NITROGEN AND POTASSIUM CITRUS TREE UPTAKE, FRUIT REMOVAL AND SEASONAL DISTRIBUTION IN THE ROOT ZONE UNDER IMPROVED FERTIGATION MANAGEMENT PROGRAM

L'ABSORPTION, LA MOBILISATION DANS LES FRUITS ET LA DISTRIBUTION SAISONNIÈRE DE L'AZOTE ET DU POTASSIUM DANS LA ZONE RADICULAIRE MOYENNANT UN PROGRAMME DE GESTION AMELIORÉE DE LA FERTIGATION

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ABSTRACT

Optimum application of nitrogen and potassium fertilizers to citrus grove requires information's regarding existing soil N and K residues, dynamics in soil, and tree N and K requirements. However, more understanding of the fate of nutrients in the tree root zone soil matrix provides useful information to develop fertilization management practices with an adequate balanced N and K citrus needs that maximize tree uptake efficiency by minimizing losses of water soluble nutrients. The objectives of this work, was to assess the effects of nitrogen and potassium rates applied through drip irrigation system, on the citrus trees nutrient uptake, fruit nutrient removal and seasonal dynamics of fertilizer-N and K in the root zone. A field trials were conducted from 2005 to 2007 in the citrus production area located in the North East of Tunisia (El Gobba, Cap Bon); on sandy soil with 25 years old 'Clementine mandarin' trees (C.*reticulata*) on 'Sour orange'(C.*aurantium)* rootstock. Nitrogen and potassium rates from 160 to 232 kg $ha^{-1}yr^{-1}$ and 200 to 290 kg $ha^{-1}yr^{-1}$, respectively, were applied as fertigation through a drip irrigation system. Irrigation was scheduled based on soil water content monitoring by daily tensiometer readings at the root zone.
Fruit yield was positively associated with N (r^2=0.91**) and K (r^2=0.84**) rates, indicating that application of 192 and 200 kg $ha^{-1}yr^{-1}$ of N and K_2O (N:K=0.9), respectively, are required for Clementine mandarin trees to support optimal fruit yield of 43 T $ha^{-1}yr^{-1}$. These responses suggest that N and K tree use efficiency varied from 4.5 to 3.9 kg T^{-1} of Clementine mandarin fresh fruit, respectively. On the other hand, tree nutrient removal indicated that both total N (r^2=0.97**) and K (r^2=0.98**) in fruit were positively linear correlated with fruit load, and there was also, a strong linear relation (r^2=0.97**) between N and K in fruits, which supports the needs to maintain 1:1 ratio between the rates of N and K_2O applications. Further more, nutrient uptake

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efficiency (mineral fruit removal: fertilizer applied ratio) were 32.5% and 27.5% for N and K, respectively.
However, the selected fertigation management program, has contributed not only to optimize fruit yield but also to enhance tree nutrient uptake and water use efficiency by minimizing losses below tree root zone. Consequently, it should be an essential component of best management practices for Clementine mandarin under semi arid Mediterranean conditions.

Keywords: Tree nutritional requirements, nutrient use efficiency, Mediterranean conditions.

RÉSUMÉ ET CONCLUSIONS

La nutrition, minérale et hydrique, forme la plus importante composante de conduite culturale dont dépendent le développement, la croissance et la productivité des vergers d'agrumes. La fertigation qui associe à la fois la fourniture des éléments nutritifs et l'eau constitue la technique la plus élaborée permettant une meilleure valorisation de ces deux ressources, et donc l'optimisation des rendements et de la qualité des fruits. Néanmoins, l'amélioration de la compréhension de la cinétique d'absorption des éléments minéraux par les arbres, de leur mobilisation dans les fruits des récoltes et de leur dynamique dans la zone radiculaire, contribuera à l'édification de programmes améliorés de gestion nutritionnelle et hydrique des vergers d'agrumes, bien adaptés à leurs contextes pédoclimatiques de production. L'objectif de ce travail, est d'évaluer les effets de la fertigation azotée potassique sur le rendement en fruit, le statut nutritionnel et l'absorption N et K des arbres de Clémentinier, leurs mobilisations dans les fruits et leurs distributions saisonnières dans la zone radiculaire sous frondaison des arbres.
Les essais expérimentaux ont été conduits (2005-2007) sur un verger de Clémentinier (C.*reticulata*) composé d'arbres matures greffés sur bigaradier (C. *aurantium)*, sise à El Gobba, au Cap Bon, région Nord Est de la Tunisie. Le protocole expérimental est à blocs complètement randomisés avec dix traitements nutritionnels (N_i et K_j) (i et j sont relatifs aux doses respectives de N et de K_2O) et qui consiste à l'application de trois doses croissantes d'azote : 160; 192; 232 kg ha^{-1}an^{-1}, combinées à trois doses de potassium : 200 ; 240 ; 290 kg ha^{-1}an^{-1}, associées à un témoin et répliquées trois fois. Pour l'optimum de développement des arbres et de production, les doses d'engrais phosphatés ont été reliées avec celles en azote suivant l'équilibre N : P_2O_5 de 1 :0.2. La fertilisation du verger a été réalisée exclusivement à base de nitrate d'ammonium (N=33%), de sulfate de potasse (K_2O=50%) et d'acide phosphorique (P_2O_5=85% et densité 1.6). Les engrais minéraux ont été appliqués associés à l'eau d'irrigation (12 fertigations an^{-1}) en les modulant en fonction des besoins spécifiques des stades phénologiques caractéristiques de l'espèce. La moitié de la dose d'azote et 30% de celle en potassium ont été fournies du démarrage de la vague de croissance printanière jusqu'à l'initiation de la nouaison (mi Février-fin Mars) alors que 50% de N et 40% de K_2O ont été appliquées durant l'achèvement de la nouaison jusqu'à la période poste chute physiologique de Juin (mi Mai - fin Juin). La dernière fraction de potassium (soit 30%) a été appliquée au cours du stade grossissement des fruits (Juillet-Août). Le système d'irrigation adopté est composé de deux rampes jumelées, portant des goutteurs intégrés équidistants de 0.33 m, débitant 2 L h^{-1} et assurant ainsi 0.048 m^{3}h^{-1}arbre^{-1}. Le pilotage de l'irrigation a été conduit à travers la lecture journalière de tensiomètres implantés à différentes profondeurs du sol de la zone radiculaire sous frondaison des arbres (0.25, 0.5, 0.75 et 1.0m).

Les résultats obtenus démontrent que :

a) Les doses de 192 kg de N et 200 kg K_2O $ha^{-1}an^{-1}$ représentent la fertilisation minérale adéquate pour cette variété d'agrumes permettant aux arbres de soutenir un rendement optimum de 43 T $ha^{-1}an^{-1}$.

b) Ces mêmes doses d'azote et de potassium ont été nécessaires pour maintenir les concentrations des feuilles de 6 mois d'âges prélevées des rameaux non fructifères issus de la vague de croissance printanière de l'année, à des niveaux optimum de 27 à 29 et de 10 à12 g kg^{-1} respectivement pour N et K.

c) L'efficacité de gestion de la nutrition minérale et de l'alimentation hydrique, résultant de la synchronisation des fournitures d'eau et d'éléments nutritifs avec les besoins spécifiques des stades phénologiques de l'espèce, a permis de contribuer à l'amélioration de l'absorption des éléments nutritifs par les arbres, à la limitation des pertes par lessivage et donc à la meilleure valorisation des engrais chimiques appliqués. Ainsi, ces pratiques améliorées ont conduit à une efficience d'utilisation d'éléments nutritifs évaluée à 4.5 kg de N et 3.9 kg de K par tonne de fruits frais produite, associée à une efficience d'absorption évaluée à des taux de mobilisations (Exportions d'éléments nutritifs dans les fruits/Apports d'éléments nutritifs par les engrais en %) de 32.5% et de 27.5% , respectivement pour l'azote et le potassium ; du fait que pour les espèces pérennes, la majeure partie des mobilisations annuelles d'éléments nutritifs du système sol-arbre réside dans les fruits des récoltes.

d) K et N dans les fruits du Clémentinier sont linéairement corrélées (r^2=0.97**) et cela révèle une similarité de comportement à tendance ascendante et positive des deux éléments. Ainsi cette allure croissante consolide et justifie le choix du rapport N:K=1 qui a été retenu et utilisé pour l'élaboration des programmes de fertigation et encore supporte son maintien à ce niveau pour cette variété d'agrume.

e) En fin, le total aussi bien de N (r^2=0.97**) et de K (r^2=0.98**) mobilisé dans les fruits est linéairement corrélé avec les rendements et cela montre combien ces deux éléments minéraux sont profondément liés à la charge en fruits et donc à la productivité des arbres de Clémentinier.

L'adoption des techniques appropriées de fertilisation associées à l'irrigation localisée a permis une meilleure synchronisation, du moment, des quantités et de la fréquence d'apports nutritionnels et hydriques avec la demande physiologique spécifique de chaque stade phénologique du Clémentinier. Cela a contribué non seulement à l'optimisation des rendements mais aussi à l'amélioration de l'efficience d'absorption et d'utilisation de ces deux ressources, éléments nutritifs et eau, à la limitation des pertes par lessivage en dehors de la zone radiculaire et donc a conduit à une meilleure gestion de la nutrition minérale et hydrique des vergers d'agrumes. Par conséquent, cette approche de gestion nutritionnelle et hydrique des plantations de Clémentinier devrait être considérée l'une des composantes essentielles des meilleures pratiques de conduite culturale des agrumes en condition semi aride Méditerranéenne.

1. INTRODUCTION

Nitrogen is the most important of all nutrients for citrus tree growth, and productivity. It's availability in adequate amount during the critical stages of fruit initiation and development is necessary to support optimum yield of good quality citrus fruit (Dasberg et al., 1983, 1984; Koo et al., 1984; Syvertsen and Smith, 1996). However, N fertilisation plays an important role in fruit yield and quality; especially in the sandy soil that contain small amounts of available N (Calvert, 1969, 1970; Smith et al.,1969; Futch and Alva, 1994; He et al., 2003).When it's supplied in excess to what is required, it will encourage excessive vegetative tree growth (Alva et al., 2003; Shumann et al., 2003) or will lead to nitrate leaching and contamination of surface water tables (Alva and Paramisvam, 1998; Alva et al., 2001, 2006; He et al., 2000).
Potassium is the second nutrient that citrus needed in large amounts; nevertheless, tree potassium requirements are similar to those for N. Most of the K movement in the soil is associated with diffusion, and adequate soil K levels are required to ensure optimal root uptake (Mills and Jones, 1996), as well as it will increase fruit size, yield, vitamin C content and fruit quality (Ritenour et al., 2002). However, excessive high potassium levels will result in large, coarse, fruit with a rather thick and greenish peel and high juice acidity (Wutscher and Smith, 1993).
The implementation of a citrus orchard guiding fertilization program should be based on a diagnosis of a nutrient status of citrus trees. Owing to the fact that the leaf tissue testing is the most important valuable tool which allows accomplishing this goal, particularly with respect to mobile nutrient such as N and K, and micronutrients such as copper, iron, manganese, and zinc (Obreza et al., 1992). The recommended citrus plant tissue for mineral analysis is 4-6 month-old spring flush leaves from non-fruiting twigs, which are published elsewhere (Koo and Sites,1956; Smith,1966; Koo et al,1984); and the interpretation of mineral concentrations depends on the physiological stage of leaves that are sampled, leaf decontamination procedure, and analytical methods (Tucker et al., 1995).
Seasonal splitting of N and K fertilizers referred to the nutritional requirements of the citrus growth stages and their specific phases (Bevington et al., 2003) as well as to minimize nutrient loses by leaching and volatilization. However, the high nitrogen tree demands during the main critical phases of citrus flowering and fruiting process, determine tree yield and productivity, according that fruit set, fruit persistent number and initial fruit size were take place during this period of time. Consequently, to support fruit tree yield and quality implies that supplying N and K should be synchronized with those seasonal critique nutritional needs. In a perennial tree production system, the major component of the annual nutrient removal from the tree-soil system is in the harvested fruits, and this is depends on the total fruit production, as well as on the concentration of the nutrients in the fruit (Alva et al., 2006).
The objectives of this work, was to assess the effects of nitrogen and potassium rates applied through drip irrigation system, on the fruit yield, nutritional status, trees nutrient uptake, fruit removal and seasonal dynamics of fertilizer-N and K in the root zone.

2. MATERIALS AND METHODS

2.1 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 (lon: 10°35'23"E and lat: 36°36'50"N). The soil was sandy especially at 0-0.6m depth, and loam to clay in depth (0.6-1.2m); the main chemical and physical proprieties of the soil at various depths are summarized in Table1 and 2. The citrus trees were 'Clementine mandarin' (Citrus *reticulata Osbeck*) grafted on 'Sour orange' (Citrus *aurantium Osbeck*) rootstock, planted in 1978 at 6.0 x 4,0m spacing with 416 trees ha^{-1}.

Table 1. Chemical soil proprieties of the experimental site
(Propriétés chimiques du sol du site expérimental)

Soil depth	**pH in H_2O**	**Organic mater**	**C/N**	**EC S. Past.**	**CEC**	**K_2O ex. ($Ac.NH_4$)**	**P_2O5 ass. (Olsen)**
(m)	(1: 2.5)	gkg^{-1}		$dS\ m^{-1}$	$Cmol\ kg^{-1}$	$mgkg^{-1}$	
0.0-0.3	7.4	3.25	6.53	3.7	3.7	197	75
0.3-0.6	7.3	1.16	5.00	2.8	2.8	185	38
0.6-0.9	7.5	1.04	7.85	2.0	2.0	91	22
0.9-1.1	7.9	-	-	6.5	6.5	-	-
1.1-1.2	7.6	-	-	19.5	19.5	-	-

Table 2. Physical soil proprieties of the experimental site
(Propriétés physiques du sol du site expérimental)

Depth	**Soil components**			$^{(*)}\theta_{fc}$	$^{**)}\theta_{wp}$	**TAW**	**Bulk Density**
	Clay	**Silt**	**Sand**				
(m)		(%)		$(m^{-3}\ m^{-3})$		(mm)	$(mg\ m^{-3})$
0.0-0.3	5	8	87	0.156	0.063	27.9	1.54
0.3-0.6	4	9	87	0.138	0.042	28.8	1.53
0.6-0.9	35	20	45	0.225	0.145	24.0	1.43
1.1-1.2	27	13	60	0.266	0.145	36.3	1.32

$^{(*)}\theta_{fc}$: soil water content at field capacity, $^{(**)}\theta_{wp}$: soil water content at wilting point,
TAW: Total Available Soil Water

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 3), we added, the fertilization program used by the grower, as a second control treatment (N_GK_G). Every plot was composed of three disease-free trees adjacent 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^{-1}).

Table 3. Treatments used with their corresponding rates of N and K
(Traitements utilisés avec leurs doses correspondantes en N et K)

Treatments (N_iK_j)		**Nitrogen rates (kg N $ha^{-1}yr^{-1}$)** (1)				
		$N_0 = 0$	N_1=160	N_2 = 192	N_3=232	N_G =300
Potassium rates (kg K_2O $ha^{-1}yr^{-1}$) (2)	K_0= 0	N_0K_0	-	-	-	-
	K_1 =200	-	N_1K_1	N_2K_1	N_3K_1	-
	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	-	-	-	-	$N_G K_G$

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

To achieve optimal tree growth, phosphate was applied to all treatments as phosphoric acid (P_2O_5=85%) with N: P_2O_5 (1:0.2).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 potassium was added during fruit growth stage. The drip-irrigation system used consisted of two drip lines delivering approximately $0.048m^3h^{-1}$ 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 0.25m 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, 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 0.25m tensiometer read $10x10^{-3}$ MPa and $15x10^{-3}$ MPa during July through October (Smajstrala et al 1985; Pearsons, 1989).

2.2 Soil plant and fruit sampling and analysis

During the experimental period (2005-2007), soil sampling was taken under the tree canopy at 0-0.3, 0.3-0.6, 0.6-0.9 and 0.9-1.2cm depth, twelve times per year (approximately each 2-3 weeks interval). At each depth three core (5cm diameter) samples were taken from under the canopy of three trees which composed the plot.
The soil samples were air dried and sieved to less then 2mm diameter particle size. The extractable NO_3-N and NH_4-N was measured by steam distillation with MgO and Deverda's alloy, respectively, using KCL as extracting agent and the semi Micro-Kjeldahl method determination as described by Bremner (1965a). Potassium concentration in soil material was evaluated by flame photometry. .
Six-month-old spring flush leaves from non-fruiting terminals were sampled, each of 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 1*M* HCL (Alva et al.,2005). Leaf total N content was determined by the semi micro-Kjeldahl method (Bremner,1996); 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.
Fruits were harvested in last decade of November of each year, by manually picking from each tree of the plot. 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. For the evaluation of the total N and K fruit removal, 30 fruits were sampled from each plot, each of the three years and the same analytical methods were used as well as for citrus leaves.

2.3 Statistical data treatments

Response of fruit yield, Soil Nitrogen and potassium concentrations, leaf N and K nutritional status and fruit N and K removal, to nitrogen and potassium fertigation; were evaluated by analyses of variance (ANOVA) and regression analyses using PROC ANOVA and PROC REG of SAS (1996).Treatments means separation was determined using Student-Newman-Keuls tests or LSD tests (t) at threshold of 0.05.

3. RESULTS AND DISCUSSIONS

3.1 N and K fertigation effects on fruit yield and leaf nutritional status

Over the ranges of N (160 to 232 $kgha^{-1}y^{-1}$) and K (200 to 290 $kgha^{-1}y^{-1}$) rates, the mean fruit yield response followed a quadratic relationship (Fig.1) similar to those reported by Schumann et al. (2003) and Alva et al.(2005). Mean fruit yields were 39.2, 41.7, and 42.6 Mg $ha^{-1}yr^{-1}$ for N_2K_1, N_3K_3 and N_2K_2 treatments, respectively. Increasing N rate from 160 to 192 $kgha^{-1}yr^{-1}$ 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$kgha^{-1}yr^{-1}$, respectively, reduced the fruit yield. A1: 1.09 nitrogen to potassium ratio seems to be the most adequate ratio for 'Clementine mandarin' under these Mediterranean conditions. Fruit yield is most sensitive to nitrogen than to potassium.

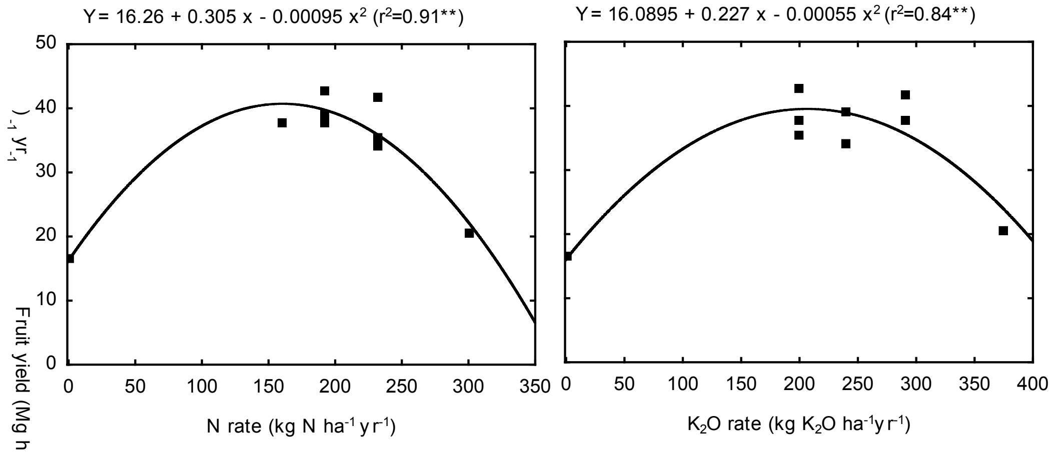

Figure 1. Effect of nitrogen and potassium rates on Clementine mandarin fruit yield, 2005-2007. (Effet des doses d'azote et de potassium sur les rendements en fruit du Clémentinier 2005-2007).

Calculated nitrogen/potassium requirements were 4.5/3.9; 5.7 /5.75; and 4.9/5.0 kg kg^{-1} for N_2K_1, N_3K_3 and N_2K_2 treatments, respectively. However, N use efficiency varied between 4.5 and 5.7 kg N per Mg (1metric tonne) of fruit which is substantially higher than 4.4 kg N Mg^{-1} as reported by Koo et al. (1984) for Florida orange trees. Application of 192 kg N $ha^{-1}yr^{-1}$ and 200 kg K $ha^{-1}yr^{-1}$ (N: K ratio of 1:0.9) would allow 'Clementine mandarin' trees to support an optimum fruit yield of 42.6 Mg $ha^{-1}yr^{-1}$. This is a very adequate yield given the alternate bearing nature of this cultivar and relatively low irrigation water quality ($2.10 \le Ec_w \le 2.53$ dSm^{-1}).
Analysis of the 6-month-old spring flush leaves of Clementine mandarin trees for mineral-Nutrients provide à valuable tool to evaluate the nutritional status of the trees. It is also a best indicator of tree response to different fertilizer management program. Leaf averaged N and K concentrations ranged between 26.2 to 29.0 and 10.7 to 12.2 g kg^{-1}, respectively. The increasing of N rate from 0 to 192 kg $ha^{-1}yr^{-1}$ 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 4).
On the basis of the pooled data for all treatments and their replicates of the 6-month-old spring flush leaf N and K concentrations (20005-207), surface response second order regression model was used to correlate the relative fruit yield to the leaf N and K concentrations (Fig.2).Relative fruit yield was calculated as percent of the maximum

fruit yield across all treatments and replicates. 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^{-1} 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 (25-27 gkg^{-1}). Thus, 'Clementine mandarin' trees seem to have high N requirements (4.5 to 5.7$kgMg^{-1}$) as compared to other citrus trees (Hammami et al.; 2009).Whereas, leaf K concentration ranges between 10 and 12 g kg^{-1} 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).

Table 4. Means of fruit yield, N and K concentrations in 6-month-old spring flush leaves, 2005-2007. (Similar letters within rows indicate no significant differences among treatments, $LSD_{0.05}$). (Moyennes des rendements en fruits, des concentrations N et K des feuilles de six mois d'âge, issues de la vague de croissance printanière, 2005-2007). (Les même lettres sur la colonne indiquent qu'ils n'ya pas de différence significative entre les traitements au $PPDS_{0.05}$, 2005-2007).

Treatments	**N_iK_j**	**N and K_2O rates ($kgha^{-1}yr^{-1}$)**		**Fruit yield ($Mgha^{-1}yr^{-1}$)**	**Leaf N and K Concentrations(gkg^{-1})**	
T_4	N_2K_1	192	200	42.6a	27.61edc	11.89ba
T_9	N_3K_3	232	290	41.7a	27.81bedc	11.66ba
T_5	N_2K_2	192	240	39.2a	28.12bdc	11.37ba
T_6	N_2K_3	192	290	37.7ab	27.43edc	11.70ba
T_1	N_1K_1	160	200	37.7ab	26.87fe	11.42ba
T_7	N_3K_1	232	200	35.5ab	28.97ba	10.74b
T_8	N_3K_2	232	240	34.1ab	26.97fed	11.70ba
T_3	N_1K_3	160	290	30.3bca	27.47edc	12.17a
T_2	N_1K_2	160	240	26.4bca	29.31a	10.88ba
T_{11}	N_GK_G	300	375	20.5cd	28.51bac	11.83ba
T_{10}(control)	N_0K_0	0	0	16.7d	26.21f	11.91ba
$LSD_{0.05}$				12.7	1.18	1.39

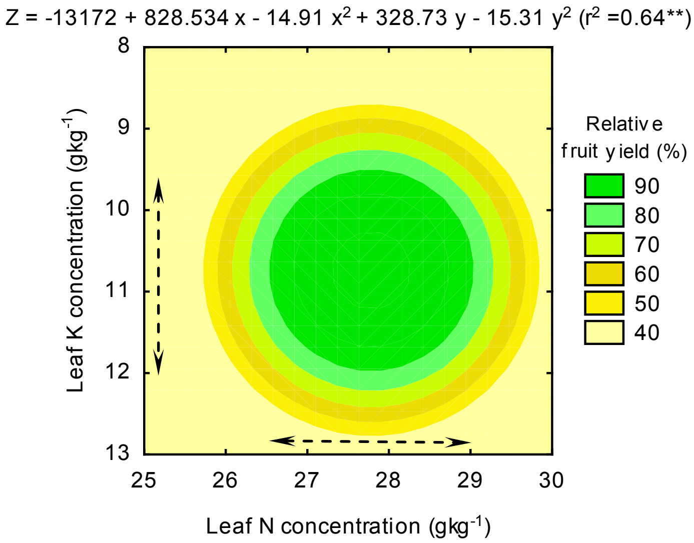

Figure 2. Clementine mandarin relative fruit yield (Z, 2D Projection) in relation to leaf N (x) and K(y) concentrations in 6-monts-old spring flush, 2005-2007. (Rendement relatif du Clémentinier (Z, Projection 2D) en relation avec les concentrations N(x) et K (y) des feuilles de six mois d'âge issues de la vague de croissance printanière,2005-2007)

3.2 N and K uptake and citrus tree physiological cycle

Over the three years of follow-up, mineral-N and K concentrations in the soil profile (0.0-1.0m) which represented the most nitrogen and potassium available for root uptake were used to evaluate nutrient dynamics pattern during the cropping season. Mineral-N concentrations have developed a similar cyclic pattern each year, with three successive soil N concentrations cycle. Each one is composed of an ascending portion, culminating at a peak of maximum concentration followed by a descendant one (Fig 3.).
Each N concentration cycle describes a nitrogen replenishment and depletion in the root zone soil matrix (0.0-1.0m depth). However, the first peak of soil mineral-N concentration which appeared subsequently to the beginning of the fertilizers injections (first decade of February) and associated to the starting of the spring flush tree growth; was the most important.
The second cycle occurred from fruit set to the physiological fruit drop end. The latest one is related with the beginning of the fruit growth development (Cell enlargement phase), combined with the starting of the autumnal flush growth.

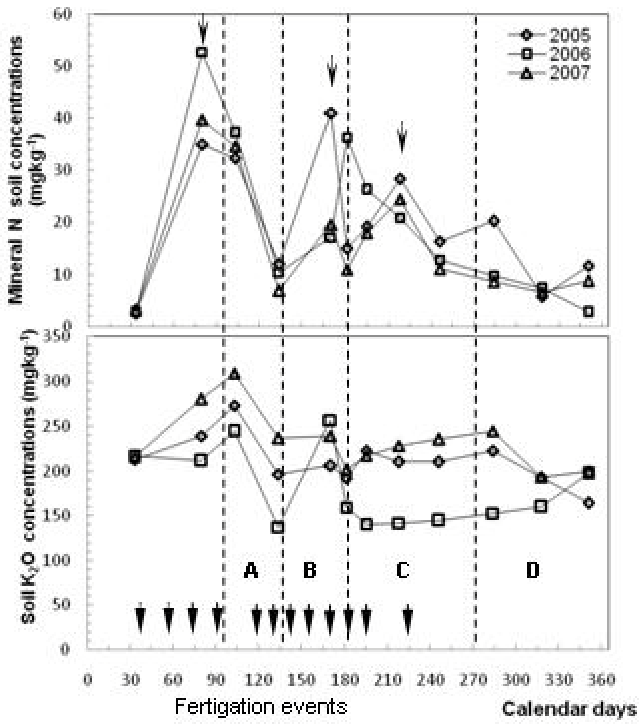

Figure 3. N and K replenishment and depletion cycles in the soil root zone (0-1m depth) during the Clementine mandarin cropping seasons of 2005, 2006 and 2007. (With A: Flowering-fruit set phase, B: fruit set-Jun physiological fruit drop, C: fruit growth phase - cell enlargement- and D: fruit ripening-harvesting). (Cycles de recharge-épuisement en N et K du sol de la zone radiculaire (0-1.0m) durant les saisons de production des arbres de Clémentiniers, 2005,2006 et 2007 ; avec A : Stade floraison-nouaison, B:Stade nouaison-chute physiologique de Juin, C: Stade grossissement du fruit (élargissement des cellules) et D: Stade maturité-récolte).

At the starting of the spring flush growth (day 33), the soil native mineral-N was at its lower concentration level (2.4 to 3.2 mg kg^{-1}); after the first N fertigation events (mid February), N soil content rose progressively to reach its highest concentrations of 35.0 to 51.6 mg kg^{-1}, on day 80 to 103; due to the low tree N uptake during this time. Thus very little N of the soil solution resources was requested (Legaz et al., 1983)

because N trees requirements seem to be satisfied with N supplies coming from the endogenous reserves stored in their biomass.
Through the four following weeks (day 103 to 134), and although the continuous fertilizers supply, soil N concentration decreased intensively and progressively in the root zone, which translated the high tree N uptake activity process. However, this period corresponded yearly to the flowering-fruit set initiation phase which represents the highest and critical tree N requirements. For the remaining part of the cropping season, two other N concentrations peaks was recorded; the first one on June 20 (day170) and the second one on July 15 (day 195) followed respectively by two successive decreasing trends in soil N concentrations with similar patterns; on June 30 (day 180) and July 15 or August 8 (day 195 or 218).
The first soil mineral-N concentration fall corresponded to the fruit set-June physiological fruit drop phase, during which N tree utilisation was at its maximum, due to the high fruit let N competition for persistence and remaining to continue their growth. The second fall was at the starting of the fruit growth stage (cell enlargement), which sometimes was combined with the autumn flush growth (case of the two latest cropping seasons 2006 and 2007). Physiological fruit drop phase, could also be extended to end July (year 2006), due to the annual variability of the climatic conditions, and therefore the two latest soil N concentration cycles merged to give only one, starting at end fruit set (day 150) and continue until end July (day 210).
During flowering-physiological fruit drop stage, as a mainly critical phase on which the Clementine mandarin trees developed the highest nitrogen requirements (day 103 to 180). Similar results were obtained by Obreza et al. (2008) in orange case under Florida conditions. The mean concentrations of mineral N in soil root zone were in ranges of 41.9 to 12.0; 51.6 to 10.1 and 42.4 to 8.28 mg kg^{-1}respectively for 2005, 2006 and 2007. Consequently, during the fruit growth stage until harvesting (day 318), the tree nitrogen requirements decreased, and soil mineral-N concentrations falls to achieve the lowest levels, as well as 5.7 to 8.9 mg kg^{-1}.
From what discussed above, it was indicated that the careful synchronization of nitrogen supply, in the beginning of the cropping season, allowed soil N concentration to rise rapidly before the triggering of N tree uptake process. During flowering-physiological fruit drop stage, which represents the mainly critical phase when Clementine mandarin trees developed the highest nitrogen requirements, and consequently soil N concentration must be maintained at optimum level to provide tree nutritional requirements without constraint. To achieve this goal, the rate of nitrogen supply to replenish soil solution must be slightly higher than of the tree uptake speed, but no in excessive amount because it could be leached below the tree root zone. After the physiological fruit drop until the harvesting, the progressive decreasing of the soil N concentration is allowable, according to the decrease of the tree N requirements. Nevertheless, only wise improved water irrigation management allowed a homogeneous N distribution in the soil root zone, and thus could enhance N uptake and minimize losses by leaching process.
Potassium in the soil presents many levels of availability, relatively unavailable forms, slowly available forms, and readily available forms. According to the coarse soil texture of the experimental site, and thus, to its low nutrient holding capacity, the essential soil potassium is only readily available forms. It consists of two forms: 1) potassium ions in the soil solution and 2) exchangeable potassium adsorbed on the soil colloid surfaces. From a practical standpoint, it’s important that these two forms of readily available potassium are in dynamic equilibrium (Roy et al., 1981), and the K absorption from the soil solution by trees results in a temporary disruption of the equilibrium. Although the low holding nutrient capacity of the experimental site soils, due to the coarse texture of the soil material, initial soil potassium mean concentrations, at the starting of the field trials, were at an adequate range, 213.5,217,3 and 215.6 mg kg^{-1}, respectively in 2005,2006 and 2007.
After the higher K soil concentrations (Fig.3) following the first fertigation events, a very important fall of soil K content has occurred just with starting of flowering-fruit set phase (day 103 to 134). But during the remaining period of the cropping season, soil solution showed a quite stability of K concentrations what demonstrated better

synchronization of the K fertilizers supplied compared to the trees nutritional needs. That, indicated potassium fertigation management program applied allowed soil solution dealing with K tree uptake, in spite of the high tree potassium requirements, during this physiological phases. In addition, K tree uptake rate appeared to be enough stable specially during fruit growth stage until harvesting (day 180 to 285). However, potassium concentrations in the soil profile at the cropping season end were 164.1, 197.2, and 199.5 mg kg^{-1}, respectively in 2005, 2006 and 2007 which are slightly less than soil potassium concentrations of each year's spring flush.

3.3 Seasonal distribution of N and K in the root zone at different N_iK_j rates

The residual mineral-N concentrations in the soil profile during the cropping season at a any given date represents the temporary nitrogen soil stock resulting from the interaction between N fertigated and the Clementine mandarin tree N up took, combined with a probably N leached and percolated below the root zone. Owing to the fact that in 2007, the monitoring of N and K have included the whole depth of the soil profile (0.0-1.0m), data collected were used to investigate seasonal nitrogen and potassium dynamics in the soil matrix under tree canopy. A surface response second order regression model was used to correlate mineral-N concentrations to the soil depth associated to the period of time (Fig.4). This three-dimensional correlation showed not only the residual N mineral concentrations variations in the soil profile, during the tree physiological cycle; but also described N dynamics resulting from the interaction between the processes of N refill and of exhaustion of the soil solution and consequently the effectiveness of the N fertigation management program used. Mineral-N concentrations rise initially in soil surface layers (0-0.4m) as well as fertiliser's injection progresses in time, and then the homogenization of the nutrient in the root zone was ensured by the gradual propagation of the soil moisture matrix.

During the first physiological phase of the trees phonological cycle (Beginning of the spring flush growth-flowering-fruit set) and succeeding the first fertigation events, N soil concentration in the surface layers reaches its highest level (day 80), owning to the fact that tree N uptake did not intensify yet, and thus a fraction of injected nitrogen will be prone for leaching and percolating to gain the deeper layers as reported by Legaz and al, (1983). It was is noted also from all mineral-N soil profiles, that starting of N leaching process is always associated with the movement of the soil moisture profile and thus to the intensification of the irrigation; independently of applied N rates and period of time during the cropping season. Consequently; and although this N movement process was extended until mid May (day 135), following the soil moisture of the soil profile, the highest mean N concentrations at 1.0 m depth, were 15, 30 and 20 mg kg^{-1}, respectively for 160,192 and 232 kg $ha^{-1}an^{-1}$ N rates. In the same way, and through all the depth of the active root zone (0-0.9 m), the mean N concentrations were≥20 mg kg^{-1} which was quite sufficient to provide N trees requirements according to the different N rates applied.

From mid May to June end (day 135 to 180), period with high N tree demand, coinciding with fruit set-Jun physiological fruit drop phase, we noted a stability of surface layers N concentrations associated with a fall of soil mineral N in average soil root zone depth (0.4 to 0.8m), related to a gradual and progressive decreasing of leaching and percolation processes. That can be explained by the fact that increasing N in soil solution by fertigation events, at the time when trees N uptake is with excess had induced a buffer effect which improved efficiency uptake of nitrogen via tree root system (Alva and Al, 1998; Paramasivan and Al, 2001).

During the fruit growth (enlargement) phase, (July-September), combined effects of increasingly low N tree demand, the end of nitrogen supply by injection and the dilution of the soil solution resulting from continuous watering by irrigation, have induced decreasing of N soil solution as well as we advanced towards the end of the physiological tree cycle. Nevertheless the residual mineral-N soil concentration in the surface layers (0.0-0.4m) allowed Clementine mandarin trees to provide their N needs to complete their annual growth cycle without constraints. Consequently, mineral-N concentrations, at the cropping season end, regained their original levels 5 to 10 mg kg^{-1} in the soil root zone and that for all the nitrogen rates applied.

In addition, the three-dimensional representation of the temporal distribution of soil potassium in the tree root zone (Fig.4) has given brought the required explanations regarding nutrients dynamics comprehension process and especially its fate with respect to the various parameters responsible for physicochemical environment of the soil solution. In this respect, the essential pathways which characterized and dominated the distribution of the soil K concentrations in the root zone were identified.

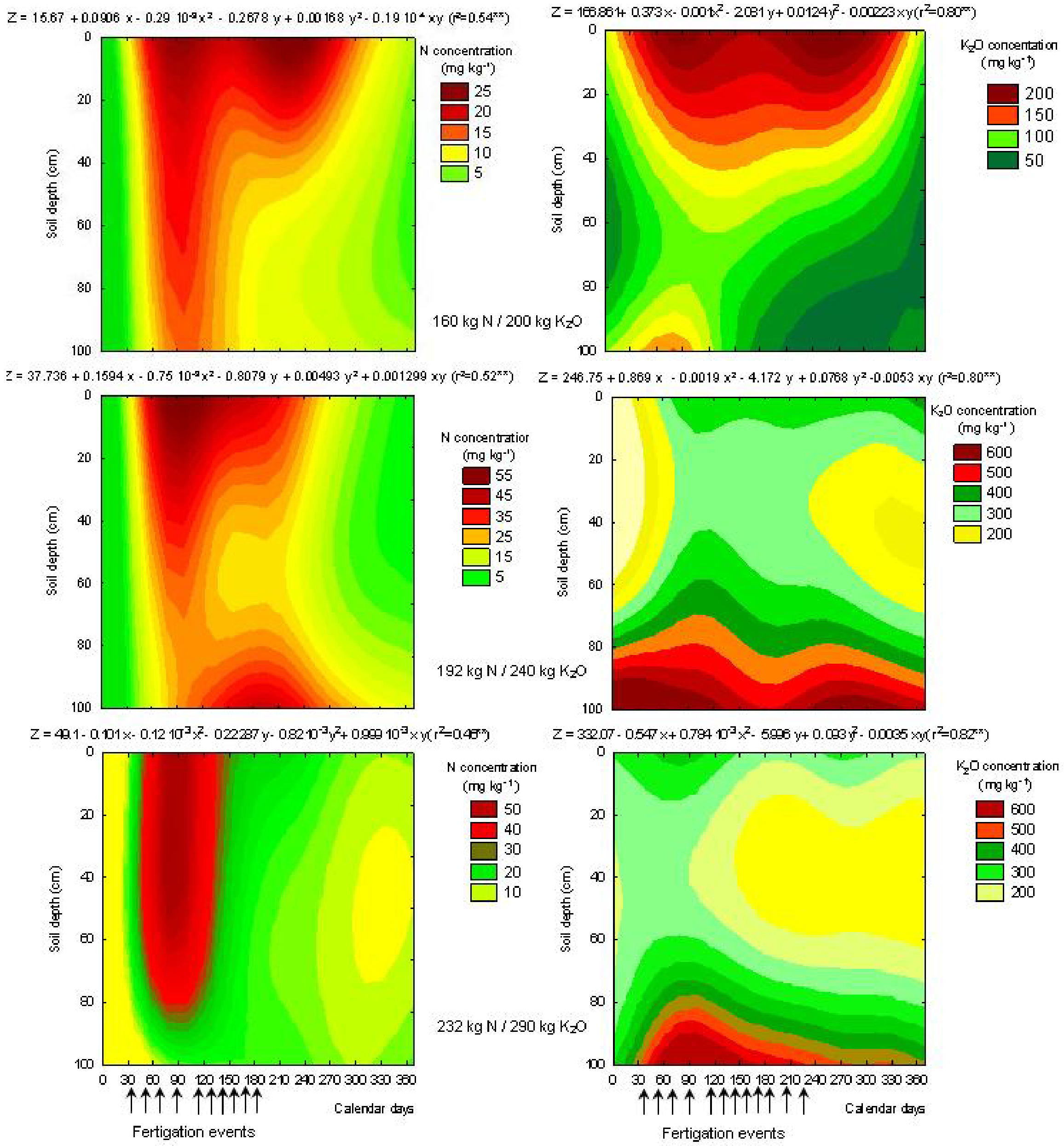

Figure 4. Seasonal distribution of N and K soil mean concentrations (Z, 2D Projection) during the tree cropping season (x) in relation to soil root zone depth (y) at N_iK_j rates (2007). (Distribution saisonnière des concentrations moyennes N et K (Z, Projection 2D) durant le cycle physiologique des arbres (x) en relation avec la profondeur su sol de la zone radiculaire (y) à différentes doses N_iK_j (2005-2007).

Consequently, the K soil kinetics could be described by the following parameters:

- the potassium supply rate which represented the refill behaviour of the momentary K soil solution stock according to its adaptation degree compared to the tree uptake intensity;
- the rhythm of K absorption via the roots defined by the uptake root intensity developed by the Clementine Mandarin trees, and his variation during the various physiological cycle phases to provide nutritional tree needs;
- the morphology of the soil watering which orchestrated the displacement of the soil matrix moistening, responsible for the nutrient migration and transport to percolate towards the depth layers;
- the physical and physic-chemical soil characteristics under tree canopy (soil texture and original fertility);
- and finally the exceptional intensity tree root system uptake, during the post-Jun physiological fruit drop-fruit enlargement phase (day 180 to 270), with depths ranging between 0.2 and 0.7 m, resulting in a considerable fall of the K concentrations to reach their low levels (100 $mgkg^{-1}$, for K_1 rate and 200 for K_2 and K_3 rates).

On the basis of the previous discussion, it has been demonstrated that establishment of a three-dimensional model describing the temporal distribution of the soil mineral-N and K concentrations in the root zone under Clementine mandarin tree canopy, through a sufficient number of observations, could be a useful tool of assistance to the improvement of comprehension of nutrient soil dynamics, specially the exhaustion of the nutrient soil solution which describes at the same time, interaction between multiple processes : Nutrient supply, tree uptake and nutrient loss by leaching below the root zone.
However, the improved N and K management program must translate the optimal adequacy between nutrient supplied to the soil solution and trees nutritional request throughout their physiological cycle of growth under the given climate and edaphic conditions.

3.4 Fruit nutrient removal

3.4.1 Relationship between N and K in fruits

In a perennial tree production system, the major component of the annual nutrient removal from the tree-soil system is that in the harvested fruits, and this is depending on the total fruit production, as well as the concentration of the nutrients in the fruit (Alva et al., 2006). During the experimental period (2005-2007), the N removal in harvested Clementine mandarin fruits over the range of N rates 160-232 kg N $ha^{-1}yr^{-1}$ varied from 17 to 78 (2005), 23 to 98 (2006) and 51 to 88 kg $ha^{-1}yr^{-1}$ (2007). Whereas, potassium fruit removal varied from 13 to 65 kg $ha^{-1}yr^{-1}$ in 2005, from 18 to 70 kg $ha^{-1}yr^{-1}$ in 2006 and from 25 to 73 kg $ha^{-1}yr^{-1}$ in 2007 for the range of K_2O rates 200- 290 kg K_2O $ha^{-1}yr^{-1}$. The K and N relationship in fruit followed a significant and positive linear correlation (r^2=0.97**) which demonstrated how strongly were related those two nutrients in fruit yield (Fig.5).
In addition, this correlation of total K and N fruit removal reveals a similar trend of the two nutrients. This fact justifies and consolidates the choice of the nutritional ratio N: K=1.04, used for implementation of the fertigation program and this supports also the need to maintain it for Clementine mandarin mature trees. These results are similar to those published by Tucker et al. (1995); Alva et al. (2006) and Obreza et al. (2008) (N: K=1).

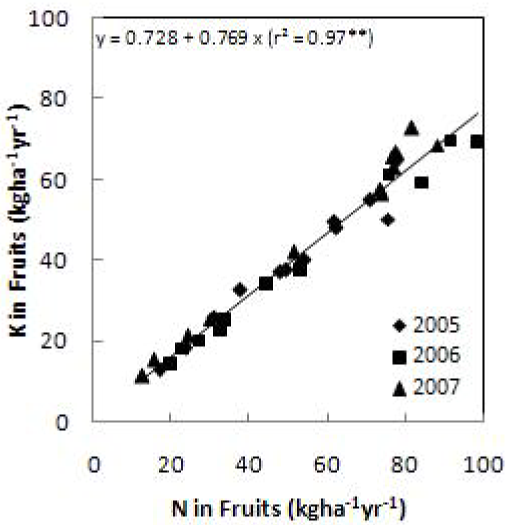

Figure 5. Relationship between N and K in fruits of 25 year-old 'Clementine mandarin' trees (on sour orange). (Regression was calculated on the data pooled across three years, 2005-2007). (Relation entre N et K fruits d'arbres de Clémentinier -greffés sur bigaradier- de 25 ans d'âge, la régression a été calculée sur la base d'un regroupement des données à travers les trois années 2005-2007).

3.4.2 Total N and K in fruits and fruit yield

N removal in harvested fruit over a range of N rates varied from 17 to 78 kg ha^{-1}, 23 to 98 kg ha^{-1} and 51 to 88 kg ha^{-1} for 2005, 2006 and 2007, respectively. Total N fruit removal over multiple years (2005-2007) follows the fruit production cycle witch varied from 11 to 53 Mg ha^{-1}, 13 to 60 Mg ha^{-1} and 19 to 55 Mg $ha^{-1,}$ respectively. However, total N fruit removal is significantly linear correlated with fruit yield (r^2=0.97**and r^2=0.96**) at each N rate, showing how much this nutrient was directly related to the fruit load and thus to the Clementine mandarin tree fruit yield (Fig.6). In the same way, the total potassium removal in the fruits per hectare demonstrated the similar trend as that for the total Nitrogen (Fig.6).

At each K_2O rate, K in the harvested fruits was also directly related to the tree fruit yield. In the other hand, the slope of the regression increased slightly with each increment in annual N and K_2O rates (Table 5) and this is quite expected because of improved nutrient supply and irrigation practices applied in this trials. In addition, the simultaneous variation at the same time of N and K fruit removal translated the citrus fruit yield pattern generally follows a cycle of alternating high and low yields defined as "Alternate Bearing Habit" (Alva et al; 2006).

The nitrogen accumulation in fruits was 32.5%; 29.9% and 32.5% of N applied for N_2K_1, N_3K_3 and N_2K_2 treatments, respectively, however, potassium was 27.5% (N_2K_1), 21.0% (N_3K_3); and 24.5% (N_2K_2) of K applied. Alva and Paramasivam (1998) and Paramasivam et al., (2000) indicated that N accumulation by citrus fruit was in range of 32 to 40% of total N applied.

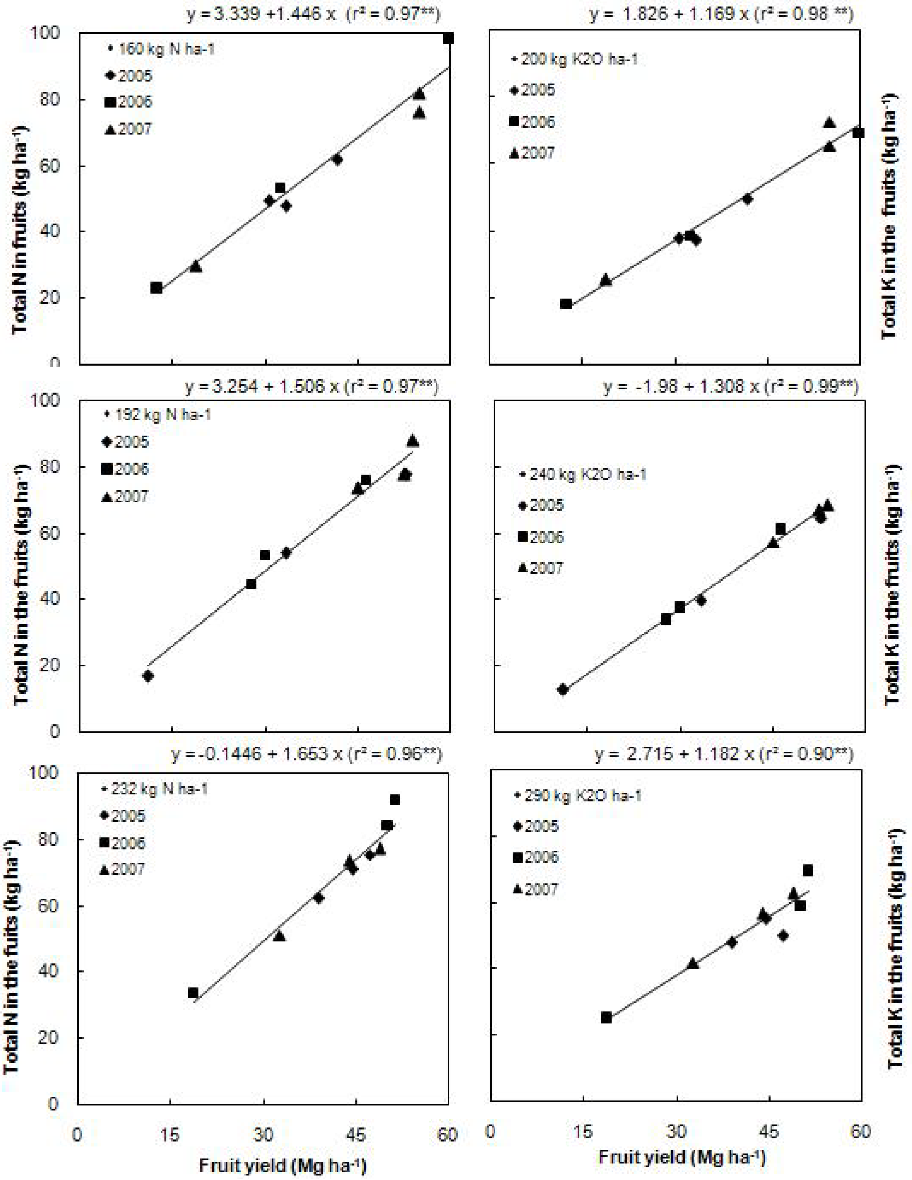

Figure 6. Relationship between total N and K in fruits of 25 year-old 'Clementine mandarin' trees (on sour orange), across all years (2005-2007), at each N and K_2O rates. (Relation entre total N et K fruits d'arbres de Clémentinier -greffées sur bigaradier- de 25 ans d'âge à travers les années 2005-2007, et pour chaque dose d'azote et de potassium).

Tableau 5. Correlation models of N, K fruit removal in relation to fruit yields at different N and K_2O rates (2005-2007). (Les modèles de corrélation de N et K exportés par les fruits en relation avec les rendements, à différentes doses d'azote et de potassium (2005-2007)

Nutriments	Rates (kg $ha^{-1}yr^{-1}$)	a	b	r^2 (1)
	160	3.339**	1.446**	0.97
N	192	3.254**	1.506**	0.97
	232	- 0.145**	1.653**	0.96
	200	1.826*	1.169*	0.98
K_2O	240	-1.980*	1.308*	0.99
	290	2.715*	1.182*	0.90

(1) Model coefficient: y= a+bx, with y:N, K fruit removal, x:Fruit yield (Mg $ha^{-1}yr^{-1}$)

4. CONCLUSION

Three years (2005-2007) of field trials was conducted using 25 years old mature Clementine mandarin trees grown in sandy soil, in order to evaluate the optimal N and K management practices under carefully scheduled irrigation management to minimize leaching of water and nutrient below the root zone. Results have been shown relationships between annual N and K applications, Clementine mandarin fruit yield, tree nutritional status, mineral fruit removal and accumulation.

Findings on the effect of rates of nitrogen and potassium fertigation under semi arid Mediterranean conditions demonstrated that N and K_2O fertigation rates of 192 and 200 kg $ha^{-1}yr^{-1}$, respectively are the optimum fertility rates. These N and K rates were necessary to maintain adequate N and K concentrations of 6-month-old leaves spring flush at the ranges of 27 to 29 and 10 to 12 g kg^{-1} for N and K, respectively, and to allow trees also to support optimum fruit yield of 43 Mg $ha^{-1}yr^{-1}$.

The improved irrigation and N, K fertilization practices adopted in this study, has contributed to enhance nutrient tree uptake and to limit losses in the root zone under tree canopy. However, N and K use efficiency were 4.5 kg and 3.9 kg of N and K , respectively, per ton of fresh Clementine mandarin fruits produced, associated with a nutrient uptake efficiency (Nutrient accumulation by fruits: Fertilizer applied ratio) of 32.5 and 27.5% for N and K, respectively. In addition, the total N (r^2=0.97**) and K (r^2=0.98**) removal in the harvested fruits were high significantly linearly correlated with fruit yield across the experimentation years and at each N and K_2O rates. Such results demonstrate how strongly related nutrients accumulation in fruits and the tree fruit load ability. Furthermore, the relationship between K and N in fruits followed a significant linear correlation (r^2=97**), which demonstrated how strongly were related those two nutrients in fruits. This correlation of K and N fruit removal reveals the similar trend of the two nutrients, and consequently, justifies the used nutritional ratio N: K=1, for implementation of the fertigation program and also supports the need to maintain it for Clementine mandarin mature trees.

The association of the fertilization to drip irrigation allows careful synchronisation of timing, frequency and amount of water and fertilizers applications according to the nutritional requirements of various physiological citrus tree stages. That contributes not only to optimize fruit yield but also to enhance tree nutrient uptake and water use efficiency by particularly minimized leaching losses. Consequently, it should be an essential component of best management practices for Clementine mandarin under semi arid Mediterranean conditions.

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