FOLIAR POTASSIUM FERTILIZATION OF MUSKMELONS ON CALCAREOUS SOILS IN SOUTH TEXAS: EFFECTS ON YIELD AND QUALITY

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ABSTRACT

Among the essential plant nutrients, potassium (K) has the strongest influence on crop quality parameters. However, many soil and plant factors often limit adequate soil K uptake to satisfy plant requirements during fruit development stages. The objectives of this multiyear field study were to determine if this apparent K deficiency and the associated fruit quality problems can be alleviated by supplementing soil-derived K with foliar K nutrition and whether differences exist among K salts for foliar feeding. Even though pre-plant soil K concentrations were high, foliar K treatments resulted in higher plant tissue K concentrations, suggesting that K uptake from the soil solution was not sufficient to satisfy plant requirements. Fruits from treatments receiving foliar K had higher soluble solids concentrations, total sugars, and bioactive compounds (ascorbic acid and β-carotene). Among the different K salts, KNO_3 consistently resulted in non-significant effects on fruit quality compared to control treatments. Yields were significantly affected by these late-season foliar K treatments only in one year (2007) with unfavorable growing conditions, and potentially due to increased stress tolerance associated with adequate K nutrition. The results demonstrate that carefully-timed foliar K nutrition can improve muskmelon fruit quality by alleviating the apparent K deficiency during fruit development. The data also reveal differences among potential foliar K salts and suggest a reassessment of K management strategies aimed at improving fruit quality.

INTRODUCTION

Potassium (K) is well recognized as the essential plant nutrient with the strongest influence on many quality parameters of fruits and vegetables (Usherwood, 1985). Although K is not a constituent of any functional molecules or plant structures, it is involved in numerous biochemical and physiological processes vital to plant growth, yield and quality (Marschner, 1995). In addition to stomatal regulation of transpiration and photosynthesis, K is also involved in photophosphorylation, photoassimilate transport from source tissues via the phloem to sink tissues, enzyme activation, turgor maintenance, stress tolerance (Usherwood, 1985; Marschner, 1995; Doman and Geiger, 1979) Adequate K nutrition has also been associated with increased yields, fruit size, increased soluble solids and ascorbic acid concentrations, improved

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* This material is based upon work supported in part by the Cooperative State Research, Education, and Extension Service, U.S.D.A. under Agreement No. 2006-34402-17121, “Designing Foods for Health” through the Vegetable & Fruit Improvement Center, Texas A&M Univ. and by the Fluid Fertilizer Foundation, The International Plant Nutrition Institute (IPNI), Tessenderlo Kerley, Inc, and Rotem BKG LLC.

fruit color, increased shelf life and shipping quality of many horticultural crops (Lester et al., 2005, 2006; Geraldson, 1985).

Even though K is abundant in most calcareous soils, the bulk of soil K is unavailable to plants, in part, due to an imbalance between available Ca, Mg and K ions which can lead to K deficiencies through competitive uptake interactions (Brady 1984). Uptake of K from the soil solution also depends on plant factors, including genetics (Rengel et al., 2008). In many species, uptake occurs mainly during the vegetative stages when root growth is not inhibited by carbohydrate availability. Competition for photoassimilates between developing fruits and vegetative organs during reproductive growth stages can limit root growth/activity and K uptake. Increasing soil K fertilization may not be enough to alleviate this developmentally-induced deficiency partly because of reduced root growth/activity during reproductive development and also because of competition from other cations for binding sites on roots (Marschner, 1995). Previous greenhouse studies have shown that supplementing soil K supply with foliar K applications during the fruit development period can improve fruit quality and that differences may exist among K compounds for foliar feeding (Lester et al., 2005, 2006). The objectives of this multiyear field study were to determine whether mid-to-late season foliar K applications during the fruit development and maturation stages can ameliorate the developmentally-induced K deficiency thereby improving muskmelon fruit quality, and to determine whether differences exist among potential K salts for foliar feeding.

MATERIALS AND METHODS

This study was conducted during the Spring growing seasons (February-May) of 2005, 2006 and 2007 in fields near Weslaco, TX (annual rainfall ~ 22 inches). Soils are predominantly calcareous (Table 1). Soil type at the study fields is a Hidalgo sandy clay loam soil. In each study year, netted, muskmelon (*Cucumis melo* L. var 'Cruiser') was planted in early spring (February-March) following standard commercial practices for spring muskmelon production including irrigation, nutrient management, and pest control were followed. Pre-season soil analyses of the top 30 cm layers were performed prior to planting (Table 1). Plants were fertilized at the two-leaf stage with liquid N (50 $kgN\cdot ha^{-1}$; Urea ammonium nitrate, 32% N) and P (20 $kgP\cdot ha^{-1}$) fertilizers and again at the vine elongation stage (50 $kgN\cdot ha^{-1}$, plus micro nutrients). No additional soil K was added since pre-plant soil analyses indicated high K levels (>500ppm).

Foliar K treatments were applied weekly, starting at fruit set, and continuing till fruit maturation. The treatments were: control (no K, de-ionized water), potassium chloride (KCl), potassium nitrate (KNO_3), potassium sulfate (K_2SO_4), and a glycine amino acid-complexed K (Potassium Metalosate™, KM, 20% K; Albion Laboratories, Inc, Clearfield, Utah). In 2006 and 2007, two additional K sources were included, namely, monopotassium phosphate (PeaK™, 24% K, Rotem BKG LLC, Ft Lee, NJ), and potassium thiosulfate (KTS™ , 20% K, Tessenderlo Kerley Inc., Phoenix, AZ). A non-ionic surfactant (Silwet L-77; Helena Chem. Co., Collierville, TN) was added to all treatment solutions at 0.3% (v/v). Proprietary fertilizer K sources were formulated according to manufacturer recommendations. Treatment solutions, except the control, were formulated to supply the equivalent of 3.7 $kgK\cdot ha^{-1}$ during each foliar application in 378 $L\cdot ha^{-1}$ spray volume. All treatments were applied between 0500 and 0800 HR on each spray event using a tractor-mounted spray boom with multiple, calibrated spray heads and a multi-unit spray control system.

Matured (full slip), marketable fruits from each plot were harvested, weighed and classified by size as small (≤ 1kg), medium (1-2 kg) or large (≥ 2.0kg). In order to minimize variability in fruit quality parameters, fruits were further graded on the basis of maturity/harvest date and size before processing and analysis. For brevity, only data from fruits collected during early harvests ('crown-set' fruit which is set near the base of the plant) are included in this report. After firmness and soluble solids determinations, fruit middle-mesocarp tissue samples were freeze-dried and used for dry matter, K, sugars, ascorbic acid, and beta-carotene analyses following the procedures of by Lester et al. (2005, 2006).

RESULTS AND DISCUSSION

Foliar K applications significantly increased tissue (leaf, stem, petiole) K contents ($P < 0.001$; Table 2) compared to the control treatment, suggesting that plant K uptake from this calcareous soil was not sufficient to satisfy plant K requirements and that the K supplying power of this soil may be low even though pre-plant soil K content was high. The low K supplying capacity of this soil is further indicated by the high pH and high Ca and Mg concentrations (Table 1) since these conditions are known to suppress crop K uptake, presumably, through competitive and antagonistic uptake mechanisms (Marschner, 1995; Brady 1984).

Among the K salts evaluated, KNO_3 tended to have only non-significant increases in tissue K. Foliar fertilization with KNO_3 during the fruit development stages significantly increased leaf and petiole N concentrations but reduced Mg concentrations in petioles and stems probably due to a dilution effect resulting from N stimulation of vegetative growth at the expense of roots and fruits. Fruit sugar contents (Table 2) and phytochemical compounds (ascorbic acid and beta-carotene; Table 2) responded positively to foliar K applications in two of the three study years. The relatively low sugar contents in 2007 were likely due to reduced leaf CO_2 assimilation rates resulting from frequent cloudy weather conditions in that year. These weather conditions delayed canopy development, and fruit set leading to a reduction in the fruit development and maturation period. Although fruit quality enhancements were generally higher with organic K sources, differences among K salts were not always significant except for KNO_3 whose effects were nearly always statistically similar to those of control fruit.

Fruit firmness, a good indicator of shipping quality, texture and shelf life of many horticultural produce (Harker et. al., 1997), was also increased by foliar K feeding (Table 3). This may be related to increased fruit tissue pressure potential (Lester et al., 2006) as well as enhanced phloem transport of Ca to fruits following K applications.

Fruit yields ranged from 16,000 to 25,000 lbs/ac and were generally highest in 2006 than in 2005 or 2007 (Table 4). Even though foliar K-treated plots had slightly higher yields in all three study years, significant yield increases were recorded only in 2007 and with one K salt. Significantly more non-marketable fruits (culls) were harvested from KNO_3-treated plots than from plots treated with the other K-salts. Fruit yields from KNO_3-treated plots were also slightly lower than those from plots treated with the other K-salts. Given the high K_{ex} of this soil, perhaps these non-significant responses are not surprising. Hartz et al. (2005) found that K fertigation (supplemental K injected into the irrigation water) increased tomato fruit yields even when K_{ex} was high, but found no effect of foliar K applications on yield and quality. In another study, Hartz et al. (2001) also found no tomato yield or quality responses to foliar K fertilization, even though K fertigation increased fruit yields in instances where $K_{ex} < 0.35$ cmol·kg^{-1}. Yield responses to foliar K applications in agronomic crops such as cotton are also inconsistent (Oosterhuis et al., 1994) perhaps due to confounding effects from factors related to soil processes and climatic conditions. A plausible mechanism for the yield increase in 2007, following foliar K treatments, is increased stress tolerance resulting from adequate K status. Ascorbic acid and beta-carotene (both of which were increased by foliar K applications) are antioxidants capable of protecting plants and humans from the damaging effects of oxidative stress during unfavorable environmental growth conditions such as those encountered during the 2007 season.

Salt crystallization and injury (leaf 'burn') symptoms were not observed with any of the treatments, in part, because all treatments were applied between 0500 and 0800 when high air relative humidities, (>80%), low air temperatures (<25°C) and low wind speeds (<1mph) prevailed. Several studies have shown that such effects are common when compounds such as KCl with high salt indices (approx. 120; Mortvedt, 2001) and relatively high point of deliquescence (POD, 86%; 58 Schönherr and Luber, 2001) are used, and this is more pronounced when applied under conditions of high temperature and/or low humidity. These observations indicate that the experimental conditions (solution concentrations and timing) during foliar K applications in this study were adequate for minimizing residue formation and salt injury. The consistent lack of significant differences between controls and KNO_3-treated plots indicates that this source of K may not be suitable for late-season foliar nutrition because of its N component. Although N is the mineral nutrient required in the greatest quantity by plants, and productivity is strongly correlated with N nutrition, excessive N availability is known to stimulate vegetative growth (shoots and leaves), and reduce fruit quality. Given that K is the quality nutrient, and that calcareous soils have a low K supply capacity, the current results also call for a reassessment of nutrient management strategies to improve the quality of crops grown on such soils.

ACKNOWLEDGEMENTS

This material is based upon work supported in part by the Cooperative State Research, Education, and Extension Service, U.S.D.A. under Agreement No. 2006-34402-17121, "Designing Foods for Health" through the Vegetable & Fruit Improvement Center, Texas A&M University. Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the authors and/or their affiliations.

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Table 1: Pre-plant soil chemical properties during each growing season. Phosphorus (P), potassium (K), and calcium (Ca), were extracted using the Mehlich III procedure (Mehlich, 1984), while nitrate-nitrogen (NO_3-N) was determined by the reduction method (Keeney and Nelson, 1982).

Year	pH	NO_3-N	K	P	Ca	Mg	[z]Potassium activity ratios	
				mg·kg^{-1}			$\frac{[K^+]}{\sqrt{[Ca^{2+}]+[Mg^{2+}]}}$	$\frac{[K^+]}{\sqrt{[Mg^{2+}]}}$
2005	8.2a	29.3a	664.7a	55.2a	7307.0a	442.0a	0.27a	0.90a
2006	8.3a	23.0a	612.0a	53.7a	7677.5a	390.5a	0.24a	0.87a
2007	8.4a	24.9a	572.7a	51.5a	8069.0a	430.2a	0.22a	0.79a

[z] based on cmol.kg^{-1}.

Table 2. Tissue potassium (K) concentrations, fruit soluble solids concentrations (Brix) and sugars of field-grown muskmelons ('Cruiser') determined at fruit maturity following weekly foliar applications of K during the fruit development period using various salts.

Treatment (K salt)	Petiole K	Fruit K	Fruit Brix	Total Sugars
	(mg·gdw^{-1})		(%)	(mg·gfw^{-1})
2005				
Control	32.5 c[z]	22.0 d	8.2 c	47.2 c
Potassium chloride	40.2 b	26.0 bc	10.5 ab	59.3 ab
Potassium nitrate	41.7 ab	24.3 cd	8.9 bc	50.5 bc
Potassium sulfate	42.2 ab	25.6 a	11.2 a	59.1 ab
Potassium Metalosate	47.1 a	25.6 ab	10.1 ab	62.1 a
2006				
Control	48.2 d	26.2 b	9.0 c	53.2 d
Potassium chloride	55.0 bc	33.5 a	10.3 ab	61.4 bcd
Potassium nitrate	47.5 d	29.2 ab	9.1 bc	54.7 cd
Monopotassium phosphate	51.6 cd	33.9 a	10.3 ab	67.3 abc
Potassium sulfate	50.2 d	31.4 a	10.6 a	72.5 ab
Potassium thiosulfate	64.2 a	32.4 a	11.2 a	69.1 ab
Potassium metalosate	57.8 b	34.0 a	10.6 a	76.3 a
2007				
Control	55.1 b	21.9 c	8.0 c	36.7 a
Potassium chloride	63.3 ab	24.1 bc	9.8 ab	44.5 a
Potassium nitrate	55.3 b	22.9 bc	8.5 bc	39.9 a
Monopotassium phosphate	61.3 ab	24.6 bc	10.0 a	44.3 a
Potassium sulfate	59.7 ab	25.6 b	9.7 ab	45.0 a
Potassium thiosulfate	73.8 a	29.2 a	10.1 a	43.8 a
Potassium metalosate	66.5 ab	25.6 b	9.4 abc	44.7 a

[z] Means within a column and within a year followed by the same letter are not significantly different using the Ryan-Einot-Gabriel-Welsch multiple-range test.

Table 3. Effects of weekly foliar potassium (K) applications using various K salts on fruit mesocarp total ascorbic acid (TAA) concentrations, beta-carotene concentrations, internal color and firmness of field-grown muskmelon (‘Cruiser’).

Treatment (K salt)	TAA (mg·100gfw^{-1})	Beta-carotene (µg·gfw^{-1})	Fruit color (h°)	Fruit firmness N
2005				
Control	30.3c [z]	14.2 b	72.8 a	12.7 b
Potassium chloride	33.2abc	18.8 a	71.8 ab	17.1 a
Potassium nitrate	31.6bc	16.7 ab	71.9 ab	14.5 ab
Potassium sulfate	35.5a	18.1 a	71.3 b	15.4 ab
Potassium Metalosate	34.5ab	18.0 a	71.2 b	16.2 a
2006				
Control	19.3 c	18.3 b	72.7 a	10.6 b
Potassium chloride	22.8 a	21.1 ab	72.2 ab	11.8 ab
Potassium nitrate	20.0 bc	18.0 b	72.4 ab	10.1 b
Monopotassium phosphate	21.4 abc	21.3 ab	72.0 ab	13.7 a
Potassium sulfate	22.1 ab	19.8 ab	72.1 ab	11.9 ab
Potassium thiosulfate	22.4 ab	21.1 ab	71.3 b	13.2 a
Potassium Metalosate	23.7 a	23.9 a	71.7ba	12.7 a
2007				
Control	15.7 a	10.3 b	73.0 a	8.5 b
Potassium chloride	16.7 a	11.1 ab	71.9 abc	10.3 ab
Potassium nitrate	16.9 a	10.8 ab	72.8 ab	8.7 b
Monopotassium phosphate	17.1 a	11.5 ab	71.6 c	11.0 a
Potassium sulfate	18.1 a	10.9 ab	72.2 abc	10.6 ab
Potassium thiosulfate	18.6 a	11.6 ab	72.3 abc	11.2 a
Potassium Metalosate	18.4 a	13.0 a	71.9 bc	11.3 a

[z] Means within a column and within a year followed by the same letter are not significantly different using the Ryan-Einot-Gabriel-Welsch multiple-range test.

Table 4. Effects of weekly foliar potassium (K) applications during the fruit development period using various K salts on yield and fruit numbers (by size class) of field-grown muskmelon ('Cruiser'). Sizes were: small (≤ 14 cm diam. or ≤ 1kg), medium (15-16 cm diam. or 1-2 kg) or large (≥ 17 cm diam. or ≥ 2.0kg).

Treatment (K salt)	Yield lbs/ac	Small	Medium (x 1000·ha^{-1})	Large	Culls lbs/ac
2005					
Control	17096 a[z]	3.4 a	4.1 a	1.4 a	2491 b
Potassium chloride	18700 a	2.4 a	4.5 a	2.5 a	1432 b
Potassium nitrate	16793 a	3.3 a	4.0 a	1.9 a	6063 a
Potassium sulfate	20581 a	3.0 a	5.6 a	3.1 a	1382 b
Potassium Metalosate	20394 a	1.9 a	6.2 a	2.1 a	1602 b
2006					
Control	21641 a	3.2 a	4.6 a	1.7 a	1780 b
Potassium chloride	22968 a	2.7 a	5.2 a	2.9 a	1194 b
Potassium nitrate	20330 a	3.6 a	4.8 a	1.5 a	3236 a
Monopotassium phosphate	21903 a	2.5 a	6.5 a	2.5 a	1529 b
Potassium sulfate	24775 a	2.8 a	5.9 a	3.0 a	1158 b
Potassium thiosulfate	25635 a	2.8 a	7.0 a	2.6 a	1691 b
Potassium Metalosate	23655 a	2.6 a	6.1 a	2.9 a	1594 b
2007					
Control	18054 b	6.2 a	2.7 a	1.4 a	2373 b
Potassium chloride	20049 ab	5.5 a	4.0 a	2.0 a	1593 b
Potassium nitrate	17920 b	6.1 a	2.6 a	1.6 a	4315 a
Monopotassium phosphate	20989 ab	4.6 a	3.3 a	2.1 a	2039 b
Potassium sulfate	20475 ab	5.2 a	2.4 a	2.4 a	1544 b
Potassium thiosulfate	22719 a	5.4 a	2.5 a	1.9 a	2255 b
Potassium Metalosate	20668 ab	5.1 a	3.3 a	2.1 a	2126 b

[z] Means within a column and within a year followed by the same letter are not significantly different using the Ryan-Einot-Gabriel-Welsch multiple-range test.