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Mineral Concentration of Yellow Squash Responds to Irrigation Method and Fertilization Management

G.H. Clough[1] and S.J. Locascio
Vegetable Crops Department, Institute of Food and Agricultural Science, University of Florida, Gainesville, FL 32611

S.M. Olson
North Florida Research and Education Center, Institute of Food and Agricultural Science, University of Florida, Quincy, FL 32351

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Abstract. **Squash *(Cucurbita pepo* L. var. melopepo) was grown at two locations with different soil types as a second crop in a succession cropping study that used previously cropped polyethylene-mulched beds. Squash was produced with drip or overhead irrigation and with concurrent N-K fertilization or residual fertilizer from the previous crop. Tissue mineral concentration responses to irrigation method were variable; in early fruit, N and K concentrations were higher with overhead than for drip, but leaf Ca and Mg concentrations were higher with drip than with overhead irrigation. Concentrations of N and K were higher with concurrent than with residual fertilization and increased with an increase in application rate. In contrast, concentrations of P, Ca, and Mg decreased with concurrent fertilization and an increase in application rate.**

Multiple crop vegetable production has received considerable attention in recent years (Albregts and Howard, 1985; Brown et al., 1985; Clough et al., 1990; Csizinszky et al., 1985). The practice has been shown to reduce costs and/or inputs by enabling succeeding crops to further use fumigants, polyethylene mulch, drip tape, and fertilizers applied to the first crop (Bryan and Dalton, 1974; Hayslip et al., 1978; Stall et al., 1978).

Numerous reports have been published regarding the effects of fertilizer application and irrigation methods on crop yield and mineral accumulation in most important crop species (Bhella, 1988; Bhella and Wilcox, 1986; Bryan and Dalton, 1974; Locascio et al., 1989; Persaud et al., 1976). However, no information was found regarding the effects of these cultural practices on mineral element concentration and distribution in yellow squash when produced in a drip-irrigated, polyethylene-mulched sequential crop production system.

This study was conducted to examine the effects of rate of residual and concurrent fertilizer application and irrigation methods for successive cropping on mineral accumulation of second-crop squash.

Materials and Methods

Yellow squash was produced as a component in a succession cropping study (Clough et al., 1990) conducted on a fine sand (loamy, siliceous hyperthermic, Grossarenic Palendult) at Gainesville, Fla., and on a loamy fine sand (fine-loamy, siliceous, thermic, Typic Palendult) at Quincy, Fla. Crops were produced with overhead sprinkler or drip irrigation and with concurrent application of N-K fertilizer at 135-202 or 270-404 $kg \cdot ha^{-1}$, or with residual nutrients from the previous broccoli crop that had been fertilized at the same rates. The design was a split-split plot replicated four times with location as main plots, irrigation method as sub-plots, and N-K rate and application time as sub-sub-plots. Data were examined using analysis of variance procedures (SAS Institute, 1985).

In the spring, 'Dixie' yellow squash was direct-seeded 30 cm apart, 60 cm between rows, two rows per bed (36,000 plants/ha) into the same holes used for the previous fall broccoli crop. Overhead-irrigated, concurrently fertilized plots received 100% of the treatment N-K as NH_4NO_3 and KC1 applied by hand to the soil surface through holes 30 cm apart in the bed center at the time of crop establishment. Drip-irrigated plots received the same total amount of fertilizer apportioned in weekly increments injected through the irrigation system beginning 1 week after emergence and continuing for 10 weeks. Squash fruit were harvested every 2 to 3 days for 5 weeks, beginning 6 weeks after emergence. Six fruit per plot (fruit 1) and most recently matured leaves were sampled at the first harvest, while six fruit (fruit 2) and the aboveground portion of two plants per plot were collected at the final harvest for mineral analysis. Samples were prepared according to Lockman (1980) for K, Ca, and Mg by atomic absorption spectroscopy (Perkin Elmer Corporation, 1976), and P determination was done with a Technicon autoanalyzer (Technicon Industrial Systems, 1976) at the IFAS Extension Soil Testing Laboratory, Gainesville, Fla. (Rhue and Kidder, 1983). Tissue total N was determined by micro-Kjeldahl analysis (Gallaher et al., 1975).

Irrigation was applied two to three times weekly to overhead-irrigated plots in an amount equal to pan evaporation (ET_{pan}) as measured with a U.S. Weather Bureau class A evaporation pan at each site. Drip irrigation was applied daily in an amount equal to 0.55 ET_{pan} to the entire plot area based on the average ET_{pan} for the previous 10 days (the mulched, raised bed area received water in an amount equal to ET_{pan}). The quantity of water applied to each irrigation treatment was reduced to compensate for rainfall since the previous irrigation application. Recommended commercial production practices for insect and disease control were followed.

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[1]Present address: Oregon State Univ., Hermiston Agricultural Research and Extension Center, Box 105, Hermiston, OR 97838.

Results and Discussion

Due to the different soil types and more rainfall between the fall harvest and spring planting at Quincy than Gainesville (682 vs. 299 mm, respectively), independent statistical analyses of preplant soil data were performed for each location. Analysis of water-extractable nutrients from soil samples taken to a 30-cm depth from the center and shoulder of the bed following the preceding broccoli crop showed that soluble salts concentrations (EC) were lower with drip than with overhead irrigation (Table 1) at both locations. Soil NO_3-N, NH_4-N, and K, while extremely variable, did not differ significantly between irrigation methods at Gainesville. This high variability is not uncommon for soil nutrient levels, especially when related to previous cropping practices (James and Wells, 1990). Nitrate-N and K were higher with overhead than with drip at Quincy, but NH_4-N did not differ significantly between irrigation treatments. Soil P was higher with drip than with overhead at Gainesville, but was similar with each irrigation method at Quincy. The broccoli crop yield was significantly higher with drip than with overhead irrigation (Clough et al., 1990); removal of more mineral nutrients with the broccoli harvest may explain these findings. Nutrient leaching by drip irrigation may have further reduced nutrient concentrations. Persaud et al. (1976) reported reduced yields of drip-irrigated as compared to either overhead or seep-irrigated tomato *(Lycopersicon esculentum* Mill.) due to leaching of soil nutrients by drip irrigation. Soil EC, NO_3-N, and K concentrations were higher at the higher rate of fall-applied N-K at both locations; NH_4-N was higher with the higher rate only at Gainesville. Soil P was not affected by fall N-K application rate.

Squash leaf N concentrations 6 weeks after emergence were higher at Quincy than at Gainesville (Table 2), due probably to the higher cation exchange capacity associated with the soil type at that location. Fruit and plant N concentrations did not differ between locations, however, total N uptake (fruit + plant) was 113 kg-ha-' at Gainesville and 74 $kg \cdot ha^{-1}$ at Quincy, due to higher yield and larger plants at Gainesville.

Table 1. Soil chemical characteristics preceding spring squash as affected by irrigation method and N-K application rate to previous fall crop.

Treatment	EC ($dS \cdot m^{-1}$)	NO_3-N ($mg \cdot kg^{-1}$)	NH_4-N ($mg \cdot kg^{-1}$)	P ($mg \cdot kg^{-1}$)	K ($mg \cdot kg^{-1}$)
		Gainesville			
Irrigation					
Drip	1.14	2.2	0.71	1.03	14.5
Overhead	2.61	18.3	8.81	0.61	35.9
	*	NS	NS	*	NS
N-K rate ($kg \cdot ha^{-1}$)					
135–202	1.31	6.5	2.54	0.87	13.1
270–404	2.43	13.9	6.98	0.76	37.4
	***	**	*	NS	***
		Quincy			
Irrigation					
Drip	1.18	2.8	2.70	0.21	12.0
Overhead	1.84	10.5	3.00	0.27	22.6
	**	**	NS	NS	*
N-K rate ($kg \cdot ha^{-1}$)					
135–202	1.34	2.5	2.13	0.26	11.3
270–404	1.69	10.9	2.57	0.22	23.2
	*	**	NS	NS	***

NS,*,**,***Nonsignificant or significant at P = 0.05, 0.01, or 0.001, respectively.

Table 2. Nitrogen concentration of squash as affected by location, irrigation method, N-K rate, and N-K application time.

	Tissue N (% dry wt)			
Treatment	Leaf	Fruit 1	Fruit 2	Plant
Location				
Gainesville	2.63	2.53	2.40	1.91
Quincy	3.58	2.57	2.50	2.14
	*	NS	NS	NS
Irrigation				
Drip	3.03	2.28	2.32	1.97
Overhead	3.18	2.82	2.57	2.09
	NS	**	NS	NS
N–K rate ($kg \cdot ha^{-1}$)				
135–202	3.02	2.47	2.42	1.72
270–404	3.19	2.63	2.47	2.33
	NS	NS	NS	***
Application time				
Residual	2.43	2.19	2.21	1.83
Concurrent	3.77	2.91	2.69	2.22
	***	***	**	***

NS,*,**,***Nonsignificant or significant at P = 0.05, 0.01, or 0.001, respectively.

Leaf N concentration was not affected by irrigation method (Table 2). In the fruit, N concentrations were higher with overhead than with drip irrigation at the first sampling, but were similar for both fruit and plant at the later sampling date. Total N uptake averaged 98 and 90 kg-ha-' with overhead and drip irrigation, respectively. The early concentration differences may have been caused by differences in timing of fertilizer application. All the fertilizer was applied at planting to the overhead-irrigated plots while the drip-irrigated plots were fertilized through the irrigation system over 10 weeks.

Leaf and fruit N concentrations were similar with both N-K rates, but plant N concentration increased with an increase in N-K rate (Table 2). Crop N accumulation increased from 71 to 118 $kg \cdot ha^{-1}$ with an increase in N-K application rate.

Concurrent fertilization resulted in significantly higher leaf, fruit, and plant N than did residual fertilization (Table 2). The 2.43% N in the squash leaf with residual fertilization was within the deficiency range for squash (Hochmuth et al., 1991) and for several other vegetable crops (Lorenz and Tyler, 1976). However, the 12.2 $t \cdot ha^{-1}$ yield (Clough et al., 1990) associated with that value exceeded the average squash yield for Florida (Florida Agr. Stat. Serv., 1987). At the time of leaf sampling, plant size was small and leaf color was pale in the residual fertilizer plots. Nitrogen uptake averaged 155 $kg \cdot ha^{-1}$ with concurrent fertilization and 43 $kg \cdot ha^{-1}$ with residual nutrients.

Phosphorus concentrations of leaf and fruit at the first sampling were similar at both locations (Table 3). However, fruit and plant P concentrations were higher at Gainesville than Quincy at 11 weeks after emergence. The higher soil P content at Gainesville than at Quincy (Table 1) likely was responsible for the location effect.

Tissue P concentrations were higher with drip than with overhead irrigation in the fruit at the last harvest (Table 3). More soil P was available in the drip than in the overhead-irrigated plots at Gainesville before squash planting (Table 1). Values were similar for both irrigation methods at Quincy. Bacon and Davey (1982) suggested that the higher soil moisture associated with drip irrigation resulted in cyclic release of native and applied phosphates by reduction of amorphous iron phosphates during the anaerobic phase of the irrigation cycle, thus increas-

Table 3. Phosphorus concentration of squash as affected by location, irrigation method, N-K rate, and N-K application time.

Treatment	Tissue P (% dry wt)			
	Leaf	Fruit 1	Fruit 2	Plant
Location				
Gainesville	0.59	1.02	0.97	0.68
Quincy	0.60	0.98	0.66	0.50
	NS	NS	**	***
Irrigation				
Drip	0.62	1.03	0.85	0.65
Overhead	0.57	0.98	0.78	0.53
	NS	NS	*	NS
N–K rate ($kg \cdot ha^{-1}$)				
135–202	0.63	1.03	0.86	0.67
270–404	0.56	0.98	0.77	0.51
	*	NS	***	***
Application time				
Residual	0.65	1.09	0.88	0.72
Concurrent	0.54	0.91	0.74	0.46
	***	***	**	***
Rate × time	NS	NS	*	**

NS,*,**,***,Nonsignificant or significant at $P = 0.05$, 0.01, or 0.001, respectively.

ing P available in the soil for plant uptake. Total P uptake averaged 30 $kg \cdot ha^{-1}$ with both irrigation methods, due to higher average yields obtained with overhead irrigation.

Phosphorus concentrations of leaf tissue at 6 weeks and fruit and plant tissues sampled 11 weeks after emergence decreased with an increase in N-K rate (Table 3). Fruit P concentration 6 weeks after emergence was not significantly affected by N-K rate. Application time interacted with N-K rate to influence fruit and plant P concentrations at the final harvest (data not shown). Late fruit and plant P concentrations decreased with an increase in residual nutrient application rate; a similar response was obtained with concurrent fertilization, but the decrease was not significant. However, P accumulation increased in late fruit from 2 to 5 kg-ha-' and in the plant from 8 to 14 $kg \cdot ha^{-1}$, as the residual fertilizer rate increased. With increasing rate of concurrent fertilization, late fruit uptake also increased from 7 to 10 $kg \cdot ha^{-1}$, but plant accumulation decreased from 18 to 16 $kg \cdot ha^{-1}$. Total crop P uptake increased from 23 to 31 $kg \cdot ha^{-1}$ as N-K application rate increased from 135-202 to 270-404 $kg \cdot ha^{-1}$. With the N-K rates increased together, dilution appears to be the primary effect. Thomas and McLean (1967) varied N and K rates separately and reported that increasing rates of either nutrient resulted in decreased P concentration of squash stem + leaf tissue sampled 8 weeks after transplanting. They hypothesized that increased N rate decreased P concentration by dilution due to increased plant dry matter production, and increased K rate decreased plant P concentration by ion antagonism.

The P concentrations of all tissues sampled were lower with concurrent than with residual fertilization (Table 3). However, uptake was 18 $kg \cdot ha^{-1}$ with residual and 40 $kg \cdot ha^{-1}$ with concurrent N-K fertilizer application. Francois (1985) reported decreased leaf P concentration as soil soluble salts increased for both zucchini and scallop squash. The 0.60% average leaf P concentration in this study was higher than the 0.38% reported by Francois (1985) for zucchini and scallop squash leaf blades, and plant P concentrations equaled or exceeded the 0.50% critical concentration value for yellow squash suggested by Thomas and McLean (1967).

Leaf, fruit, and plant K concentrations were similar with both irrigation methods (Table 4); however, location and irrigation method interacted to affect fruit K concentration 6 weeks after emergence. At Gainesville, K concentrations were not affected by irrigation method (averaged 5%), but at Quincy, squash fruit K was 5.21% with overhead and 4.57% with drip irrigation. Preplant soil K at Quincy was significantly higher in the overhead than the drip-irrigated plots (Table 1). Also, at 6 weeks only 60% of the scheduled K fertilizer had been applied to the drip-irrigated squash, while 100% had been applied to the overhead-irrigated plots. By the time all the K had been applied with the drip-irrigation treatment, fruit K concentrations were similar with both irrigation methods. Total K uptake by fruit, however, averaged 79 $kg \cdot ha^{-1}$ with overhead irrigation and 64 $kg \cdot ha^{-1}$ with drip.

The K concentrations of squash leaf and fruit 6 weeks after emergence were higher with the higher than lower N-K application rate (Table 4). The later fruit K concentration was lower with the higher N-K application rate; nonetheless, total fruit K accumulation was higher with the higher rate (85 vs. 59 kg-ha-‘) due to the increased yield.

Application rate and time interacted to affect plant K concentration. With fall-applied; residual fertilization plant K concentration was similar with both rates (averaged 3.42%), but with concurrent application, plant K was higher with the 270-404 $kg \cdot ha^{-1}$ rate (5.20%) than with the 135-202 kg-ha-r rate (4.04%). Thomas and McLean (1967) obtained an increase in plant K concentration with a higher K application rate, but reported that increased N application rate did not affect plant K concentration.

Lorenz and Tyler (1976) report that for zucchini squash, 10% petiole K concentration is adequate and 6% is deficient. In this study with yellow crookneck squash, the lowest whole leaf (petiole + blade) K concentration (4.14%) was associated with an adequate yield (12.2 $t \cdot ha^{-1}$) (Clough et al., 1990). Exceptional yields were associated with the higher leaf K concentrations, yet the highest value obtained was only 5.21%.

In all tissues sampled, Ca concentrations appeared higher at Gainesville than at Quincy, but the differences were significant

Table 4. Potassium concentration of squash as affected by location, irrigation method, N-K rate, and N-K application time.

Treatment	Tissue K (% dry wt)			
	Leaf	Fruit 1	Fruit 2	Plant
Location				
Gainesville	4.69	5.00	4.45	3.80
Quincy	4.66	4.89	3.60	4.24
	NS	NS	**	***
Irrigation				
Drip	4.63	4.80	4.02	3.99
Overhead	4.72	5.08	4.02	4.04
	NS	NS	NS	NS
Location × irrigation	NS	*	NS	NS
N-K rate ($kg \cdot ha^{-1}$)				
135–202	4.46	4.72	4.13	3.72
270–404	4.89	5.17	3.92	4.32
	*	***	*	***
Application time				
Residual	4.14	4.86	4.28	3.42
Concurrent	5.21	5.02	3.76	4.62
	***	NS	***	***
Rate × time	NS	NS	NS	*

NS,*,**,***Nonsignificant or significant at $P = 0.05$, 0.01, or 0.001, respectively.

only at 6 weeks after emergence (Table 5). Soil Ca preceding the spring squash crop averaged 21 mg·kg^{-1} at Gainesville and 14 mg·kg^{-1} at Quincy.

Leaf Ca concentration was higher with drip than with overhead irrigation at the first time of sampling, but was similar with both irrigation methods in the fruit and whole-plant tissue at the later sampling date (Table 5). Total accumulations were similar also, averaging 109 kg-ha-‘. Ion antagonism due to higher soil soluble salts concentration with overhead than with drip irrigation early in the season may have been responsible for lower leaf Ca concentrations.

A similar effect (antagonism) resulted from the influence of N-K rate on Ca concentration (Table 5). At the first sampling, leaf and fruit Ca concentrations were similar; later, the higher N-K application rate resulted in a reduction in Ca concentrations in the fruit and plant. However, application rate and time interacted to affect plant Ca concentration. With residual fertilization, concentration was not affected by N-K rate (average 4.01%), but plant accumulation increased from 37 to 91 kg·ha^{-1} as residual N-K rate increased. With concurrent application, concentration was reduced by 25% with the 270-404 as compared to the 135-202 kg·ha^{-1} N-K rate (4.38 to 3.29%). Accumulation also decreased, from 158 to 124 kg·ha^{-1}. Ion antagonism from increased concentrations of NH_4^+ and K^+ with higher rates of concurrent N-K fertilization probably caused this effect. With residual fertilization, although initial soil K concentrations were higher with the higher fall application rate, the level was not great enough to sustain the effect through the spring crop. Total uptake of Ca was greater with the higher than with the lower (116 and 100 kg·ha^{-1}, respectively) N-K application rate.

While leaf tissue concentration was unaffected by application time, fruit Ca concentration at the first harvest was higher with concurrent than residual fertilization (Table 5). At the last harvest, however, fruit Ca concentration decreased with concurrent as compared to residual fertilization. About 5% of the total Ca was partitioned into the fruit, with the remainder in the plant tissue.

Leaf and plant Mg concentrations were higher at Quincy than at Gainesville (Table 6). Although soil Mg preceding the spring

Table 5. Calcium concentration of squash as affected by location, irrigation method, N-K rate, and N-K application time.

Treatment	Tissue Ca (% dry wt) Leaf	Fruit 1	Fruit 2	Plant
Location				
Gainesville	3.08	0.36	0.37	4.15
Quincy	1.80	0.29	0.33	3.69
	**	***	NS	NS
Irrigation				
Drip	2.61	0.32	0.34	3.85
Overhead	2.26	0.33	0.36	4.00
	**	NS	NS	NS
N–K rate (kg·ha^{-1})				
135–202	2.50	0.33	0.37	4.19
270–404	2.37	0.32	0.33	3.65
	NS	NS	**	**
Application time				
Residual	2.49	0.31	0.40	4.01
Concurrent	2.38	0.34	0.30	3.83
	NS	*	***	NS
Rate × time	NS	NS	NS	*

NS,*,**,***Nonsignificant or significant at P = 0.05, 0.01, or 0.001, respectively.

Table 6. Magnesium concentration of squash as affected by location, irrigation method, N-K rate, and N-K application time.

Treatment	Tissue Mg (% dry wt) Leaf	Fruit 1	Fruit 2	Plant
Location				
Gainesville	0.67	0.31	0.39	0.95
Quincy	0.81	0.30	0.36	1.39
	*	*	NS	**
Irrigation				
Drip	0.80	0.30	0.37	1.14
Overhead	0.68	0.31	0.38	1.20
	**	NS	NS	NS
N–K rate (kg·ha^{-1})				
135–202	0.79	0.31	0.39	1.26
270–404	0.69	0.30	0.36	1.08
	**	NS	**	**
Application time				
Residual	0.83	0.32	0.39	1.23
Concurrent	0.65	0.29	0.36	1.11
	***	***	**	**
Rate × time	NS	NS	NS	*

NS,*,**,***Nonsignificant or significant at P = 0.05, 0.01, or 0.001, respectively.

squash crop averaged 3.5 mg·kg^{-1} at Gainesville and 5.4 mg·kg^{-1} at Quincy, this was a dilution effect. Plant dry matter accumulation averaged 104 and 75.9 g/plant, and total plant uptake averaged 33.1 and 26.7 kg·ha^{-1} at Gainesville and Quincy, respectively. Fruit Mg concentrations were slightly higher at Gainesville than at Quincy after 6 weeks, but similar at harvest.

Tissue Mg concentration responses to treatments were similar to those for Ca (Table 6). Total accumulation averaged 36 kg·ha^{-1} for both irrigation methods. As with Ca, Mg uptake was greater with the higher than with the lower N-K application rate (39 and 33 kg-ha-‘, respectively). About 15% of the Mg was partitioned into the fruit, with the remainder in the plant tissue. The interaction between application rate and time was similar to that for plant Ca. With fall-applied residual fertilization, Mg concentration was not affected by N-K rate (1.23%), but plant accumulation increased from 12 to 27 kg-ha-’ as residual N-K rate increased. With concurrent application, concentration and accumulation decreased with the 270-404 as compared to the 135-202 kg·ha^{-1} N-K rate (1.26% to 0.95%, 46 to 36 kg·ha^{-1}).

All leaf sample mineral concentrations tested in the adequate or high range for sufficiency, with the exception of the N concentration with residual N-K fertilizers (Hochmuth et al., 1991). Tissue mineral analyses frequently are used as a basis for determining crop fertilization requirements and often are correlated with yield. As our data show, tissue mineral concentration is not always related directly to mineral uptake; factors such as ion antagonism and dilution due to greater growth and/or yield must be considered.

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