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Evaluation of Controlled-release Fertilizers for Young Citrus Trees

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Abstract. **Controlled-release sources of N and K were compared with soluble sources on young 'Valencia' orange trees *(Citrus sinensis [L.]* Osb.). The effects of these fertilizers on leaf mineral concentration, soil chemical analysis, and tree growth were evaluated for 3 years. Soluble fertilizers were generally more readily available but had shorter residual effects on leaves and soil than controlled-release fertilizers. In the top 30 cm of soil, the plots treated with controlled-release N had 23% more total N than those treated with soluble N sources, while the plots fertilized with controlled-release K contained 56% more extractable K than those that received soluble K. Different effects on leaf and soil N between the two controlled-release N sources, sulfur-coated urea (SCU) and methylene urea (MU), were also found. With the use of controlled-release fertilizers, application frequency was reduced from a total of 15 to six applications with no adverse effects on tree growth, leaf mineral composition, or soil fertility during the first 3 years. Combining soluble and controlled-release fertilizers in a plant nutrition program offers an economical and effective strategy for citrus growers.**

Most Florida citrus is grown on sandy soils of low native fertility and low nutrient and water-holding capacities. Florida has a high annual rainfall (1300 to 1600 mm). Because the major proportion of this rainfall comes from June to September, supplemental irrigation during the spring dry season is needed to maximize growth and fruit production. The combination of poor soils, abundant rainfall, and high supplemental irrigation requires up to six annual, applications of soluble fertilizers to young citrus trees (Koo et al., 1984).

In the last few years, the interest in fertilizer movement and loss from the soil root zone is increasing not only because this loss results in lower growth and yield of crops, but also because of possible contamination of surface and groundwater. Because Florida climatic and edaphic conditions make soluble fertilizers vulnerable to substantial leaching losses, the use of controlled-release fertilizers has been of particular interest. Compared with soluble sources, controlled-release fertilizers reduced leaching losses of N, lengthened or prolonged the effect of fertilizers, reduced luxury consumption of nutrients, induced more growth and yield due to a continuous rather than a fluctuating supply of nutrients (Khalaf and Koo, 1983; Koo, 1986, 1988). The use of controlled-release fertilizers led to reduced rates and number of applications during the growing season (Jackson and Davies, 1984; Koo, 1986, 1988; Zekri and Koo, 1991) that could bring about substantial labor and time savings, especially in groves where reset trees are mixed with mature trees.

Controlled-release fertilizers have been tested on citrus for only a few years (Ferguson et al., 1988; Jackson and Davies, 1984; Khalaf and Koo, 1983; Koo, 1986, 1988; Marler et al., 1987; Zekri and Koo, 1991). Most of these studies conducted on young trees were short-term experiments focused mainly on the effect of several controlled-release fertilizer sources on tree growth. None of these studies with young trees appears to have extensively investigated the effects of controlled-release fertilizers on soil fertility and plant nutritional status. The objectives of this research were to compare the effects of soluble and controlled-release fertilizers on soil chemical properties, leaf mineral concentration, and growth of young citrus trees.

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Materials and Methods

Two-year-old 'Valencia' orange trees on Carrizo citrange (*C. sinensis* [L.] Osb. x ***Poncirus tnfoliata*** [L.] Raf.) rootstock were planted at 3 x 6 m spacing in June 1986 on Astatula fine sand (hyperthermic uncoated Typic Quartzipsamments). The soil is a well-drained deep sand with water-holding capacity of 1 cm water per 15 cm soil and cation exchange capacity of 3 $cmol{\cdot}kg^{-1}$ soil. The trees were irrigated using a microsprinkler system with one emitter per two trees delivering ≈ 50 $liters{\cdot}h^{-1}$. Treatments were initiated in June 1986 and terminated following the Dec. 1989 freeze.

SCU (SCU-3, 37% N; SCU-6, 34% N), MU (MU-3, 41% N; MU-6, 38% N) of 3 and 6 months N-release periods, and ammonium nitrate (NH_4N0_3, 33% N) were compared as sources of N. SCK of 3 and 6 months K-release periods (SCK-3, 43% K_20; SCK-6, 41% K_20) were compared with potassium chloride (KCI, 60% K_20) as sources of K. The same quantities of N and K_20 were applied to all trees. These rates were 272,408, and 544 g/tree of N and K_20 during the first, 2nd, and 3rd years, respectively. Controlled-release fertilizers (SCU, MU, SCK) were applied twice a year, usually in March-April and September-October. Soluble fertilizers (NH_4N0_3, KC1) were applied six times the first year, five times the 2nd year, and four times the 3rd year.

There were eight treatments in the experiment (Table 1) with four-tree plots arranged in a randomized complete block with four replications and with one buffer tree between each two plots. The fertilizer was uniformly spread by hand under the tree canopy.

Three- to 4-month-old leaves were collected two or three times each year from all treatments. Each leaf sample consisted of 40 to 50 leaves taken from four trees per treatment per replication. The samples were oven dried for 2 days at 65C, ground in a Wiley mill to pass a 1.7-mm screen, and stored for mineral

Abbreviations: MU, methylene urea; SCK, sulfur-coated potassium; SCU, sulfur-coated urea.

analysis. Nitrogen was determined by the micro-Kjeldahl method using Büchi digestion, control, and distillation units. Analysis of the other macronutrients (P, K, Ca, Mg) was conducted after wet-digesting leaf samples with a mixture (4:1) of nitric-perchloric acid. Phosphorus concentration was determined by the vanadomolybdophosphate yellow color method with a spectrophotometer (Bausch and Lomb Spectronic 20; Bausch and Lomb, Rochester, N.Y.). Potassium, Ca, and Mg concentrations were determined using an atomic absorption spectrophotometer (Perkin-Elmer Model 503; Perkin-Elmer, Norwalk, Corm.).

Soil samples were collected at O to 8, 8 to 15, and 15 to 30 cm depths, then air-dried for 2 days, screened through a 2-mm stainless steel sieve, and analyzed for pH, N, K, Ca, and Mg. Soil pH was determined in aqueous extracts [2 water : 1 soil (v/v)] using a microprocessor pH/millivolt meter 811 (Orion Research; Cambridge, Mass.). Analyses of total N, extractable K, Ca, and Mg were performed with the same instruments used for leaf analyses. Potassium, Ca, and Mg were extracted from the soil with neutral, one-normal ammonium acetate.

Tree trunk diameters were measured at the beginning of the experiment and twice a year thereafter, using the same location on the tree trunk. Tree canopy surface area was calculated by measuring tree height and width in two directions and computing the values using a formula for a parabolic cone (Zekri and Parsons, 1989).

Fruit were sampled in Apr. 1989 for juice quality determinations. Each fruit sample consisted of 40 fruit taken from four trees (10 per tree) per treatment per replication. Fruit yield was calculated by. multiplying average fruit weight by the number of fruit on each tree.

Data were subjected to analysis of variance, and Duncan's multiple range test was employed for mean comparison where F was significant.

Results and Discussion

Leaf analysis. The N concentration was high in all treatments (Table 1), according to the current leaf standards (Koo et al., 1984). Leaves from the soluble fertilizer treatment (Treatment 8) had the highest N in Nov. 1986 and the lowest N in Nov. 1987. Leaf N from the combination of soluble and controlled-release fertilizers (Treatment 7) was among the highest throughout the study. On two occasions, N concentration in the SCU plots was higher than that in the MU plots. Leaf N was similar for SCU or MU whether those with the 3- or 6-months release periods were used. KhaIaf and Koo (1983) and Koo (1986) found that citrus trees treated with the controlled-release fertilizer isobutylidene diurea (IBDU) had higher leaf N than those treated with either SCU or soluble fertilizers.

Leaf K, like N, was high in all controlled-release fertilizer treatments (Table 2) according to the current leaf standards (Koo et al., 1984). Leaf K was similar between SCK with the 3- and 6-months release periods. All trees treated with SCK had higher leaf K than those fertilized with soluble K (Treatment 8). Leaf P, Ca, and Mg concentrations did not show a consistent trend (data not shown).

Symptoms of biuret toxicity (Oberbacher, 1954) in leaves were observed in the controlled-release N plots, especially those treated with MU (data not shown). These symptoms were attributed to biuret impurities in the urea from which the MU and SCU were made. These toxicity symptoms seemed to decrease as tree age increased. Appearance of biuret toxicity symptoms might result in grower resistance to the use of these materials.

Soil analysis. Because differences among treatments were found mostly in the top 8 cm of soil, soil analysis data were reported only for this first depth. Significant differences in soil N were found among treatments in all samplings (Table 3). On many of the sampling dates, the soluble fertilizer treatment (Treatment 8) produced the lowest soil N, while the MU treatments (Treatments 5 and 6) produced the highest, and the SCU treatments (Treatments 1-4) had intermediate soil N. Nitrogen was similar between SCU with the 3- and 6-months release periods. However, the MU with the 6-months release period (Treatment 6) led to higher N than the MU with the 3-months release period (Treatment 5).

Similar to these results, Khalaf and Koo (1983) and Zekri and Koo (1991) found that more N remained in the soil fertilized with controlled-release sources than with soluble sources. Khalaf and Koo (1983) also found < l% of applied N in the drainage water collected from the pots treated with IBDU and SCU compared with 22% for those treated with NH_4NO_3. Overall, the controlled-release N plots contained 23% more total N than the soluble N plots in the top 30 cm of soil ($P < 0.05$). All of these results point out the advantage of controlled-release fertilizers that not only provide a continuous supply of N over much of the growing season but also reduce leaching losses and the danger of groundwater contamination.

Significant differences in soil K were found among treatments on most of the sampling dates (Table 4). On some of the sampling dates, SCK-treated plots (Treatments 1-7) had higher K levels than the soluble fertilizer plots (Treatment 8). Overall, in the top 30 cm of soil, the SCK plots contained 56% more extractable K than the soluble K plots ($P < 0.01$). No consistent

Table 1. Effects of N and K fertilizers on leaf N concentration in young 'Valencia' orange trees.[z]

Fertilizer combination	Leaf N (% dry wt)							
	Nov. 1986	July 1987	Nov. 1987	Mar. 1988	July 1988	Nov. 1988	Aug. 1989	Avg
1. SCU-3/SCK-3	3.13 b	3.43 b	3.31 a	2.90	3.56 a	3.52	2.98 bc	3.26
2. SCU-3/SCK-6	3.19 b	3.52 abc	3.38 ab	3.00	3.41 ab	3.42	2.93 bc	3.26
3. SCU-6/SCK-3	3.21 b	3.48 bc	3.33 ab	2.84	3.27 bc	3.37	3.15 a	3.24
4. SCU-6/SCK-6	3.23 b	3.59 ab	3.24 ab	2.96	3.29 bc	3.40	2.98 bc	3.24
5; MU-3/SCK-3	3.15 b	3.39 c	3.31 ab	2.93	3.31 bc	3.47	2.94 bc	3.21
6. MU-6/SCK-3	3.05 b	3.34 c	3.25 b	2.86	3.14 c	3.28	2.97 bc	3.13
7. SCU-6 + NH_4NO_3 SCK-6 + KC1	3.24 b	3.68 a	3.49 a	2.96	3.46 ab	3.30	3.05 ab	3.31
8. NH_4NO_3 KC1	3.50 a	3.52 abc	3.00 **c**	2.77	3.23 bc	3.62	2.75 C	3.20
Significance (P)	0.01	0.05	0.01	NS	0.05	NS	0.05	NS

[z]Mean separation within columns by Duncan's multiple range test; NS = not significant.

[y]3 and 6 = durations of N and K release in months. In Treatment 7, 50% of N and K derived from controlled-release fertilizers.

Table 2. Effects of N and K fertilizers on leaf K concentration in young 'Valencia' orange trees.'

Fertilizer combination	Leaf K (% dry wt)							
	Nov. 1986	July 1987	Nov. 1987	Mar. 1988	July 1988	Nov. 1988	Aug. 1989	Avg
1. SCU-3/SCK-3	1.63 a	1.95 de	1.53 b	1.17 b	2.05 a	2.13 ab	2.12 a	1.80 a
2. SCU-3/SCK-6	1.76 a	2.13 cd	1.60 ab	1.27 b	2.05 a	2.13 ab	2.17 a	1.87 a
3. SCU-6/SCK-3	1.88 a	2.29 bc	1.73 ab	1.31 ab	2.22 a	2.21 a	1.68 b	1.90 a
4. SCU-6/SCK-6	1.72 a	2.20 cd	1.51 b	1.20 b	1.76 b	1.72 **C**	1.90 ab	1.72 a
5. MU-3/SCK-3	1.72 a	2.52 ab	1.81 a	1.51 a	2.11 a	1.80 C	2.05 a	1.93 a
6. MU-6/SCK-3	1.88 a	2.58 a	1.70 ab	1.36 ab	2.19 a	1.86 bc	2.08 a	1.95 a
7. SCU-6 + NH,N04 SCK-6 + KCI	1.71 a	2.16 cd	1.63 ab	1.33 ab	2.14 a	2.00 abc	2.06 a	1.86 a
8. NH,NO$_3$/KCl	1.24 b	1.74 e	1.07 c	0.78 C	1.39 c	1.18 d	1.62 b	1.29 b
Significance (P)	0.05	0.01	0.01	0.01	0.01	0.01	0.05	0.05

'Mean separation within columns by Duncan's multiple range test.
[y]3 and 6 = durations of N and K release in months. In Treatment 7, 50% of N and K derived from controlled-release fertilizers.

Table 3. Effects of N and K fertilizers on total soil N at O to 8-cm depth.'

Fertilizer combination	Soil N (kg.ha-')							
	Jan. 1987	Apr. 1987	July 1987	Mar. 1988	July 1988	Nov. 1988	Aug. 1989	Avg
1. SCU-3/SCK-3	482 b	542 C	525 b	486 bc	473 ab	471 abc	514 b	499 bc
2. SCU-3/SCK-6	445 b	560 C	474 b	510 bc	47.5 ab	452 abc	482 b	485 bc
3. SCU-6/SCK-3	465 b	586 C	517 b	551 bc	458 ab	425 bc	558 b	509 bc
4. SCU-6/SCK-6	482 b	500 c	534 b	505 bc	514 ab	424 bc	483 b	492 bc
5. MU-3/SCK-3	603 b	1034 b	792 b	677 b	513 ab	518 ab	505 b	663 b
6. MU-6/SCK-3	1043 a	1495 a	1284 a	1293 a	651 a	534 ab	728 a	1004 a
7. SCU-6 + NH,NO/ SCK-6 + KC1	500 b	551 c	551 b	545 bc	492 ab	560 a	639 a	548 b
8. NH,NO/KCl	422 b	439 c	491 b	439 c	390 b	353 c	487 b	432 C
Significance (P)	0.01	0.01	0.01	0.01	0.10	0.05	0.01	0.05

'Mean separation within columns by Duncan's multiple range test.
[y]3 and 6 = durations of N and K release in months. In Treatment 7, 50% of N and K derived from controlled-release fertilizers.

Table 4. Effects of N and K fertilizers on extractable soil K at O to 8-cm depth.'

Fertilizer combination	Soil K (kg.ha-')							
	Jan. 1987	Apr. 1987	July 1987	Mar. 1988	July 1988	Nov. 1988	Aug. 1989	Avg
1. SCU-3/SCK-3	26	357 a	112 ab	57 abc	67 ab	136 a	99	122 a
2. SCU-3/SCK-6	44	272 abc	156 a	76 ab	77 a	86 b	84	114 a
3. SCU-6/SCK-3	36	298 ab	75 bc	47 c	71 ab	68 b	76	96 a
4. SCU-6/SCK-6	48	139 cd	127 ab	75 ab	63 ab	76 b	76	86 a
5. Mu-3/sSCK-3	27	309 ab	92 bc	52 bc	53 ab	59 b		95 a
6. MU-6/SCK-3	26	297 ab	102 bc	67 abc	57 ab	66 b	89	101 a
7. SCU-6 + NH^{4}N 0^3 SCK-6 + KC1	27	190 bc	96 bc	80 a	68 ab	89 b	83	90 a
8. NH,NO$_3$/KCl (soluble)	21	25 d	54 c	47 c	45 b	72 b	67	47 b
Sirmificance (P)	NS	0.01	0.05	0.05	0.10	0.01	*m*	0.05

'Mean separation within columns by Duncan's multiple range test; NS = not significant.
[y]3 and 6 = durations of N and K release in months. In Treatment 7, 50% of N and K derived from controlled-release fertilizers.

differences were found between the SCK with the 3- and 6-months release periods.

Significant differences in Ca and Mg were found among treatments on some of the sampling dates, but they were not consistent (data not shown). Significant differences in soil pH were found among the treatments beginning in July 1987 (Table 5). The soluble fertilizer plots (Treatment 8) were among those having the highest soil pH. Reduced pH in some of the other plots might be due to the presence of sulfur in SCU and SCK fertilizers.

Tree *growth.* No difference in trunk diameter was found among treatments (data not shown). These results concur with those of Ferguson et al. (1988), Jackson and Davies (1984), and Marler et al. (1987), who found no differences in growth of citrus trees treated with controlled-release vs. soluble fertilizers. However, tree canopy area increased more in SCU-3 (Treatments 1 and 2) than soluble fertilizer-treated plots (Table 6). Under greenhouse conditions and with relatively uniform young citrus seedlings, Khalaf and Koo (1983) also found that controlled-release fertilizers produced more growth than soluble fertilizers. The excellent agreement among all these studies indicates that controlled-release fertilizers have the potential for reducing application frequency to one-half as compared with soluble fertilizers without decreasing tree growth.

Fruit qualiy and fruit production. Differences among treatments were found in fruit weight (Table 6). The MU-fertilized

Table 5. Effects of N and K fertilizers on soil pH at 0 to 8-cm depth.[z]

Fertilizer combination[y]	Soil pH							
	Jan. 1987	Apr. 1987	July 1987	Mar. 1988	July 1988	Nov. 1988	Aug. 1989	Avg
1. SCU-3/SCK-3	5.1	5.8	4.4 c	5.0 d	4.9 b	5.2 ab	5.8 b	5.2
2. SCU-3/SCK-6	4.9	5.7	4.8 abc	5.1 cd	5.6 a	5.3 ab	5.8 b	5.3
3. SCU-6/SCK-3	4.9	5.8	4.7 bc	5.3 bcd	5.3 a	5.0 b	5.8 b	5.3
4. SCU-6/SCK-6	5.1	5.4	4.7 bc	5.3 bcd	5.3 a	5.0 b	5.6 b	5.2
5. MU-3/SCK-3	5.6	5.7	4.9 abc	5.4 ab	5.5 a	5.5 a	5.7 b	5.5
6. MU-6/SCK-3	5.0	5.6	4.9 abc	5.5 ab	5.6 a	5.3 ab	5.7 b	5.4
7. SCU-6 + NH_4NO_3/ SCK-6 + KCl	5.2	5.7	5.1 ab	5.3 bc	5.4 a	5.0 b	5.7 b	5.3
8. NH_4NO_3/KCl	5.5	5.3	5.2 a	5.7 a	5.6 a	5.3 ab	6.2 a	5.5
Significance (*P*)	NS	NS	0.05	0.01	0.05	0.10	0.01	NS

[z]Mean separation within columns by Duncan's multiple range test; NS = not significant.
[y]3 and 6 = durations of N and K release in months. In Treatment 7, 50% of N and K derived from controlled-release fertilizers.

Table 6. Effects of N and K fertilizers on the weight per fruit (fruit size) and tree canopy growth of young 'Valencia' orange trees.'

Fertilizer combination	Tree canopy growth (%)[x]		Wt/fruit (g)
	Nov. 1988	Aug. 1989	Am. 1989
1. SCU-3/SCK-3	138 a	203 a	216abc
2. SCU-3/SCK-6	133 a	195 a	194bc
3. SCU-6/SCK-3	116ab	180 ab	215abc
4. SCU-6/SCK-6	112 ab	183 ab	201abc
5. MU-3/SCK-3	109 ab	174b	230a
6. MU-6/SCK-3	128 ab	176 b	232a
7. SCU-6 + NH_4NO_3/ SCK-6 + KCI	124 ab	181 ab	225ab
8. NH_4NO_3/KCl	95 b	170 b	187c
Significance (*P*)	0.05	0.10	0.05

'Mean separation within columns by Duncan's multiple range test.
[y]3 and 6 = durations of N and K release in months. In Treatment 7, 50% of N and K derived from controlled-release fertilizers.
'Percent increase in the tree canopy area from the original measurements conducted in Dec. 1987.

trees had the highest weight per fruit, while those of the soluble fertilizer treatment had the lowest, but the weights for the former were similar to those of most of the other groups. The reduced weight per fruit from the soluble fertilizer treatment could have been caused by reduced K in the leaves (Reese and Koo, 1975). In another study, Zekri and Koo (1991) also found that individual fruit weight increased with controlled-release fertilizers as compared with soluble sources. The lack of differences in other fruit quality characteristics and fruit yield could be attributed to high variability in the first year of fruiting. With mature citrus trees, Koo (1986) found that trees fertilized with IBDU yielded more fruit than trees fertilized with either SCU or NH_4NO_3. He did not find significant differences in juice quality between controlled-release and soluble N sources but NH_4NO_3 produced fruit with a higher soluble solids concentration than IBDU and SCU.

Treatment 7 (50% controlled-release and 50% soluble fertilizers), which was applied only twice a year, generally had higher leaf and soil N and K contents than the total soluble fertilizer treatment and promoted growth similar to controlled-release fertilizer treatments. Because the combination of soluble and controlled-release fertilizers offers similar advantages to totally controlled-release fertilizers (long and continuous supply of nutrients), it might be of significant importance to citrus growers. Combining soluble and controlled-release fertilizers likely is an economical and an efficient strategy in a fertility program and may avoid the biuret toxicity noted.

This field experiment supports previous studies showing the effectiveness of controlled-release fertilizers for citrus trees. With the use of controlled-release fertilizers, application frequency was reduced from 15 to six applications with no adverse effects on tree growth, leaf mineral status, or soil fertility during the first 3 years.

Differences in the effects of controlled-release fertilizers in this study and in earlier work could be related to the release characteristics of these compounds. The higher leaf N and the lower residual soil N concentration in the SCU treatments compared with MU show that N from MU is not released as rapidly as that from SCU. Furthermore, Koo (1986) found that SCU was less effective than IBDU in terms of leaf N concentration and fruit production. Controlled-release fertilizers differ in their release properties, effectiveness, mineral content, and price. Hence, economic factors and reliability of controlled-release fertilizers will determine the extent of their usage on young citrus trees.

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