

EFFECTS OF HIGH RATES OF POTASSIUM FERTILIZATION ON RAW PRODUCT QUALITY AND CHANGES IN pH AND ACIDITY DURING STORAGE OF CONCORD GRAPE JUICE

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ABSTRACT

Excessive levels of potassium (K) fertilizer (225 to 900 kg/ha) were applied to Concord grapevines for five years in a vineyard with adequate initial levels of petiole K. Petiole K increased from 1.24% (dry weight basis) in control plots to 6.07% in high K plots. Petiole Ca and Mg showed highly significant negative correlations with petiole K, while Mn decreased only slightly with K fertilization. Juice K increased with high levels of K fertilization, resulting in pH increases and titratable acidity reductions in the juice. As fresh juice K content increased, significant increases in pH and acidity loss occurred during juice storage. K levels in the fresh juice and acidity and K loss during storage were highly correlated. K fertilization did not affect total pigment content of the juice, but tristimulus color values were reduced, probably through K-induced pH effects on the anthocyanin molecule. K fertilization reduced the amount of green fruit present at harvest, but had little effect on % soluble solids.

Potassium tartrate crystals were reported in grapes as early as 1914 (2). Potassium in grape juice is responsible for much of the change in pH and acidity incurred during processing through formation and precipitation of potassium tartrates, and the relationship between juice potassium content and acidity loss during cold storage stabilization of Concord grape juice was shown by Mattick et al. (12). Through vineyard surveys, these researchers concluded that grapevine uptake of potassium could not be increased sufficiently to result in a reduction of acidity in the high acid juice produced from New York grown Concord.

Application of potassium fertilizers in amounts sufficient to prevent deficiency symptoms in grapes is necessary for maximal fruit production, while excess potassium applications have little effect (8,11,16,19). The optimum potassium level for Concord grape petioles during July and August samplings has been estimated in the range of 1.0 to 2.0% (dry weight basis) (4,10,11,16).

With numerous publications in past years (6,9,13) and research indicating the benefits of massive applications of potassium (7), commercial Concord grape growers in this region are applying large quantities of potassium fertilizer to their vineyards. Excessive potassium uptake by grapevines in a production region which normally produces low acid juice could have detrimental effects upon pH and acidity, resulting in loss of quality in grape juice. Little is known of the effects of luxury feeding of potassium by Concord grapevines and its ultimate effect on juice quality.

The purpose of this study was to determine the effects of high rates of potassium fertilization on the elemental composition of the petioles and the quality of fresh and stored juice from a Concord vineyard with adequate petiole potassium content.

MATERIALS AND METHODS

This study was initiated in a uniform nine-year-old, own-rooted Concord vineyard and continued for five years. The vineyard was located on a Lintonia silt loam at the Arkansas Agricultural Experiment Station, Fayetteville. Initial soil samples tested 358 kg/ha K₂O, 1568 kg/ha Ca, 142 kg/ha Mg, and 179 kg/ha P₂O₅ with a pH of 5.8. However, research has shown that soil tests are not a reliable method of estimating nutrient status of grapevines (6,19).

Vines were spaced 2.4 m within the row and 3.1 m between rows and trained to a single-wire cordon system 1.8 m high. All vines were spur pruned (4 to 5 nodes in length) and balanced to a 30 + 10 pruning severity (30 nodes retained for first 454 g of dormant prunings removed and 10 additional nodes retained for each additional 454 g of prunings). The average weight of prunings prior to the initiation of the study was 1.9 kg per vine. During the study, a rye-vetch cover crop was grown in the vineyard each winter and 67 kg/ha actual nitrogen was applied prior to bloom each year.

In the fall and spring prior to the initial sampling year and in each succeeding year prior to bud swell, muriate of potash (KCl) was applied at rates to provide 0, 225, 450, and 900 kg/ha of actual K to 12 replications of eight-vine plots. Fertilizer was broadcast uniformly between the rows and incorporated to a depth of 8 cm. All treatments were randomized throughout the vineyard and separated by guard vines.

Petiole nutrient analysis: Fruiting primary shoots that were exposed to the sun were selected for petiole sampling. Petioles for analysis were taken from the most recently matured leaf each year at 60 days after bloom. The petioles were separated from the blades, dried at 80°C, ground in a micro-Wiley mill to pass through a 40-mesh screen, and stored in tightly capped glass bottles. Before being weighed for analysis, the samples were redried to remove any moisture that might have accumulated.

Samples for K, Ca, Mg, and Mn analyses were dry ashed and washed into 50-mL volumetric flasks with hot water, and then 2 mL of concentrated HCl was added. Each sample was cooled to room temperature, brought to volume, and filtered. Total K, Ca, Mg, and Mn were determined flame photometrically using a Beckman Model DU spectrophotometer. Total N was determined by the Kjeldahl method as described by the A.O.A.C. (3). P was determined by the Emil Truog Method (18).

Juice analysis: Approximately 2 kg of grapes were collected from each plot at harvest by selecting two or three representative clusters from each vine. The fruit was stemmed, % green fruit determined, and random samples were frozen in polyethylene bags for later juice preparation. To make juice, the samples were thawed and blended for 15 seconds in a laboratory blender. After being heated in a water bath at 85°C for one hour to extract color and solublize tartrates, samples were strained through two layers of coarse cheesecloth to remove pulp. A portion of the juice was collected for immediate analysis and another portion was placed in 114-mL bottles and stored at 0°C for six weeks.

For fresh juice analysis, samples were cooled to 20°C, and % soluble solids was determined using a Bausch and Lomb Abbe refractometer. K content of juice was determined flame photometrically using a Beckman Model DU spectrophotometer.

A 2-mL sample of the juice was diluted to 100 mL with distilled water, acidified to pH 1.5 with HCl and centrifuged for 30 minutes at 4000 rpm. Optical density was read on the centrifuged samples using a Bausch and Lomb spectrophotometer (Model 340) at 520 nm. Tristimulus color of the juice was determined with a Hunter Color and Color Difference Meter standardized to the white plaque with values "L" = 92.0, "a" = -1.5, and "b" = 1.1. A 10-mL sample of juice was diluted to 125 mL with distilled water, pH was determined, and the sample was titrated to pH 8.4 with 0.1N NaOH to determine acidity.

Stored juice analyses, after a minimum of six weeks holding at 0°C, consisted of pH, titratable acidity, and K content as previously described.

RESULTS AND DISCUSSION

Petiole analysis: The K levels in Concord grape petioles were increased by each level of K fertilization during the initial year of fertilizer application (Table 1) and in each succeeding year of the five-year study. Vines receiving the continuously high rates of K(900 kg/ha) had petiole K levels ranging from 5.82% in the initial year to 6.27% in the final year. The K level in the petiole showed little additional accumulation from the continuous application of excessive K fertilizer. The five-year average for petiole K ranged from 1.24% for the control vines (no K fertilization) to 6.07% for vines receiving annual applications of 900 kg/ha. The lack of a decline in K uptake with no K fertilization indicated that the control vines maintained an adequate potassium status. K deficiency symptoms in Concord vineyards in New York are not expressed until less than 0.4% petiolar K level is reached (16).

Table 1. Effect of potassium fertilization on nutrient content of Concord grape petioles.

Actual K (kg/ha)	Percent (dry wt. basis)					
	K	Ca	Mg	Mn	P	N
Initial year						
0	1.22 d ^a	0.74 a	1.24 a	.161 a	0.19 a	1.04 a
225	3.14 c	0.71 a	0.85 b	.162 a	0.18 a	1.01 a
450	5.02 b	0.73 a	0.58 c	.160 a	0.18 a	1.07 a
900	5.82 a	0.69 a	0.41 d	.147 a	0.16 a	0.94 a
Final year						
0	1.46 d	1.19 a	0.81 a	.118 a	0.19 a	1.09 a
225	4.81 c	0.92 b	0.24 b	.101 ab	0.20 a	1.14 a
450	5.63 b	0.96 b	0.23 b	.097 b	0.20 a	1.12 a
900	6.27 a	0.88 b	0.19 b	.089 b	0.20 a	1.18 a
5-year mean						
0	1.24 d	1.35 a	0.92 a	.139 a	0.19 a	1.53 a
225	4.10 c	1.19 b	0.42 b	.138 a	0.20 a	1.62 a
450	5.11 b	1.18 b	0.34 c	.135 a	0.20 a	1.65 a
900	6.07 a	1.07 c	0.24 d	.120 b	0.20 a	1.54 a

^a Mean separation within columns and years by Duncan's multiple range test at the 5% level.

fertilization (Table 1), and these two elements were not correlated with petiole K (Table 2).

Petiole contents of Ca and Mn were not affected by high K fertilization and K uptake during the initial year, but reductions in petiolar Ca and slight but significant reductions in Mn occurred by the final year of the study (Table 1). Mg was greatly reduced in the petioles each year with increased K fertilization. The relationship between K and Mg was significant with increases in K uptake sharply reducing petiolar Mg. The correlation matrix for nutrient composition of the petiole shows that K and Mg content had the highest correlation of -.806 (Table 2). With increase in K application, petiolar Mg from vines in all plots except the controls decreased steadily and approached in the fifth year the deficiency level (0.2%) established by Shaulis and Kimball (16) for Concord vines in New York. It is possible that a K-induced Mg deficiency could develop from the continued use of high levels of K fertilization. The P and N content of petioles was not affected by K

Juice analysis: The K in fresh juice significantly increased with each increase in rate of K fertilization in the initial year and for the five-year mean (Table 3). The intermediate rates of K (225 and 450 kg/ha) produced juice with similar K content during the final year. K in the stored juice followed the same trends as in fresh juice, even though more K was lost during storage of juice from K fertilized plots.

Table 2. Correlation matrix of nutrient composition in Concord grape petioles (five-year mean).

	K	Ca	Mg	Mn	P	N
K	1.000					
Ca	-.482**	1.000				
Mg	-.806***	.531**	1.000			
Mn	-.145	.203	.343*	1.000		
P	.131	-.392*	.006	-.075	1.000	
N	.146	-.229*	-.159	-.021	.234*	1.000

*Significant at 0.05.

**Significant at 0.01.

***Significant at 0.001.

K fertilization had slight tendencies to reduce titratable acidity in the fresh juice during the initial year and for the five-year mean (Table 3). The greatest effects of K on titratable acidity was a reduction during storage. Juice from all plots receiving supplemental K fertilizer lost more of the titratable acids during storage than controls. For the five-year average K applications between the rates of 225 and 900 kg/ha resulted in approximately a 40% reduction of the titratable acids during storage that were initially present in the fresh juice and as much as 52% loss occurred in one year (data not shown).

There was a higher pH of fresh and stored juice and the increase in pH during juice storage was greater with K fertilization (Table 3). This increase in pH during juice storage conflicts with results reported by Mattick et al. (12). Their data indicate that pH decreases during storage. Since the effects of K on pH of fresh juice and the changes during storage are additive, an increase in pH for the five-year average from 3.31 in fresh juice from plots receiving no K to 3.74 in stored juice from plots receiving the highest rate of K fertilization occurred. This difference in pH can have detrimental effects, not only on flavor, but also on color due to structural alterations of the anthocyanin pigment resulting in a color loss (17).

Table 3. Effects of potassium fertilization on potassium content, acidity, and pH of fresh and stored Concord grape juice.

Actual K (kg/ha)	K (ppm)			Acidity (as % tartaric)			pH		
	Fresh juice	Stored juice	Loss ^z	Fresh juice	Stored juice	Loss ^z	Fresh juice	Stored juice	Increase ^z
Initial year									
0	2230a ^y	600a	1630a	0.97a	0.64a	0.33a	3.31a	3.33a	0.02a
225	2840b	890b	1950b	0.95ab	0.57b	0.38b	3.42b	3.48b	0.06ab
450	3070c	1030c	2040be	0.95ab	0.57b	0.38b	3.46be	3.54b	0.08b
900	3310d	1160d	2150c	0.91b	0.51c	0.40b	3.52c	3.68c	0.16c
Final year									
0	2470a	1360a	1110a	0.98a	0.77a	0.21a	3.32a	3.41a	0.09a
225	3370b	1690b	1680b	0.96a	0.66b	0.30b	3.51b	3.63b	0.12a
450	3310b	1640b	1670b	0.95a	0.65b	0.30b	3.49b	3.61b	0.12a
900	3580c	1770c	1810b	0.93a	0.61b	0.32b	3.56c	3.73c	0.17b
5-year mean									
0	2760a	1030a	1730a	0.97a	0.71a	0.26a	3.31a	3.37a	0.06a
225	3700b	1330b	2370b	0.95b	0.58b	0.37b	3.49b	3.62b	0.13b
450	3880c	1420c	2460b	0.96ab	0.58b	0.38b	3.51c	3.64b	0.13b
900	4190d	1570d	2620c	0.93c	0.54c	0.39b	3.57d	3.74c	0.1 b

^yMean separation within columns and years by Duncan's multiple range test at the 5% level.

^zChange during juice storage at 0°C for 6 weeks.

K fertilization had no effect on total pigment content of the juice as indicated by optical density of grape juice when samples were acidified to pH 1.5 (Table 4). Even though K is important for improving color of fruits, the lack of color improvement with K fertilization in this study is probably the result of no K deficiency in the controls.

Tristimulus color determinations using a Gardner Color and Color Difference meter indicate that high K fertilization was detrimental to the natural unacidified grape juice color (Table 4). Although "L" values, indicating lightness or darkness of the juice, did not show consistent trends, the "a" values decreased with high K fertilization, indicating a decrease in redness. The "b" values decreased during the initial year and for the five-year mean, indicating a tendency toward a more blue color. Chroma, calculated as $(a^2 + b^2)^{1/2}$, decreased with high K fertilization indicating a less intense color. The poorer grape juice color due to K fertilization was probably obtained indirectly through K effects upon juice pH. High K fertilization did not reduce the amount of pigment present as indicated by optical density measurements of acidified samples, but the increased pH due to formation and precipitation of potassium tartrates allowed structural transformations of the anthocyanin molecule (17), resulting in some color loss and possibly a slight shift in hue from the normal red-purple color toward a more blue color. If color had been determined on the juice after storage, more severe color changes could be expected due to the accumulative increases in pH through K effects in the fresh juice and during juice storage.

Soluble solids content of fresh juice was not affected by excessive K fertilization during the initial or final year (Table 4), nor in any single year of the study. However, when data were pooled across all five years, slight but inconsistent differences appeared.

Actual K kg/ha	Optical density ²	Color			Chroma $(a^2 + b^2)^{1/2}$	Soluble solids (%)	Green fruit (%)
		L	a	b			
Initial year							
0	268 a [†]	11.1 a	14.1 a	5.3 a	15.2 a	15.1 a	3.4 a
225	266 a	9.7 ab	12.2 b	4.7 ab	13.2 b	15.1 a	2.7 ab
450	244 a	10.9 a	11.6 bc	5.3 a	12.9 bc	15.0 a	2.5 ab
900	264 a	9.0 b	10.9 c	4.0 b	11.7 c	15.3 a	1.9 b
Final year							
0	238 a	11.3 a	9.1 a	2.0 a	9.4 a	15.5 a	8.1 a
225	222 a	11.0 a	8.5 ab	1.9 a	8.8 ab	15.1 a	5.3 b
450	208 a	11.1 a	8.3 ab	1.8 a	8.5 bc	14.9 a	4.4 b
900	231 a	10.5 a	7.6 b	1.5 a	7.8 c	15.3 a	3.9 b
5-year mean							
0	242 a	11.7 a	9.8 a	3.8 a	10.7 a	15.0 ab	5.5 a
225	244 a	10.8 bc	8.7 b	3.1 b	9.4 b	15.1 ab	3.1 b
450	226 a	11.2 ab	8.2 c	3.3 b	9.1 b	14.9 b	3.0 b
900	248 a	10.3 c	7.9 c	2.8 c	8.6 c	15.2 a	2.3 c

[†] Mean separation within columns and years by Duncan's multiple range test at the 5% level.
[‡] Hunter Color and Color Difference meter standardized to a white plaque with "L" = 92.0, "a" = -1.5 and "b" = 1.1.
² Optical density at 520 nm of 2 mL juice diluted to 100 mL with distilled water and acidified to pH 1.5.

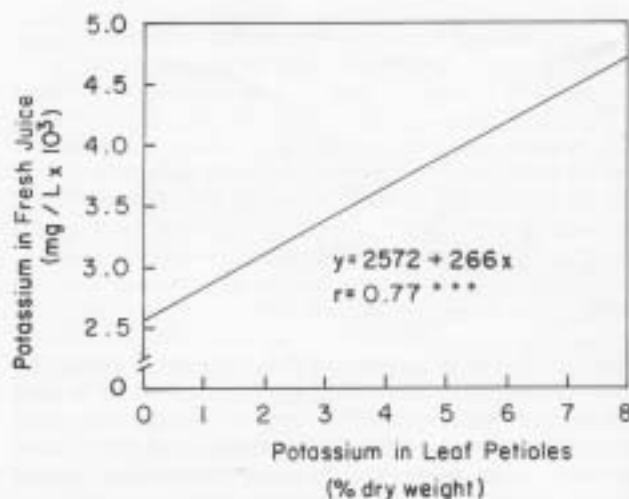


Fig. 1. Relationship between potassium in leaf petioles and potassium in Concord grape juice before storage (5-year mean)

Uneven ripening of Concord is a problem in southern growing areas (14,15) and if severe enough, can result in fruit rejection at the processing facility due to limits imposed by USDA Grades and Standards (20). K fertilization reduced the percentage of green fruit present at harvest in the final year and for the five-year mean (Table 4). Response during the initial year was limited to the highest (900 kg/ha) rate of K application.

Petiole K content showed positive correlations (above 0.6) with fresh and stored juice K content, K and acid loss during storage, and pH of both fresh and stored juice (Table 5). However, K content of the fresh juice was more highly correlated with these variables than petiolar K. The relationship between K in the petiole and in the fresh juice is graphically presented in Fig. 1. This relationship was found to be linear under Arkansas conditions; however, a curvilinear response was found in a New York study (12).

High correlations existed between fresh juice K content and K and acid loss during storage with correlations coefficients of .929 and .840, respectively (Table 5). Acidity and K loss during storage as related to fresh juice K content is illustrated in Fig. 2. The close relationship between acid and K loss during juice storage ($r = .822$) and their dependency upon fresh juice K content is attributable to potassium tartrate precipitation. For the five-year average, approximately two-thirds of the K present in the fresh juice was precipitated during juice storage and, for each 1000 mg/L of K in the fresh juice, approximately 0.1 percentage unit of acidity was lost during storage. The high positive correlations between K and total acidity loss is partially due to the low malic acid levels of Concord grapes produced under hot southern growing conditions. In one Arkansas study (5), 62% of the total acids present in Concord at harvest was tartaric, while only 28% was malic.

Table 5. Correlation matrix for potassium and Concord juice quality (five-year mean).

	K petiole	K in juice			% acid in juice			pH in juice			
		Fresh	Stored	Loss	Fresh	Stored	Loss	Fresh	Stored	Increase	
K petiole	1.000										
K in juice											
Fresh	.774***	1.000									
Stored	.704***	.758***	1.000								
Loss	.673***	.929***	.496***	1.000							
% acid in juice											
Fresh	-.031	-.149	-.117	.019	1.000						
Stored	-.444***	-.503***	-.422***	-.465***	.788***	1.000					
Loss	.715***	.840***	.604***	.822***	.026	-.550***	1.000				
pH in juice											
Fresh	.611***	.716***	.714***	.585***	-.299*	-.613***	.647***	1.000			
Stored	.671***	.792***	.691***	.697***	-.372**	-.689***	.719***	.711***	1.000		
Increase	.302***	.349**	.251*	.317**	-.067	-.213*	.347**	.016	.667***	1.000	
Sol. sol.	-.100	-.173*	-.099	-.175	-.564***	-.392**	-.187	.005	.077	.026	1.000
% green	-.195	-.232*	-.333*	-.139	.646***	.837***	-.223*	-.403***	-.415***	-.110	-.110

* Significant at 0.05.
 ** Significant at 0.01.
 *** Significant at 0.001.

Even though high rates of K fertilization tended to reduce acidity of fresh juice (Table 3), neither K in the petiole nor K in the fresh juice ($r = -.031$ and $-.149$, respectively) correlated with fresh juice acidity (Table 5). The pH in both fresh and stored juice was positively related to petiole and juice K content. Mattick et al. (12) also showed a relationship between K and juice pH before and after storage; however, the changes in pH during storage in their study were not related to K probably because of the buffering capacity of malic acid which remains soluble during juice storage. In our study, the relationship between petiole and juice K with the increase in pH during juice storage was significant (Table 5) although the correlations were not as high as for changes in titratable acidity during storage. The buffering capacity of malic acid is probably contributing to the low correlations between K and changes in pH, although the influence of malic acid in juice from Arkansas-grown Concord grapes would not be as great as in juice from grapes produced under cooler climates.

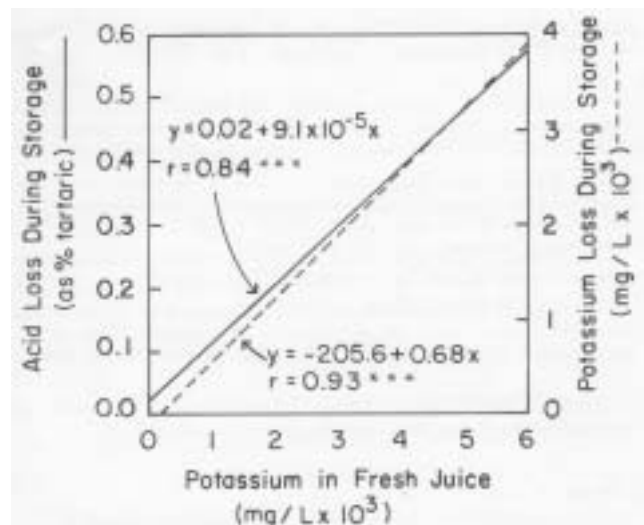


Fig. 2. Relationship between potassium in Concord grape juice before storage and loss of acidity and K during storage (5-year mean).

prunings/vine). Yield and vine growth are inversely related and the reduced yield could have accounted for some of the increase in vine growth. Correlation coefficients indicated that no relationship existed between level of petiolar K and vegetative growth.

CONCLUSIONS

High rates of K fertilization increased both petiole and juice K content significantly. This increased K uptake by the vine reduced both Ca and Mn in the petioles and lowered petiole Mg content to near deficiency levels.

High juice K content resulted in higher pH of fresh juice and increases in pH and acidity loss during juice storage. Two-thirds of the original K content of fresh juice was lost during storage. Highly significant positive correlations were obtained between fresh juice K content, acid loss, and K loss during juice storage.

The strongest correlations for % soluble solids and % green fruit were with juice acidity (Table 5) which are typical relationships associated with changes in fruit maturity.

Yield and vine size: Yield in the K plots was significantly reduced during the final year of the study (no K = 11.1 MT/ha; 225 kg/ha K = 8.1 MT/ha; 450 kg/ha K = 9.1 MT/ha; and 900 kg/ha K = 8.9 MT/ha). The objective of this study was not to investigate the influence of excessive levels of K on yield, but these data from the final year would indicate that additional research is needed on the effect of annual applications of excessive K in the absence of a deficiency. Since KCl was used as a source of potassium, all plots were visually monitored for Cl toxicity symptoms. Although no Cl toxicity was observed, it is possible that on some soils Cl could become a problem with continued use of KCl.

Vine size was significantly increased in the K plots during the final year of the study (no K = 1.84 kg prunings/vine; 225 kg/ha K = 2.27 kg prunings/vine; 450 kg/ha K = 2.24 kg prunings/vine; and 900 kg/ha K = 2.29 kg

This study indicates that in warm climates, which result in grapes with low acid content, excessive K fertilization and "luxury feeding" of K to grapevines is detrimental to the quality of grape juice products. Maintaining petiolar K no higher than the established 1 to 2% level to satisfy the vines requirements appears optimum for production of juice products in warm climates. Application of K fertilizer to Concord vineyards which have adequate levels of K is not recommended because of the potential loss in juice acidity, pH, and product quality.

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