Potassium Affects Citrus Tree Performance

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Abstract

Potassium plays a critical role in citrus trees and it affects many phenomena, both visible and invisible. The requirement for K in trees is next to that for nitrogen and ranges from 0.5 to 2% of dry matter. Adequate yield, for the fresh fruit market can be achieved only when the level of K is in the optimum range. The element has dominant effects on external and internal fruit qualities, including yield, colour, size, acidity and roughness. The various potassium fertilizers should be used with attention to the effects of rainfall, salinity and counter ions. Cultivators of modern intensive citrus orchards should pay attention to the potassium level in the trees and react accordingly.

Introduction

Citrus trees require large quantities of mineral nutrients to attain adequate growth and yield, and the requirements for some of the nutrients vary with soil fertility and type. Although the mineral nutrition of citrus trees has been studied intensively, additional information is published frequently, especially after the introduction of new fertigation technologies and of other manipulations. Among the important elements, potassium (K) plays a major role, second only to nitrogen, and is considered as a key element in fruit production and quality worldwide.

Considerable attention has been paid to the symptoms and consequences of K deficiency (Embleton *et al.*, 1973; Koo, 1985). Potassium is not metabolized and it forms only weak complexes in which it is readily exchangeable. The high concentrations of K in the cytosol and chloroplast neutralize the soluble and insoluble macromolecular anions and stabilizes the pH in these compartments (Marschner 1995). The well-known relationship between potassium and sugar/starch accumulation, which is found in many plants, has not been found in practice in field-grown citrus trees. No differences in the total soluble sugars (TSS) contents were found in the fruits of 'Shamouti' orange, in spite of significant differences in the concentrations of K in the leaves (Lavon and Goldschmidt 1996, Data in this paper). The relationship between K, on the one hand, and sugars/starch, on the other hand, has been demonstrated in citrus, mostly with plants grown in K-deficient nutrient solutions (Lavon and Goldschmidt, 1996; Lavon *et al.*, 1995).

The present paper will review the most significant effects of potassium on citrus production.

Soils with low K contents need applications of fertilizer in order to maintain high yield and quality.

Potassium Requirement

Normal vegetative growth of citrus can occur under a wide range of K content in the leaves (Smith 1966). On the other hand, the leaves should contain a certain level of potassium, if the tree is to provide fruit with high yield and quality. The potassium content of mature citrus trees is somewhat lower than that of nitrogen (N), but K is the most abundant mineral in the fruit (**Table 1**). Alternate bearing can change the K contents of various organs, and

Table 1. Nitrogen and potassium distribution in mature citrus trees

	*Grapefruit**		*Wilking***				*Shamouti****	
			"ON"		*"OFF"*		*High*	*Low*
Plant Parts	*N*	*K*	*N*	*K*	*N*	*K*	*N*	*K*
grams per tree								
Total	2.061	1.920	858	490	811	305	2.379	2.072
per cent								
Fruits	6	7	32	52	–	–	20	11
Leaves	18	19	14	2	26	23	22	20
Trunk and branches	33	37	44	39	52	55	42	44
Roots	43	36	10	6	22	22	15	25

Adapted from Dasberg 1988.
*Tree age 19 years old, Barnette *et al.*, 1931
**Tree age 15 years old, Golomb and Goldschmidt, 1981.
***Tree age 20 years old, Feigenbaum *et al.*, 1987

K imbalance between years can increase the fluctuations. The juice is a strong sink for K, which occurs there mainly in the form of soluble K salts of the organic acids. Therefore, it is essential to apply potassium fertilizers: a) to replace the K removed by the fruit; b) to improve fruit quality; and c) to maintain soil productivity. According to various sources, one ton of oranges exports an average of 2.5 kg of K_2O, corresponding to 125-250 kg ha^{-1}, according to the yield potential.

Potassium Effects on Growth and Yield

Potassium content does not usually affect tree growth over a wide range of variation, unless it falls below 0.4% (Rees and Koo, 1975). Since yield is positively correlated with tree size (volume) it is essential to have adequate content of K in the tree. The K content in the leaves decreases throughout the season and fruit load can enhance this decrease as a result of K uptake by the fruit. Appropriate fertigation can prevent the decrease in K or reduce the negative effect of yield on K content (**Table 2**).

Potassium fertilization was reported to increase fruit production up to leaf K contents of 1.5-1.7% in Florida, Brazil and Australia (Chapman, 1968; Koo, 1985; Malavolta, 1992). Du-Plesis and Koen (1988) emphasized the importance of the ratio between N and K; they found a maximum yield at the high N:K ratio of 2.8, with the N and K contents exceeding 2.1 and 0.8%, respectively; as the ratio diminished to 1.6, with N and K contents exceeding 1.8 and 0.9%, respectively, the fruit size increased. Moreover, the increase in fruit size was accompanied by a reduction in yield.

The use of K as an antagonist to sodium uptake clearly affected the soil K status, but failed to decrease Na uptake by the tree. On the other hand, the

Table 2. Potassium Balance in 'Shamouti' Orchard

	K_1I_2	K_2I_1	K_2I_2	K_2I_3	K_3I_2
	kg ha⁻¹				
Applied K	1.2	89	117	139	219
Uptake by fruit	93	108	113	112	131
Balance (+ -)	– 81	– 19	+ 4	+ 27	+ 88

K_1 - 1.2 kg ha^{-1}; K_2 – 89-139 kg ha^{-1}; K_3 – 219 kg ha^{-1}
I_1 – 620 mm; I_2 – 765 mm; I_3 – 940 mm

K application led to increases in leaf K content, yield and fruit size in alternate years (**Table 3**). Potassium cannot alter biennial production, but a foliar spray of KNO_3 minimized the alternate bearing of mandarin Baladi (Ebrahiem *et al.*, 1993, and **Table 3** in this paper).

Fruit set has been correlated to some extent with the mineral levels in the leaves during the time of fruit set. The mineral contents fell to a minimum at the bloom time and, therefore, are more likely to represent a limiting factor for fruit set (Sanz *et al.*, 1987). In spite of these decreasing trends in mineral contents towards flowering time, Erner (1989) could not prove the involvement of the elements in fruit set. Brosh *et al.* (1975) found that in certain cases application of a foliar spray of KNO_3 to grapefruit reduced abscission of fruitlets, especially when leaf K content was low.

External Fruit Quality

An optimum level of K is most important in relation to external aspects of fruit quality (Embleton *et al.*, 1973). Excessively high K levels result in large fruits with coarse, thick peel and poor colour. Moreover, early and intensive

Table 3. Effect of Potassium Fertilization on Leaf K, Yield and Fruit Size of 'Shamouti' Orange

Treatment	*1984*	*1985*	*1986*	*1987*
Leaf K% (D. Wt.)				
-K	0.45	0.60	0.44	0.51
+K	0.64	0.85	0.67	0.87
sign.	+	+	+	+
Yield (ton ha^{-1})				
-K	69	57	71	67
+K	77	54	86	72
sign.	+	–	+	–
Fruit weight (g)				
-K	181	211	187	172
+K	193	256	197	222
sign.	–	+	–	+

Adapted from Dasberg 1988

regreening will occur in such orchards. Too low K levels result in small fruits, which are rejected by the fresh fruit and export markets, in spite of their thin rinds and good colour. Potassium decreases the loss of fruit from creasing (**Table 4**) (Greenberg *et al.*, 1995) and splitting (**Table 5**) (Lavon *et al.*, 1992; Bar-Akiva, 1975), and the addition of auxins (2,4-D, NAA, Maxim) can further reduce these peel disorders.

Growers' income is most affected by fruit size, and potassium in combination with auxins (Erner *et al.*, 1993) has been found to increase the size by up to 35% compared with control (**Table 6**). The use of potassium at 5% with auxin 15-50 ppm (depending on the type of auxin) has become a common practice in Israel and elsewhere. In some cases, application of auxins can thin fruit – although this is not its primary purpose – and therefore increase the fruit size. However, this increase in size can take place only when other cultural practices (e.g., water and nutrient supplies, weed control) are at an optimal level.

Table 4. Effect of Potassium and Auxins on 'Valencia' Fruit Quality

Treatment	*Creasing %*	*Roughness %*	*Peel Thick. mm*
Control	42.8 a	4.7 b	5.23 b
NAA 300 ppm 4 June	5.4 c	17.7 ab	5.70 ab
NAA 300 ppm 4 July	14.9 b	10.7 ab	5.55 ab
KNO_3 4% + 2,4-D 18 ppm 7 June	23.6 b	33.4 a	6.15 a

Adapted from Greenberg et al. 1995 (Hebrew).

Table 5. Foliar Spray Treatments and their Effect on Leaf K, Fruit Weight, Percent of Split Fruit and Yield of Nova Tangerines. Adapted from Lavon.

*Spray treatment**	*Leaf K % dry wt.*	*Fruit wt. g*	*Split fruit %*	*Yield kg/tree*
Control	0.50 d**	117 c	27.5 a	47.4 c
KNO_3 (1 spray)	0.50 d	123 abc	18.0 b	54.7 bc
2,4-D (1 spray)	0.69 c	123 abc	15.0 bc	65.4 ab
KNO_3 + 2,4-D (2 sprays)	0.79 b	130 ab	15.0 bc	64.2 ab
KNO_3 + 2,4-D (3 sprays)	1.00 a	134 a	11.0 c	68.8 a

* The concentrations of KNO_3 and 2,4-D were 5% and 20 ppm, respectively, in all treatments.
** Mean separation within columns by Duncan's multiple range test at $P = 0.05$.

Table 6. Effect of Growth Regulators on 'Star Ruby' Fruit Quality

Treatment	*Acid %*	*TSS %*	*Boxes*/ 1000 fr.*	*Yield/ Tree (kg)*	*K %*
Control	2.34	11.6	22.7	91.9	0.36
2,4-D 20 ppm + KNO_3 5%[1]	2.45	11.9	26.3	89.8	0.52
NAA 300 ppm + (2,4-DP 50 ppm)[1,2]	2.29	12.2	28.8	84.9	0.33
NAA 300 ppm + (2,4-DP 50 ppm + KNO_3 5%)[1,2]	2.46	12.4	30.2	92.3	1.08
NAA 300 ppm	2.32	11.6	29.3	65.9	0.34
2,4-DP 50 ppm + KNO_3 5% + L-77 0.025%	2.27	11.7	28.8	90.3	0.53
2,4-D 20 ppm + KNO_3 5% + L-77 0.025%	2.38	11.6	26.7	90.0	0.40

[1]Acidic to pH 3-4 with HNO_3
[2]Sprayed after 3 weeks
*Number of packed boxes to contain 1000 distributed fruits

Internal Fruit Quality

The most serious disadvantage of potassium is a direct and strong link with juice acidity (Erner *et al.*. 1993; Berger *et al.*, 1996) (**Table 7**). It is not known how the K level affects the accumulation or degradation of acids in citrus fruit. Some varieties (Star Ruby, Mineola tangelo) tend to have high acid levels and therefore are not recommended to have high K levels. Potassium has never been shown to have any effect on sugar accumulation, in field experiments.

Table 7. Increase in Fruit Size - Valencia

Treatment	*Thic Equ.*	*% Acid*	*% TSS*	*A/T Ratio*	*Boxes*/ 1000 fr.*	*Yield/ Tree (kg)*
Control	5.8	1.8	11.3	6.1	11.7	146.4
NAA 300 ppm+(2,4-DP 50 ppm+KNO_3 5%[1,2]	5.9	2.2	11.1	5.1	14.9	146.7
2,4-DP 50 ppm + KNO_3 5% + L-77 0.025%	5.9	2.2	11.3	5.2	13.2	151.4
NAA 300ppm + (2,4-DP 50 ppm)[1,2]	6.1	1.9	11.6	6.0	13.8	152.1
NAA 300 ppm[1]	6.0	2.1	11.5	5.6	11.8	175.1
2,4-D 20 ppm + KNO_3 5% + L-77 0.025%	5.9	2.1	11.1	5.3	14.8	143.3

* Number of packed boxes to contain 1000 distributed fruits
[1] Acidic to pH 3-4 with HNO_3
[2] Sprayed after 3 weeks

Potassium Fertilization and/or Foliar Spray

There are several potassium chemicals that can be used commercially in citrus orchards. The effectiveness of K applications to the soil varies widely with soil type, climate and irrigation system. Potassium chloride and sulphate are equally suitable as fertilizer sources of K for citrus, while potassium nitrate and sulphate can also be applied as foliar sprays. Potassium chloride should be applied during the rainy season to enable the chloride to be leached out, while the K will move slowly from the surface to the root zone. The double-salt sulphate of potash magnesia is widely used in areas where magnesium deficiency occurs. High potassium uptake has been found in acidic, sandy soils in humid region such as Florida (Koo, 1985). Potassium availability decreases at low soil moisture content, high Ca and Mg concentrations and high fixing capacity, and large amounts of K fertilizer must be applied for several years before any response is observed (Bar-Akiva and Gotfried 1971, Embleton *et al.* 1973). On the other hand, foliar application of KNO_3 is more effective under such conditions (Embleton *et al.*, 1973; Erner *et al.,* 2001)

We should keep in mind that fertilizing with potassium sulphate or chloride might affect the uptake of other minerals, just as other minerals might affect chloride uptake. In areas with salinity problems, the potassium should be used with the sulphate rather than the chloride ion, to minimize the effect of salinity. Using ammonium fertilizers as the nitrogen source can increase the uptake of chloride from the water or potassium chloride source (**Table 8**).

Table 8. Effect of Potassium Chloride Fertilizer on Mineral Content in 'Shamouti' Leaves, after 8 Years.

Treatment	*K*	*Cl*	*N*	*P*
	%			
$Ca(NO_3)_2$ + P + K	0.92 b	1.070 b	1.94	0.07
Urea + P + K	0.82 bc	1.145 b	1.88	0.06
$(NH_4)_2SO_4$ + P + K	1.09 a	1.565 a	2.04	0.06
NH_4NO_3 + P + K	0.97 ab	1.123 b	1.92	0.06
NH_4NO_3 + P	0.52 e	0.570 cd	1.81	0.08
NH_4NO_3	0.69 d	0.483 d	2.04	0.06

Lavon and Erner, 1994, unpublished data

Foliar spray of KNO_3 is more efficient than K_2SO_4 in increasing fruit size (**Table 9**) and for quickly increasing leaf K and curing K deficiency

Table 9. Effect of Potassium and 2,4-D on Fruit Quality of 'Shamouti'

Treatment	*Conc.*	*Packed boxes %*	*Acid %*	*T:A ratio*
Control		100 (12.3*)	1.34 b	7.6
KNO_3 + 2,4-D	5.0% + 20 ppm	123	1.54 a	6.9
K_2SO_4 + 2,4-D	4.6% + 20 ppm	116	1.47 ab	7.2
2,4-D	20 ppm	112	1.34 ab	8.0

*Number of packed boxes to contain 1000 distributed fruits

(Erner *et al.,* 1993). In some cases where nitrogen as well as potassium is low, a foliar spray of KNO_3 can increase both of these minerals: K & N.

Summary

Potassium plays a critical role in tree growth and productivity. The generally accepted idea, that satisfactory vegetative growth of citrus can be obtained within a wide range of leaf K contents, might be related to the high mobility of K in plants, at all levels. This mobility can ensure that the requirements for vegetative growth are fulfilled, even when the K level is not sufficient for productivity. Moreover, the strong sink represented by the K requirements of the fruits for K highlights the importance of the element for high production.

Intensive citrus orchards should receive significant amount of K, almost at the same level as nitrogen, in order to maintain high yields of fruits with the desired qualities. The relatively high acid level caused by application of K can be alleviated, in most cases, by briefly delaying the harvest.

In arid zones, growers should take into account the counter ion of potassium as well as other minerals, in order to avoid adding to the stress on the trees.

The physiological functions of potassium and its conspicuous role in plant water relations has long been known (Hsiao and Lauchli, 1986) and serve to emphasize that there should be adequate K contents in all plant parts.

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