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EFFECTS OF NUTRITIONAL TRUNK INJECTIONS ON VALENCIA LATE ORANGE PRODUCTION

Efecto de inyecciones nutritivas al tronco en la productividad de naranja valencia

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ABSTRACT. The objective of this work was to determine the effect of nutritional trunk injections (NI) of N, P_2O_5, K_2O, CaO, and MgO on quantitative and qualitative productivity. Experimental trials were conducted during three years, between campaigns 2008/09, 2009/10 and 2010/11, in an orchard of orange "Valencia Late" in Corrientes, Argentina. NI were applied to each side of the trunk at 40 cm of soil. The treatments tested consisted of soil fertilization (50 % spring and autumn) T1: 1,5 kg plant^{-1} of 15-6-15-6 (half dose, HF); T2: HF treatment plus NI spring; T3: HF plus NI spring and summer; T4: HF plus NI spring, summer and autumn and T5: full dose 3 kg plant^{-1} of 15-6-15-6. Statistical design was a randomized complete block with four replications, experimental plot of two effective plants. Leaf concentrations of N, P, K, Ca, Mg, Fe, Zn, Cu and Mn were determined in leaves of fruiting branches obtained in autumn. Total fruit production was measured at harvest, diameter, percentage of juice, soluble solids contents, acidity, ratio and color were determined on a sample of 40 fruits per plot. Variance analysis, Duncan test and principal component analysis were done for quantitative variables and for color Kruskal Wallis test was performed. Fruit production was increases by the treatment 4 compared with same dose of soil applications (T1) added that none of the treatments significantly affected IN fruit quality. This report establishes the utility of using the IN as a complementary tool to conventional fertilization.

Key words: citrus hybrids, fertilization, sensory fruit characteristic, yield

RESUMEN. Se determinó el efecto de inyecciones nutricionales al tronco (IN) de N, P_2O_5, K_2O, CaO y MgO en la productividad de naranja "Valencia Late" en Corrientes, Argentina. Durante tres años, campañas 2008/2009, 2009/2010 y 2010/2011, se llevaron a cabo ensayos experimentales aplicando diferentes dosis de IN a cada lado del tronco a 40 cm del suelo. Los tratamientos evaluados consistieron en la fertilización al suelo (50 % en la primavera y en otoño) T1: 1,5 kg planta^{-1} de 15-6-15-6 (media dosis, MD), T2: tratamiento MD más IN en primavera; T3: MD más IN en primavera y en verano; T4: MD más IN en primavera, en verano y en otoño y T5: dosis completa de 3 kg planta^{-1} de 15-6-15-6. (DC). El diseño experimental fue de Bloques al Azar con cuatro repeticiones y parcela experimental de dos plantas efectivas. Se determinaron las concentraciones foliares de N, P, K, Ca, Mg, Fe, Zn, Cu y Mn en las hojas de ramas fructíferas en el otoño. Al momento de la cosecha se midió producción total de fruta, diámetro, porcentaje de jugo, contenido de sólidos solubles, acidez, relación SST/acidez y color de 40 frutas por parcela. Para las variables cuantitativas se realizaron análisis de varianza y test de Duncan y para el color. Kruskal Wallis. Se llevó a cabo un análisis de Componentes Principales. El rendimiento de frutas se incrementó en un 11 % en promedio con el T4 en comparación con igual dosis de aplicación de fertilizantes al suelo (T1), sumado a que ninguno de los tratamientos con IN afectaron significativamente la calidad de la fruta. Este informe establece la utilidad de usar el IN como una herramienta complementaria a la fertilización convencional.

Palabras clave: cítricos híbridos, fertilización, características sensoriales del fruto, rendimiento

INTRODUCTION

Within the group of oranges, Valencia Late is the most important commercial variety in Argentina, since being late maturing, enters the market in months

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when the heat intensifies and increases the demand for citrus fruits (1). The production of these fruits is the most important in Argentina, reaching in 2012, 2, 24 0000 t in total, accounting for more than 50 % of the supply of fruits (2).

In fruit, the quality and yield are directly related to the availability of nutrients, water and good health management, any of these three pillars can become a limiting condition for the productivity of the plantation. To ensure maximum results, plants require mineral elements, most of them come from inorganic or organic fraction of the soil; however, most modern production systems must resort to fertilization. Therefore, it is essential to determine the nutritional needs of each area plantations, which vary according to the different soils, climatic conditions, rootstocks and varieties. Thus the quantity and quality of produced fruits will be influenced by nutrients they receive, being this, a limiting productivity (1, 3) factor. In management practices that are carried out in citrus plantations, which influence productivity are: irrigation and nutrition, and in general, when one of these elements is deficient, the yield and the fruit quality can be adversely affected (4).

Fertilizers can be applied directly on the soil by foliar via (5) or fertirrigation (3, 6); however, in recent years it has been improved as a method for supplying nutrients applying nutritious injections to tree trunks. This system applies the product directly to the current xylem by moving to the needed areas (7) and allows easy and economical application of aqueous solutions to woody species (8). The development of this technique product management to plants intravascularly was initially associated with the control of diseases and pests by high efficiency, selectivity and low environmental pollution (9) and it is also more recently used to control diseases such as Huanglongbing with injections of tetracycline (10).

However, this system is also used for correction of nutritional deficiencies such as iron chlorosis in lemons; fertilization of citrus, olives (7, 8) and mango and grapes, with good responses (11).

The aim of this study was to analyze the effect of nutrient injections given in the functional trunk xylem, in plant productivity of Valencia Late orange.

MATERIALS AND METHODS

The work was conducted in Santa Rosa, Concepción Department, Corrientes, Argentina, in commercial lots of orange trees 'Valencia Late' (*Citrus sinensis* L) than twelve years of planted, grafted on Rangpur Lime (*Citrus limonia* Osbeck), planted in a soil classified as Arenosol orthodystric and a density of 285 plants ha^{-1}. To eliminate the year effect, experiments were repeated three times in campaigns 2008/2009, 2009/2010 and 2010/2011. The experimental design was randomized block with four replications; each experimental plot consisted of four plants, considered as useful plot the two central ones. The blocking factor was the slope of the site (0,5 %), which were considered as blocks, rows of plants of 100 m length, representing more homogeneous soil areas. The content of macronutrients and organic matter (OM) and soil pH are shown in Table I.

Table I. Soil analysis of experimental lot in Santa Rosa (28°22´S; 58°7´O y 79 m a. s. l.), Corrientes, Argentina

MO (%)	P	K	Ca (ppm)	Mg	pH
0,8	15,3	170	319	126	5,80

Quantitative determination of the soil OM was by Walkey and Black method; the P by Bray Kurtz I method, K was performed by flame photometry method, , Ca and Mg was by complexometric EDTA. Soil pH was measured potentiometrically in a liquid-solid mixture 1: 2½ (pH-H_2O)

Treatments consisted of applying nutrients through soil fertilization and nutritional injection supplements (NI) applied to both sides of the trunk at 40 cm from ground level to a depth of 4 cm, being the average diameter of the trunk in studied plants was 20 cm. Soil applications were carried out in two stages (early spring and autumn) distributed in each case 50 % of the dose. Treatments are detailed in Table II and consisted of the combination of 1,5 kg of fertilizer $plant^{-1}$ 15-6-15-6 (N-P-K-Mg) applied to the soil without NI, with NI and 3 kg of fertilizer per plant 15-6-15-6 applied to the soil. Each injection contained 250 mL of fertilizer solution with the following composition: N=0,8 %; P_2O_5=0,8 %; K_2O=0,7 %; Ca=0,7 %; Mg=0,25 %, being urea, potassium nitrate, potassium chloride, calcium hydrogen phosphate and magnesium sulphate, original sources of macronutrients for the preparation of NI, which are made and distributed by the Trees Healthy Commercial Company S.A.

The fertilizer applied to the soil was a mixture composed of N, P, K and Mg in relation 15: 6: 15: 6 in combination with different application times of nutrient injections to the trunk, VTSN: total volume of nutrient solution applied per plant.

Table II. Treatments applied to plants

Treatments	Fertilizer to soil (kg plant^{-1})	Nutritional Injections			TVNS (mL)
		Spring	Summer	Autumn	
T 1	1,5	NO	NO	NO	0
T 2	1,5	YES	NO	NO	250
T 3	1,5	YES	YES	NO	500
T 4	1,5	YES	YES	YES	750
T 5	3	NO	NO	NO	0

The applied fertilizer to the soil was a mixture composed by N, P, K and Mg in relation to 15:6:15:6 in combination with different application times of trunk nutritional injections, TVNS: total volume of nutritional injections applied per plant

The procedure by which the application of trunk injections consisted of drilling the trunk to a depth of 4-5 cm, using a drill, using wicks (bits) to metal. In the orifice was placed a plastic injector to which it was connected the elastic tube with the nutritive solution.

At the end of March of each year, leaf samples of fruiting branches were taken and the concentrations of total nitrogen (N) were determined by the Kjeldahl method; phosphorus (P), by molecular absorption spectrometry; potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), copper (Cu), manganese (Mn) and zinc (Zn) by atomic absorption spectrometry. The results of N, P, K, Ca and Mg are expressed as percentage (g 100 g^{-1}), while the microelements are expressed in mg kg^{-1}.

At the harvest time, in each experimental plot, the total production was determined (kg plant $^{-1}$). To determine the characters of fruit quality were taken at the harvest time, random samples of 20 fruits per plot, in which the variables equatorial diameter (mm), weight (g), percentage of juice=juice weight/weight of 10 fruits x 100, total soluble solid content (TSS) ^{o}Brix, total acidity by neutralization volumetrics (in % of citric acid) and maturity index (ratios=TSS/acidity) indicating the degree of fruit maturity were determined (1). The color of the shell is also determined according to visual scale of 1-9 points (green, light green, yellowish-green, greenish -yellow, yellow, orange yellow, light orange, orange, dark orange) (12).

Evaluating treatment effects, it is performed by analysis of variance with subsequent Duncan's test (α=0,05). For the shell color variable, a nonparametric variance analysis of Kruskal Wallis was performed.

To analyze the behavior of all studied variables, principal component analysis (PCA) was performed, considering treatments as classificatory variables. The first two components of the ACP one Biplot where it can visualize the relationships between these variables and the treatment were made. Statistical analyzes were done using the Infostat 2012 software (13).

RESULTS AND DISCUSSION

The results of leaf analysis (macro and micronutrients) are shown in Table III, in which can be seen that no significant differences among treatments for any of analyzed elements. The interpretation of values obtained from leaf analysis was made using laboratory results proposed by researchers' citrus nutrition (14) and presented in Table III. Regarding the latter, it was found that N levels were slightly lower in all treatments, while P and K levels were within the optimal range. Regarding Ca, all treatments showed slightly lower than the optimum values and Mg were poor. Regarding foliar concentrations of certain micronutrients, Fe values were found at optimal levels, whereas Zn alone in treatments T3 and T4 were suitable, presenting deficiencies in treatments T1, T2 and T5. Mn levels were above optimal while Cu was very high in all treatments (Table III).

In results shown in Table IV it can be seen that the yield variable had significant differences between T1 and T4 treatments, without differences with T2, T3 and T5 treatments of intermediate behavior. Similar responses in relation to the efficiency of the soil fertilization complementation were found in the provision of 75 kg ha^{-1} of nitrogen plus nitrification inhibitors that equal in yield to supplement 150 kg ha^{-1} of nitrogen (12).

In yield determinations, internal and external quality of fruits (Table IV), was observed that the T4 (six NI supplementation) differed significantly from T1 (soil fertilization with half dose) with production of a 26,5 % highest. This yield increase would be attributed to a higher amount of fruit rather than a larger diameter thereof, since this variable did not differ between treatments. In general, mineral deficiencies elements affect the development of plants, and therefore fruit growth can be altered.

Table III. Foliar nutrient concentrations found in terms of soil fertilization treatments and nutritional injections in orange trees "Valencia Late", in Santa Rosa, Corrientes, Argentina

Trataments	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (ppm)	Zn (ppm)	Cu (ppm)	Mn (ppm)
Optimun levels (14)	2,3 -2,7	0,12-0,15	1,0-1,5	3,5-4,5	0,3-0,4	50-100	35-50	4,1-10	35-50
T 1	2,12 ±0,08	0,12 ±0,01	0,90 ±0,08	3,10 ±0,19	0,15 ±0,01	92.13 ±8,24	30,71 ±4,55	103,88 ±22,90	72,89 ±11,40
T 2	2,22 ±0,12	0,13 ±0,01	0,95 ±0,10	3,05 ±0,18	0,15 ±0,01	110,92 ±10,99	33,88 ±5,60	86,93 ±18,06	86,92 ±13,05
T 3	2,27 ±0,11	0,13 ±0,01	1,08 ±0,11	3,07 ±0,19	0,14 ±0,01	89,57 ±10,60	36,35 ±6,31	97,42 ±20,62	60,67 ±10,58
T 4	2,22 ±0,12	0,13 ±0,01	0,99 ±0,09	2,94 ±0,21	0,14 ±0,01	93,42 ±8,39	36,13 ±7,47	93,67 ±18,25	75,38 ±10,59
T 5	2,24 ±0,09	0,13 ±0,01	0,89 ±0,11	2,89 ±0,21	0,15 ±0,01	103,14 ±8,36	31,04 ±4,71	93,26 ±21,54	82,99 ±12,48

No letters are identified as no significant differences (p<= 0,05) in any of the foliar nutrient concentrations of different treatments.

T1: half dose (HD) 1,5 kg per plant of fertilizer 15-6-15-6 (N-P-K-Mg) applied to soil; T2: HD plus nutritional injection (NI) in spring; T3: HD plus NI in spring and summer; T4: HD plus NI in spring, summer and autumn; T5: complete dose (CD) 3 kg per plant of fertilizer 15-6-15-6 applied to soil. Average values for campaigns in 2008/2009, 2009/2010 and 2010/2011.

Table IV. Parameters of external and internal quality of fruit for treatments

Treatment	Yield (kg plant^{-1})	Fruit diameter (mm)	Color	Juice (%)	TSS °Brix	Acidity (%)	TSS/acidity
T1	72,90 a ±5,99	62,45 a ±1,12	6,89 a ±0,33	52,99 a ±3,50	11,91 a ±0,15	1,46 a ± 0,05	8,21 a ±0,32
T2	82,23 ab ±7,81	60,36 a ± 1,28	7,78 a ±0,26	50,63 a ±3,51	13,10 b ±0,48	1,54 a ±0,05	8,48 a ±0,36
T3	83,30 ab ±4,46	60,97 a ±1,05	7,70 a ±0,27	51,93 a ±3,46	12,59 ab ±0,26	1,46 a ±0,06	8,68 a ±0,35
T4	92,25 b ±5,68	61,52 a ± 1,16	7,65 a ±0,15	51,25 a ±3,49	12,55 ab ±0,29	1,54 a ±0,07	8,23 a ±0,39
T5	87,88 ab ±6,43	60,72 a ± 1,27	6,86 a ±0,19	50,08 a ±3,57	13,21 b ±0,33	1,53 a ±0,06	8,71 a ±0,26

Different letters in each column indicate significant differences (p<= 0, 05).

T1: half dose (HD) 1,5 kg per plant of de fertilizer 15-6-15-6 (N-P-K-Mg) applied to soil; T2: HD plus nutritional injection (NI) in spring; T3: HD plus NI in spring and summer; T4: HD plus NI in spring, summer and autumn; T5: complete dose (CD) 3 kg per plant of fertilizer 15-6-15-6 applied to soil. Average values ± Standard error for campaigns 2008/2009, 2009/2010 y 2010/2011.

Both the color, as the percentage of juice, acidity and TSS-acid ratio were as expected for this species and variety (15) and no significant difference between treatments.

For its part, the SSC content of harvested fruit from the T2 and T5 were those with higher °Brix with 10 and 10, 9 % higher than T1, respectively. The three treatments with NI supplement did not differ significantly between them. No differences between treatments in relation to the diameter of the fruit, color, juice, acidity and TSS/acid ratio found.

The parameters of Valencia Late fruit quality that were found with and without application of NI are normal and expected for the study area (5, 12).

These results are indicating the usefulness of injections as complement to the soil fertilization, whereas the implementation of NI favors yield without significantly affecting the quality of the Valencia Late fruit. Added to that decrease the amount of fertilizer applied to the soil with the NI addition results in a consequent benefit to the environment (11).

Moreover, during the three years of the trial, no problem associated with plant health or declinations that could be attributed to the NI implementation was detected, which differs from that found by the authors who do not recommend this technique use for the application of fertilizers, considering harmful to plants (16).

In order to evaluate the relationship and incidence of different factors, Principal Component analysis was performed (Figure), which makes a dimension reduction; it summarizes 15 variables in only two components that are a linear combination of all variables.

The figure shows that between the components 1 and 2 (CP1 and CP2) 78 % of the total variability is explained. The CP1 explained 49,4 % of the data variability, the variables that have the greatest weight in this component are the total soluble solids (TSS) and acidity (ACI), with a little less weight leaf nitrogen content (N), yield (YD) and total acidity / soluble solid ratio (RAT), then equal weight but in the opposite direction the leaf content of copper (CU), juice content (JUI), fruit diameter (DIAM). For its part, CP2 explains 27 % of variability and the variables that have the greatest weight in this component are leaf magnesium content (MG), manganese (MN), the iron (FE) and in the opposite direction, leaf potassium (K) and zinc (Zn).

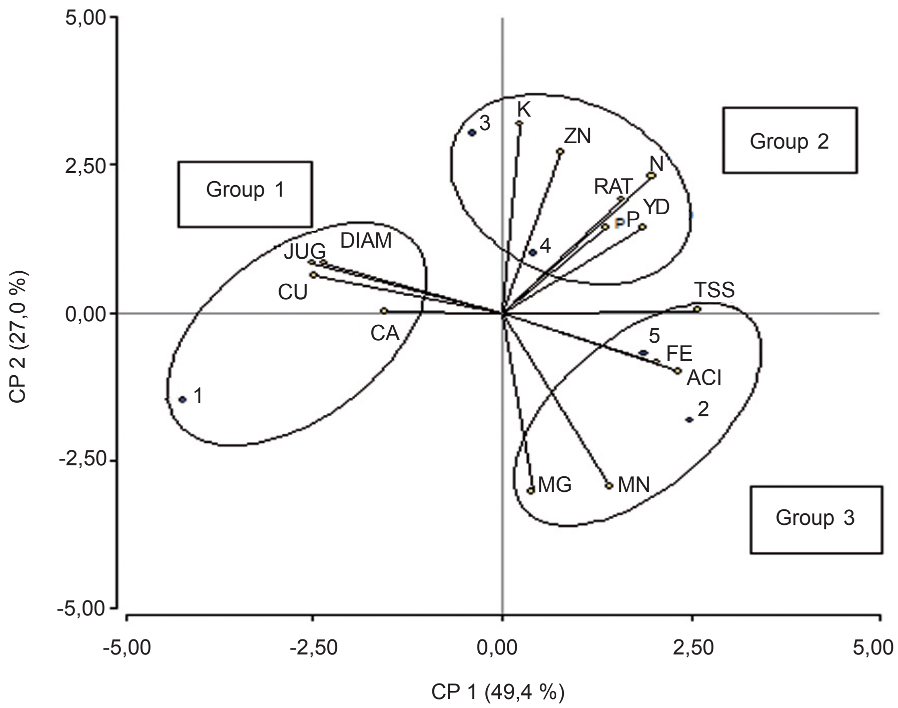
The principal component analysis allows random variables relate to each other and see the association of them with respect to any factor, which in this case are the treatments. In this analysis, three groups are defined: the first consists of the T1, JUI, DIAM, CU and CA; T3 composed of one second; T4, N, P, K, Zn, and YD RAT and the third composed of T2, T5 TSS, FE, ACI, MN, MG.

Significant correlations that arise from the analysis of the first group are CU with DIAM and JUI (positive correlation with increasing Cu increase the others), which agrees with those who report that Cu deficiency affect the size of orange fruit (17). This same element has significant correlation with TSS, ACI (negative correlation, they decrease with increasing Cu).

In the second group the positive correlation occurs among four nutrients (N, P, K and Zn) with YD and with both treatments where more nutritious dose injections (T3 and T4) It is applied by carefully considering the importance of nitrogen, phosphorus, potassium and zinc in the final fruit size and consequently productivity (18).

Components: treatments (T1, T2, T3, T4 and T5) and variables N, P, K, Ca, Mg, Mn, Fe, Zn, Cu, soluble solid acidity, TSS/acid (RAT), yield, diameter and juice. Campaigns developed in 2008/2009, 2009/2010 and 2010/2011.

Previous research concluded that foliar manganese concentration was positively correlated with the content of total soluble solids and fruit juice acidity of the orange, and negatively with the maturity index (19). These authors also report that the increase of manganese in relation to other elements decreased the size of the orange fruit (YD), which is consistent with findings in group 3 of the main component analysis, and trunk nutritional injections influence in Valencia Late orange productivity (figure).



Resulting Biplot of principal component analysis

CONCLUSIONS

- Giving injections to the trunk as a supplement to soil fertilization increased fruit production significantly.
- The nutritive injections had no significant effect on foliar nutrient content or quality parameters of Late Valencia orange fruit.
- While work does not include an analysis of nutrient uptake; it can be inferred from the results that the use of NI with half dose of fertilizer applied to the soil, means fertilizer savings and higher coefficient of nutrients utilization.
- This work shows the usefulness of nutritional injections to the trunk as a complement to the conventional fertilization in commercial plantations, especially considering that the use of NI could reduce the cost of fertilizer application with the benefit of increased fruit production without unchanged quality parameters.

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