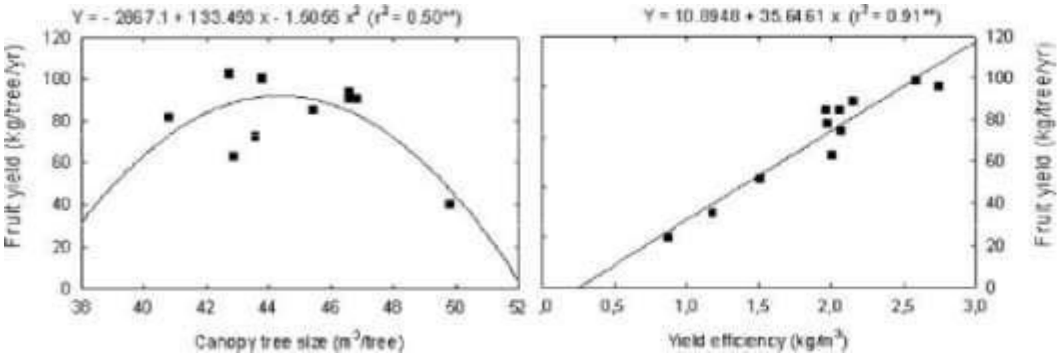


Figure 2. Clementine mandarin tree fruit yield in relation to canopy volume and the yield efficiency, 2005 - 2007.

fruit were 4.5/3.9; 5.6/5.8; and 5.1/5.1 kg/kg (nitrogen/potassium) for N_2K_1, N_3K_3 and N_2K_2 treatments, respectively. However, N use efficiency varied between 4.5 and 5.6 kg N/T of Clementine mandarin fruit. Application of 192 kg N/ha/yr and 200 kg K/ha/yr (N: K ratio of 1:0.9) would allow 'Clementine mandarin' trees to support an optimum fruit yield of 42.6 T/ha/yr. This is a very adequate yield given the alternate bearing nature of this cultivar and relatively low irrigation water quality (2.10 ≤ ECw ≤ 2.53dS/m).

Biomass tree growth and productivity

It is worth noting that year effect was significant for tree canopy size along with yield efficiency. Whereas, the tree yield efficiency which is defined as fruit tree yield /canopy volume ratio (kg/m^3) was significantly dependant on, N_iK_j effects (Table 3). However, mean tree fruit yield response followed a second order negative correlation with tree canopy size (Figure 2) indicating a slightly decrease of fruit yield from 103 to 94 kg/tree as canopy size increased from 42.7 to 46.6 m3/tree. In addition, increasing N rate from 160 to 192 kg/ha/yr translated into an increase in tree fruit load (tree canopy size associated with fruit yield), but further increases in N or K rates decreased slightly tree productivity from 2.4 to 2.3 kg of fruit /m^3 canopy volume, due to the increase of the biomass tree growth associated with decreasing of tree fruit yield (Table 4).

Further analysis demonstrated that tree fruit yield fitted a significant linear model with yield efficiency and indicated that an optimum balanced fruit yield/canopy volume ratio would allow Clementine mandarin trees to support an adequate fruit load level. Mean tree yield efficiency were 2.4; 2.3; 2.02 kg/m^3 for N_2K_1, N_3K_3 and N_2K_2 treatments, respectively. However, the optimum fruit yield of 42.6 T/ha/yr (as discussed above) was achieved by trees with 42.8 m^3 canopy size and thus translated an adequate tree yield efficiency level given of 2.4 kg/m^3.

Fruit quality

Nitrogen had a statistically significant effect on fruit weight and juice total suspended solids/total acidity ratio (Table 5). However, there are no significant effects for all the interactions despite effects of N and K on the total suspended solids TSS/TA ratio. In addition, year effect was significant for all traits.

The averages of the Clementine mandarin fruit weight and size (Table 6) produced by the highest trees fruit

Table 5. ANOVA of nitrogen and potassium fertigation effect on fruit weight, fruit size, tss/ta, leaf n and leaf k in Clementine mandarin (mean squares of all parameters, 2005-2007).

Source of variation	df	Fruit weight g/fruit	Fruit size mm/fruit	TSS/TA	Leaf N (g/kg)	Leaf K (g/kg)
Year (Y)	2	1251.715 **	267.646 **	14.464 *	86.639 **	19.266 *
Replicates (R)	6	93.817 NS	14.457 NS	2.038 NS	3.906 *	2.420 NS
Treatments (T)	10	108.804 NS	21.655 NS	6.629 NS	7.740 **	1.289 NS
Nitrogen rates(N)	2	322.991 *	19.861 NS	0.498 *	0.286 NS	1.430 NS
Potassium rates(K)	2	76.626 NS	28.957 NS	0.913 NS	2.152 NS	0.637 NS
N x K	4	40.437 NS	17.405 NS	14.513 *	11.339**	1.439 NS
Contrast C_1:(N_GK_G)	1	100.718 NS	23.337 NS	4.8163 NS	5.697 NS	0.296 NS
Contrast C_2:(N_0K_0)	1	26.341 NS	25.957 NS	0.598 NS	21.478 **	0.701 NS
TxY	20	43.299 NS	9.398 NS	4.656 NS	5.850 **	1.542 NS
N x Y	4	6.145 NS	6.916 NS	4.007 NS	13.077 **	4.389 NS
K x Y	4	96.683 NS	11.1157 NS	4.118 NS	6.468 **	0.327 NS
N x K x Y	8	38.135 NS	13.764 NS	6.985 NS	2.108 NS	1.231 NS
C_1 x Y	2	19.741 NS	1.264 NS	1.444 NS	1.496 NS	0.030 NS
C_2 x Y	2	55.011 NS	1.592 NS	0.924 NS	9.482 **	0.0284 NS
Error	60	70.221	12.464	4.542	1.581	2.190

* Significant at $p<0.05$; ** significant at $p<0.01$; NS: not significant at $p<0.05$.

Table 6. Means of fruit weight, fruit size, tss/ta ratio, leaf n and k concentrations in 6-month-old spring flush, 2005 - 2007 (similar letters within rows indicate no significant differences among treatments, $LSD_{0.05}$).

Treatments	N and K_2O rates (kg/ha/yr)		Fruit weight (g /fruit)	Fruit size (mm/fruit)	TSS/TA	Leaf N (g/kg)	Leaf K (g/kg)
N_iK_j	N	K_2O					
N_2K_1	192	200	84.49a	59.96a	14.23ba	27.61edc	11.89ba
N_3K_3	232	290	87.62a	56.13b	14.15ba	27.81bedc	11.66ba
N_2K_2	192	240	83.18ba	55.49b	12.75b	28.12bdc	11.37ba
N_2K_3	192	290	84.74a	56.01b	12.90b	27.43edc	11.70ba
N_1K_1	160	200	84.28a	56.41b	12.80b	26.87fe	11.42ba
N_3K_1	232	200	83.13a	56.32b	12.73b	28.97ba	10.74b
N_3K_2	232	240	87.63a	57.08b	12.75b	26.97fed	11.70ba
N_1K_3	160	290	82.01a	55.31b	12.52b	27.47edc	12.17a
N_1K_2	160	240	76.34b	54.67b	15.10a	29.31a	10.88ba
N_GK_G	300	375	80.58ba	54.51b	12.53b	28.51bac	11.83ba
N_0K_0	0	0	82.47ba	54.59b	13.05b	26.21f	11.91ba
$LSD_{0.05}$			7.90	3.33	2.00	1.18	1.39

yield treatments N_2K_1, N_3K_3 and N_2K_2, are in the range of 83.2 to 87.6 g/fruit and 55.5 to 60.0 mm/fruit, respectively.

The means of fruit weight and size of the optimum tree fruit yield treatment (N_2K_1 with 42.6T/ha /yr) are 84.5 g/fruit and 60.0 mm/fruit, respectively. In fact, smallest fruit size with low fruit weight characterized the fruit production of the control (N_0K_0) and N_GK_G trees treatments, which received no fertilizer or the highest fertiliser rates (300 and 375 kg /ha/yr of N and K_2O).

Relative fruit weight, relative fruit size and relative fruit yield as a function of leaf N concentrations fitted a second order regression. There were substantial increases in the values of these parameters as leaf N concentrations increased from 26 to 29 g/kg (Figure 3). These trends are similar to those of fruit yield. However, the relationship between relative TSS/TA and N leaf concentration followed a second order negative correlation with relative TSS/TA decreasing slightly as N leaf concentration increased.

Leaf nutritional status

Leaf N significantly responded to the effects of N_iK_j and N

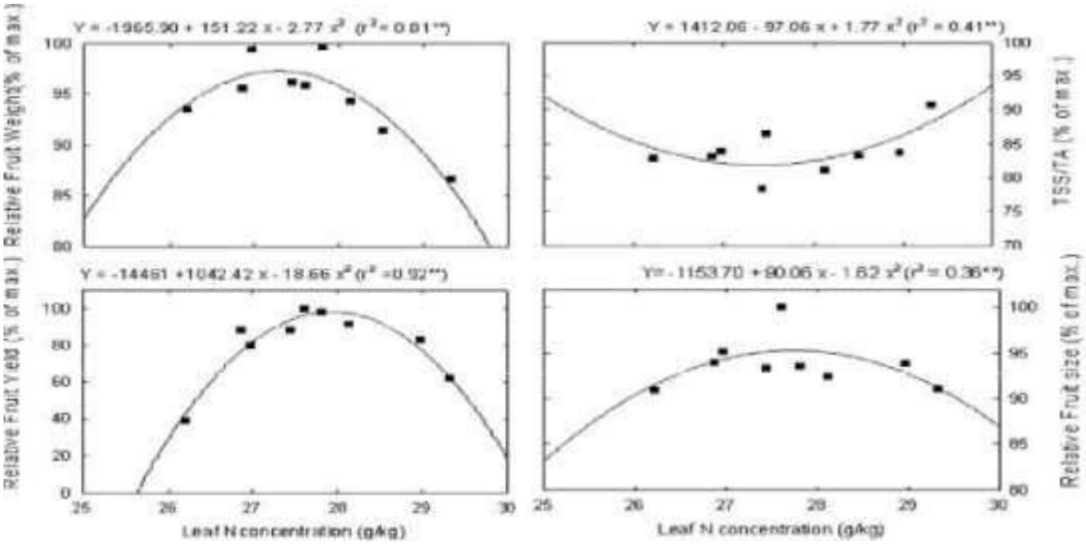


Figure 3. Clementine mandarin relative fruit yield, fruit weight, fruit size and tss/ta ratio in relation to leaf N concentration, 2005 - 2007.

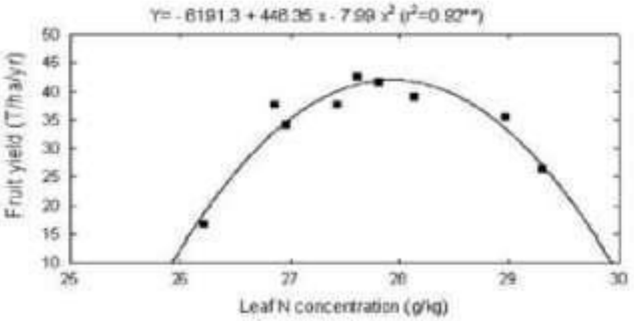


Figure 4. Clementine mandarin fruit yield in relation to leaf N concentration in 6-month old spring flush, 2005 - 2007.

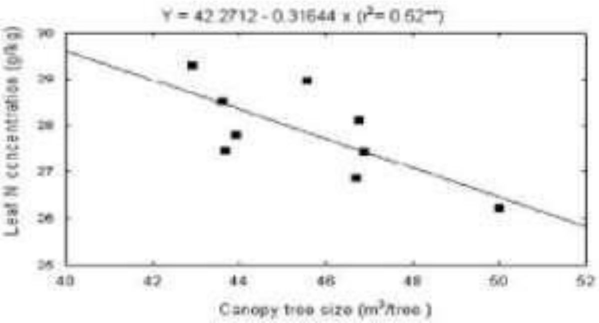
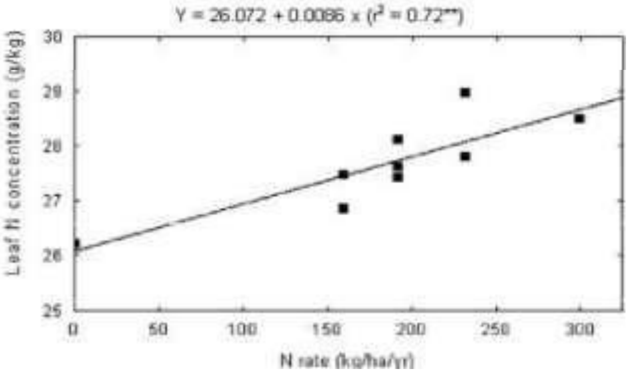


Figure 6. Leaf N concentration in 6-month old spring flush in relation to Clementine mandarin Canopy tree size, 2005 – 2007.



rates, however, leaf K, was not significantly affected by neither N¡Kj nor K fertilization rates (Table 5). It is also worth noting that year effect was significant for Leaf N and K concentrations.

Leaf averaged N and K concentrations ranged between 26.2 to 29.0 and 10.7 to 12.2 g/kg, respectively. The increasing of N rate from 160 to 192 kg/ha/yr translated into an increase leaf N concentrations, but further increases in N or K rates, increased more leaf N associated with an opposite effect on leaf K (Table 6).

The statistically significant quadratic model fitting fruit yield and leaf N concentration (Figure 4) indicates that fruit yield increased to an optimum level of 28 g/kg with increased leaf N concentration; this trend is similar to that shown above with leaf N and relative fruit quality parameters (Figure 3). There is a linear increase of leaf N as N rate increased between control and up to 232 kg/ha (Figure 5). However, further increase of N application up to 290 kg/ha resulted in a decrease of N leaf concentration. In addition, a significant linear model fitting on the averaged leaf N content and canopy volume, indicating that leaf N concentration decreased as canopy tree size increased (Figure 6). Based on these

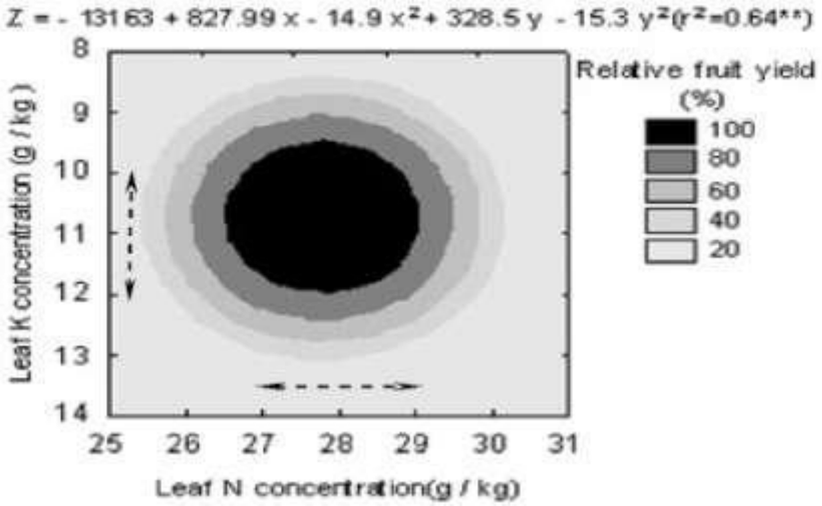


Figure 7. Clementine mandarin relative fruit yield (Z. 2D projection) in relation to leaf N (x) and K(y) concentrations in 6-month-old spring flush, 2005 - 2007.

result (Figures 3 to 6) pertaining to fruit yield and quality, N rate, tree canopy size and leaf N concentration, we can advance that optimal N rate derived on the basis of fruit yield response as well as that on the basis of 4 - 6 month old spring flush leaf N concentration, is the optimum fertility rate. Surface response second order regression model was used to correlate the relative fruit yield to the spring flush leaf N and K concentraions and as an essential step to develop leaf N and K concentrations standars(figure7).

This data shows that, at 90% of the maximum relative fruit yield, which is widely considered the optimum yield, ‘Clementine mandarin’ leaf N and K concentrations were in the ranges of 27 to 29 and 10 to 12 g/kg for N and K, respectively.

These leaf N concentrations for ‘Clementine mandarin’ could be considered relatively high compared to the critical leaf concentrations range of orange trees (25 - 27g/kg). Thus, ‘Clementine mandarin’ trees seem to have high N requirements (4.5 to 5.7 kg/T) as compared to other citrus trees. An optimum fruit yield appeared also to be achieved when leaf K concentration ranges between 10 and 12 g/kg. However, an optimum leaf concentrations of P within a range of 1.15 - 1.24 g/kg, Ca within the range of 32.0 - 34.5 g/kg and Mg within a range of 2.4 - 2.6 g/kg would be appropriate to achieve maximum fruit yield.

DISCUSSION

Mean fruit yields were 39.2, 41.7 and 42.6 T/ha/yr for N_2K_2, N_3K_3 and N_2K_1 treatments, respectively. Increasing N rate from 160 to 192 kg/ha/yr induced a significant fruit yield increase, whereas greater N and K rates beyond these levels would reduce fruit yield. This response followed a quadratic relationship (Figure 1) similar to those reported by Schumann et al. (2003) and Alva et al. (2005). However this relationship indicated that nitrogen and potassium rates in excess of 192 and 200 kg/ha/yr, respectively, reduced fruit yield. Therefore, application of these N and K_2O rates with1:0.9 nitrogen to potassium ratio seems to be the optimum for ‘Cle

under these Mediterranean conditions. Furthermore, the evaluation of the nutrient use efficiency of this N and K fertigation management program indicated that 4.5 and 3.9 kg of N and K, respectively, were needed to produce one ton of fresh Clementine mandarin fruit.

However, these nitrogen use efficiency levels, which appeared the most adequate according to the fruit yield and quality, are substantially higher than 4.4 kg N/T as

reported by Koo et al. (1984) for Florida orange trees.

Thus, ‘Clementine mandarin’ trees seem

requirements as compared to other citrus trees.

A positive linear relationship between leaf N and N rate increase within the range of 0 to 232 kg/ha (Figure 5). However, further increase of N application that is, 300 kg/ha, was found to be associated with a larger deviation from this linear fit. Otherwise, increasing N rate to 160 kg/ha/yr was translated by leaf N response of 0.008 g/kg for each supplementary kg N supply, as previously reported by He et al., (2003). But increasing more nitrogen rates from 160 to 192 and from 192 to 232 kg/ha/yr have induced a limited N leaf response at 0.004 and 0.005 g/kg, respectively, for each nutrient unit added. This observation would suggest that 232 Kg/ha N application may represent an upper limit of required nitrogen rate. Similar findings were reported by Alva et al. (2005) for ‘Hamlin’ citrus trees and H

grapefruit, under Florida conditions. The effect of Nitrogen on fruit weight and juice total suspended solids/total acidity ratio (Table 5), were comparable to those reported by Alva et al., (2005), however, year effect was significant for all traits. During the experimental years, we experienced a very variable rainfall during the different phases. The impact of limited rainfall caused major salinity levels of the irrigated water in one hand and juice quality in the other hand.

The negative second order relationship noted for TSS/TA and N leaf concentration indicated limited TSS/TA with higher N leaf concentrations. Alva et al. (2005) reported that the acid content Furtherof juice did not change across a wide range of N, P and K. They also concluded that both juice quality and external fruit quality parameters are not influenced over a wide range of nutrient rates at a fixed ratio of N:P:K.

The negative linear fit noted for the averaged leaf N concentrations and canopy volume (2005 - 2007) (Figure 6) would imply a greater dilution and probably a reduced translocation of N nutrient to the vegetative growth and particularly leaves. It would be postulated that new and expanding biomass tree growth as well as greater leaves' size and number' would significantly contribute to lower Leaf N concentrations. Similar results were also reported by Tucker et al. (1995) for Valencia citrus trees.

Therefore, it is difficult to comprehensively use this relationship to monitor N application program in Clementine mandarin grove. Thus fruit load to canopy volume would be a better indicator as well as of N Clementine mandarin tree requirement and N use efficiency.

These relationships between the tree productivity related parameters (Fruit yield and quality, relative fruit yield, nutrient rates and biomass tree growth) and leaf N concentrations, support that leaf N content between 27 to 29 g/kg, are the optimum level for 'Clementine mandarin' under the experimental conditions. Nevertheless, this N range could be considered relatively high compared to the critical leaf concentrations range of orange trees (25 – 27 g/kg). Hence the greater N use efficiency (4.5 to 5.6 kg/T of fresh fruit), suggested that 'Clementine mandarin' trees would require higher N applications than other citrus trees.

Leaf K concentration ranges between 10 and 12 g/kg which is considered within the range of leaf K for citrus trees as reported by Chapman (1960), but lower than ranges reported under Florida conditions (Alva et al., 2005; Koo et al., 1984). In addition, leaf concentrations of P (1.15 - 1.24 g/kg), Ca (32.0 - 34.5 g/kg) and Mg (2.4 - 2.6 g/kg) were all in the optimum range as compared to those reported for citrus tree. Alva et al. (2005) and Koo et al. (1984) reported leaf P concentration in the range of 0.8 - 2.4 g/kg. Since P rates were dependant on N rates at P:N ratio of 1:0.088, leaf P concentrations were maintained at an adequate range for all treatments.

Conclusion

Findings on the effect of rates of nitrogen and potassium fertigation on tree nutritional status, biomass tree growth, fruit yield and quality of 25 years mandarin' trees grafted on 'Sour orange Mediterranean conditions demonstrated that N and K fertigation rates of 192 and 200 kg/ha/yr, respectively, are the optimum fertility rates. These N and K rates were necessary to maintain adequate N and K concentrations of 6-month-old leave spring flush within the ranges of 27 to 29 and 10 to 12 g/kg for N and K, respectively.

'Hamlin' more, these N orange and K fertilization management program allowed Clementine mandarin trees also, to support optimum fruit yield of 43 T/ha/yr, with an adequate tree fruit load level of 2.4 kg/m3 (tree fruit yield/tree canopy size) and an optimum fruit quality.

These leaf N and K concentration ranges could be considered the optimal concentrations for nitrogen and potassium fertilization of Clementine mandarin under Mediterranean climatic conditions.

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