Sweet Onion (*Allium cepa*) Plant Growth and Bulb Yield and Quality as Affected by Potassium and Sulfur Fertilization Rates

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Abstract. ‘Vidalia’ onions are sweet, short day, low pungency, yellow Granex-type bulbs that are popular in the United States. The relationships of sweet onion bulb yield and quality with potassium (K) and sulfur (S) concentrations are not fully understood. The objective of this study was to evaluate the effects of K and S fertilization rates on sweet onion plant growth and bulb yield and quality. Experiments were conducted at the Horticulture Farm, Tifton Campus, University of Georgia, in the Winters of 2012–13 and 2013–14. The experiment had five treatments (K/S rates: 56/80, 112/126, 168/172, 224/218, and 280/264 kg-ha⁻¹ of K and S, respectively). K/S rates had no effect on onion biomass of roots, bulbs, and shoots during the growing season. Marketable and total number and weight of onion bulbs and individual bulb weight were also unaffected by K/S rate. Incidences of bolting, double bulbs, Botrytis leaf blight (*Botrytis cinerea*), and sour skin (*Burkholderia cepacia*), and bulb dry weight, soluble solids content (SSC), and pungency (pyruvate concentration) were unaffected by K/S rates. In conclusion, K/S rates had little effect on plant growth and bulb yield and quality. The lack of response of onion plants to K/S rates, even at the lowest rate suggests that some of the K absorbed by plants originated from K already present in the soil before planting. The average K content of sweet onion whole plants was 80 kg-ha⁻¹ K. Thus, under our experimental conditions, application of K rates above the recommended value (84 kg-ha⁻¹ K) are unnecessary and will likely not improve plant growth, yield, or quality. Regarding S, rates higher than 80 kg-ha⁻¹ S are probably unnecessary and will not enhance either plant growth or bulb yield or quality of sweet onion.

‘Vidalia’ onions are sweet, short day, low pungency, yellow Granex-type bulbs that are popular in the United States because of their mild flavor (Boyhan and Torrance, 2002). ‘Vidalia’ onions are exclusively grown in southeastern Georgia, United States, in a region that includes at least parts of 20 counties, where there are mild winters and low-S soils

(<0.001 mg-L⁻¹). High concentrations of S in the soil or large rates of S fertilizer may result in increased onion pungency (Randle and Bussard, 1993).

After nitrogen, K is the nutrient required in largest amounts by plants (Marschner, 2012). Potassium participates in various plant physiological processes associated with carbohydrate metabolism, such as photosynthesis, water relations, enzyme activation, and transport of assimilates. Potassium uptake is selective and dependent on metabolic activity.

Potassium is taken up by the plant from the soil solution in ionic form K⁺. It is very mobile within the plant and its cytosolic concentration is 100–200 mM (Walters and Bingham, 2007).

Potassium-deficient plants show reduced growth and limited photosynthesis, and, under severe deficiency, can present chlorosis. Fruits and tubers have a high K requirement and may develop physiological disorders when they are deficient in K. In

a study in Vidalia, GA, K fertilizer rates from 0 to 177 kg-ha⁻¹ K₂O were applied to sweet onion; yields showed a quadratic response with the highest yield at 84 kg-ha⁻¹ K₂O (70 kg-ha⁻¹ K) (Boyhan et al., 2007).

High sweetness and low pungency are desirable characteristics in ‘Vidalia’ onions with S implicated in higher pungency. Sulfur is taken up by the plant from the soil solution in ionic form SO₄²⁻. Onion S concentration in plant shoots midway to maturity has a sufficiency range that varies from 0.5% to 1.0% (Bryson and Mills, 1996). Onion bulbs may have increased pungency when grown in soils with high S content. Onion pungency, however, is not consistently influenced by S nutrition (Coolong and Randle, 2003; Hamilton et al., 1998; Lee et al., 2009; Randle and Bussard, 1993). Thus, the relationships of sweet onion yield and quality as a function of K and S concentrations are not fully understood. Average S concentration in plant shoot dry matter sufficient for adequate growth is 1 g·kg⁻¹. The objective of this study was to evaluate the effects of K and S rates on sweet onion plant growth and bulb yield and quality.

Materials and Methods

Land preparation and planting. Experiments were conducted at the Horticulture Farm, Tifton Campus, University of Georgia, in the Winter of 2012–13 and 2013–14. The farm is located at an altitude of 108 m above mean sea level, lat. 31°28′ N and long. 83°31′ W. The soil is a Tifton sandy loam (a fine loamy-siliceous, thermic Plinthic Kandudults) with pH 6.5. Plants were grown on raised beds (1.8 m from center to center of each bed). Each bed had four rows 23 cm apart, with a plant spacing of 15 cm. Beds were covered with black plastic film mulch and there were two lines of drip tape per bed, each drip tape being located midway between alternate rows. The drip tape (Ro-Drip; Roberts Irrigation Products Inc., San Marcos, CA) had 10-cm emitter spacing, 0.50 L·h⁻¹ emitter flow at 5631 kg·m⁻² pressure, 0.2 mm wall thickness, and was buried 3 cm deep.

Before transplanting, all treatments received 67 kg-ha⁻¹ N, 29 kg-ha⁻¹ P, 56 kg-ha⁻¹ K, and 80 kg-ha⁻¹ S from 10–10–10 fertilizer [10N–4.4P–8.3K (Agrium Super Rainbow, Denver, CO)]. Before preplanting fertilization, K concentration in the soil was low to medium (88 and 90 kg-ha⁻¹ K in 2012–13 and 2013–14, respectively). Onion seedlings ‘Yellow Granex PRR’ were grown at the Vidalia Onion and Vegetable Research Center, University of Georgia, Lyons, GA. Onion seedlings were transplanted on 12 Dec. 2012 and 2013.

Experimental design and treatments. Experimental design was a randomized complete block with six replications and five treatments (K/S levels); experimental plot consisted of a 6.1-m long bed. Starting 8 weeks after transplanting, N (as 28–0–0 kg-ha⁻¹), and K and S [as 0–0–21K + 17S kg-ha⁻¹ (potassium thiosulfate)] were applied through the drip tape. Total N applied was 169 kg-ha⁻¹. Levels

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of total K/S were 56/80, 112/126, 168/172, 224/218, and 280/264 kg·ha⁻¹ of K and S, respectively. The K/S ratio among treatments varied from 0.7 to 1.1. This change was a consequence of the difference in concentration of K and S in the potassium thiosulfate fertilizer (0N-0P-21K + 17S) applied after transplanting.

Plant growth. Shoot, root, and bulb dry weight were measured weekly during the entire season on two plants per plot. Plant samples were dried at 70 °C for several days until constant weight was obtained.

Plant mineral nutrients. Immediately after harvest, three bulbs per plot were dried at 70 °C for 3 d, ground, and analyzed for mineral nutrient concentration at the University of Georgia Agricultural and Environmental Services Laboratories, Athens, GA. Shoots of mature plants (only one sample of 10 shoots per treatment) were also analyzed for mineral nutrients.

Plant diseases and disorders. Incidences of bolting (flower stems), double bulbs, botrytis leaf blight (*B. cinerea*), and sour skin (*B. cepacia*) were determined as percentage of plants with the symptoms.

Weather. Weather data (air temperature and rainfall) were obtained from a nearby University of Georgia weather station (within 300 m).

Harvest. Plants were harvested, when 20% of the necks had collapsed (tops down), on 13 May 2013 and 12 May 2014. Onions were hand harvested and roots and tops were clipped; bulbs were left in the field for 48-h curing.

Bulb quality. After field curing, bulbs were graded by size and appearance as marketable or unmarketable (USDA, 1995), counted, and weighed. After grading, a subsample of 10 marketable bulbs per replication was used for determination of bulb dry weight percentage, SSC, and pungency. Ten wedges from each bulb group were juiced in a pneumatic press. Several drops of the juice were applied to a handheld refractometer (Kernco, Tokyo, Japan) to measure SSC. Pungency was measured using four bulbs. A 20-μL juice sample was obtained from each bulb; pyruvic acid concentration is used routinely to measure onion flavor intensity (Lancaster and Boland, 1990).

Statistical analysis. Data were analyzed using the general linear model and regression procedures from SAS (SAS version 9.4; SAS Inst. Inc., Cary, NC). Data from both years were pooled if no year × treatment interactions were found.

Results

Weather. In 2012–13, average maximum, mean, and minimum temperatures were 19.0, 13.6, and 8.2 °C, respectively, and cumulative rainfall was 807 mm. In 2013–14, average maximum, mean, and minimum temperatures were 18.6, 13.0, and 7.3 °C, respectively, and cumulative rainfall was 671 mm.

Plant growth. K/S rates had no effect on onion biomass of roots, bulbs, and shoots during the growing season or in mature plants in 2012–13 (Table 1). The K/S rates also had no impact on root-to-shoot ratio during the

season (mean = 0.127) or in mature plants (mean = 0.100).

Growth of roots, bulbs, and shoots, however, was influenced by air temperature. There was minimal plant growth before week 16. Mean air temperature in week 16 was 15.6 °C. After week 16, plant growth increased with increasing mean air temperatures as season progressed (data not shown).

Plant mineral nutrients. Onion bulb K concentration increased with increasing K/S fertilization rates ($P = 0.0003$), ranging from 1.09% to 1.40% of bulb dry weight (Table 2). Calcium concentration tended to decrease ($P = 0.057$) with increasing K/S rates. Sulfur and the rest of the bulb mineral nutrients were unaffected by K/S fertilization rates.

Foliar K and S concentrations of mature onion plants showed means of 2.11% (K) and 0.36% (S). Thus, sweet onion absorption of K was bulb (mean = 41 kg·ha⁻¹), shoot (mean = 38.4 kg·ha⁻¹), and whole plant (mean = 80 kg·ha⁻¹). Sulfur absorption in this study was bulb (mean = 16 kg·ha⁻¹), shoot (mean = 7 kg·ha⁻¹), and whole plant (mean = 23 kg·ha⁻¹). Sulfur requirement for optimal growth varies between 0.1% and 0.5% of plant dry weight, depending on the species (Marschner, 2012).

Bulb yields. Marketable and total number and weight of onion bulbs and individual bulb weight were unaffected by K/S rate (Table 3). Bulb yields and individual bulb weight were higher in 2014 than in 2013. There were no K/S × year interactions for yields or individual bulb weight.

Plant disorders and diseases. Levels of K/S had little effect on onion bulb diseases and disorders (Table 4). There were, however, differences in incidences of bulb diseases and disorders among years. Incidences of bolting, Botrytis rot, and sour skin were increased in 2014. Increased incidences of bulb diseases were likely not related to high rainfall since precipitation was higher in 2012–13 (807 mm) than in 2013–14 (671 mm). However, overall there were low incidences of bulb disease across treatments.

Postharvest bulb quality immediately after harvest. Levels of K/S had minor effects on onion bulb quality. Bulb dry weight, SSC, and pyruvate concentration were not influenced by K/S levels. Bulb dry weight and SSC, however, were decreased in 2014. There were no K/S × year interactions for bulb quality attributes.

Postharvest bulb quality after storage. There were no effects of K/S rates on

Table 1. Biomass of roots, bulbs, and shoots of sweet onion as influenced by K/S fertilization rates, Tifton, GA, Winter 2012–13.

Treatment	Dry wt (g/plant)					
	Seasonal ^z			Mature plant ^y		
	Root	Bulb	Shoot	Root	Bulb	Shoot
K/S (kg·ha ⁻¹) ^x						
56/80	0.84	6.12	6.61	1.44	25.43	13.45
112/126	0.60	4.10	5.06	0.97	18.97	11.59
168/172	0.87	5.35	6.99	1.72	24.31	14.53
224/218	0.79	5.51	6.19	1.19	26.04	13.28
280/264	0.82	5.70	5.92	1.02	20.91	10.57
Significance						
L	0.508	0.837	0.898	0.399	0.842	0.497
Q	0.477	0.319	0.954	0.514	0.978	0.564

K/S = potassium and sulfur; L = linear; Q = quadratic response.

^zTwo plants per plot were sampled weekly during the entire season.

^y9 May 2013 (3 d before harvest).

^xK/S = rate (kg·ha⁻¹) of K and S applied as potassium thiosulfate.

Table 2. Mineral nutrient concentration in mature sweet onion bulbs as influenced by K/S fertilization rates, Tifton, GA, Winter 2013 and 2014.

K/S (kg·ha ⁻¹) ^z	N	P	K	Ca	Mg	S	B	Fe	Cu	Mn	Zn
	----- (%) -----						----- (mg·kg ⁻¹) -----				
56/80	2.01	0.31	1.09	0.26	0.102	0.442	17.3	40.7	3.62	129	56.6
112/126	1.80	0.28	1.20	0.27	0.103	0.490	15.9	43.8	3.40	145	60.8
168/172	2.06	0.31	1.17	0.26	0.100	0.468	17.4	31.6	3.37	143	57.9
224/218	2.05	0.30	1.35	0.23	0.098	0.490	16.9	43.3	3.63	137	61.9
280/264	2.06	0.30	1.40	0.23	0.097	0.490	16.7	40.4	3.85	153	65.4
Significance											
L	0.273	0.937	0.0003	0.057	0.343	0.175	0.932	0.948	0.445	0.283	0.171
Q	0.501	0.920	0.002	0.159	0.621	0.331	0.993	0.851	0.404	0.566	0.376

K/S = potassium and sulfur; L = linear; Q = quadratic response.

^zK/S = rate (kg·ha⁻¹) of K and S applied as potassium thiosulfate.

Table 3. Sweet onion yields and bulb weight as influenced by K/S fertilization rates, Tifton, GA, Winter 2013 and 2014.

Treatment	Marketable		Total		Bulb wt (g)
	1,000/ha	t·ha ⁻¹	1,000/ha	t·ha ⁻¹	
K/S (kg·ha ⁻¹) ²					
56/80	104	29	153	39	281
112/126	97	28	152	42	295
168/172	102	31	149	42	310
224/218	97	29	154	42	304
280/264	92	28	147	40	301
Significance					
L	0.114	0.695	0.372	0.778	0.330
Q	0.690	0.390	0.759	0.363	0.374
Year (Y)					
2013	101	27	143	32	263
2014	95	31	159	50	333
P	0.113	0.004	<0.0001	<0.0001	<0.0001
Interaction					
K/S × Y	0.997	0.843	0.373	0.206	0.281

K/S = potassium and sulfur; L = linear; Q = quadratic response.

²K/S = rate (kg·ha⁻¹) of K and S applied as potassium thiosulfate.

Table 4. Disorders, diseases, and quality attributes of sweet onion bulbs as influenced by K/S fertilization rates, Tifton, GA, Winter 2013 and 2014.

Treatment	Bolting (%)	Doubles (%)	Botrytis rot (%)	Sour skin (%)	Bulb dry wt (%)	SSC (%)	Pyruvate (mm)
K/S (kg·ha ⁻¹) ²							
56/80	6.0	1.0	6.0	7.2	8.7	7.5	2.80
112/126	5.4	1.5	5.4	11.7	8.8	7.4	2.42
168/172	4.8	1.3	4.8	10.3	8.7	7.5	3.00
224/218	5.2	0.7	5.2	13.4	8.9	7.9	3.26
280/264	4.8	1.1	4.8	12.1	9.2	7.5	2.66
Significance							
L	0.442	0.562	0.113	0.339	0.550	0.322	0.499
Q	0.748	0.529	0.625	0.605	0.735	0.678	0.457
Year (Y)							
2013	3.6	1.0	0.3	2.0	10.4	7.9	n.d.
2014	6.9	1.2	1.6	19.9	7.7	6.8	2.83
P	0.0008	0.457	<0.0001	<0.0001	<0.0001	0.018	n.d.
Interaction							
K × Y	0.682	0.785	0.513	0.565	0.211	0.234	n.d.

K/S = potassium and sulfur; L = linear; Q = quadratic response; SSV = soluble solids content; n.d. = not determined.

²K/S = rate (kg·ha⁻¹) of K and S applied as potassium thiosulfate.

percentage of bulb dry weight, SSC, and pungency (data not shown). Percentage of bulb dry weight was lower ($P = 0.017$) immediately after harvest (7.73%) than after 3-month storage (8.41%). SSC was higher ($P < 0.0001$) immediately after harvest (6.83%) than after 3-month storage (6.10%). Bulb SSC increased with increasing bulb dry weight ($R^2 = 0.566$; $P < 0.0001$). Pungency was lower ($P < 0.0001$) immediately after harvest (2.83 mm pyruvate equivalent) than after 3-month storage (3.70 mm pyruvate equivalent). There were no K/S vs. storage and K/S vs. year interactions for bulb disorders, diseases, or bulb quality attributes.

Discussion

Potassium effects. Potassium is related with transport of water, nutrients, and carbohydrates in plants. Potassium helps to maintain both water movement within the plant and cell turgor pressure, and controls stomatal function (Bryson and Mills, 1996). In monocotyledonous species, such as onion, advanced K deficiency is manifested by

chlorotic and necrotic symptoms as small stripes along the leaf margins. These symptoms, however, were not shown by onion plants in this study.

Crops and cultivars differ in their ability for K uptake and use (Rengel and Damon, 2008). Potassium concentration in plant organs may rise by increasing K supply to roots. Potassium concentration in midseason plant shoots of sweet onion varies from 3.5% to 5.5% at sufficiency range (Bryson and Mills, 1996). Excess accumulation of K in plant tissues is known as “luxury consumption” and occurs when K supply is plentiful (Marschner, 2012). Bulb K concentration in our study increased with K/S fertilization rate indicating occurrence of luxury consumption. This excessive K accumulation does not influence yield but increases crop production costs (Bryson and Mills, 1996). High K accumulation in plant tissues, however, may induce Mg and Ca deficiencies because of imbalances in the K/Mg and K/Ca ratios (Bryson and Mills, 1996). Effects of K deficiency include growth retardation and yield reduction (Barker and Pilbeam, 2007).

Typical sweet onion fertilization in Georgia includes a complete fertilizer, which contains some micronutrients (Boyhan et al., 2007). In our study, no 0 kg·ha⁻¹ K/S treatment was used because it was considered insufficient for plant growth since the soil of the experimental area has a low fertility and low cation exchange capacity, with typically low to medium K and S levels. As a lowest K/S treatment, 56 kg·ha⁻¹ K was used with the goal of providing a base concentration of K and other nutrients to allow for plant growth. In a study on ‘Vidalia’ onion, K fertilization rate (from 0 to 177 kg·ha⁻¹ K) yields at 0 and 65 kg·ha⁻¹ K were reduced, with no difference in yield between 0 and 65 kg·ha⁻¹ K, whereas yields at 84 kg·ha⁻¹ K were among the highest (Boyhan et al., 2007).

In this study, K/S rates had little effect on plant growth, yield, and onion bulb quality and bulb diseases. The lowest K/S rate (56 kg·ha⁻¹ K) was sufficient to produce acceptable growth and yields of onion plants. Onion whole plants contained an average of 80 kg·ha⁻¹ K. Thus, it is possible that some of the K absorbed by onion plants came from the K already present in the soil before planting (mean = 89 kg·ha⁻¹ K). The K content in onion whole plants in our study is lower compared with those of dry onion. Dry onion plants have been reported to require 173 kg·ha⁻¹ K, with 123 and 50 kg·ha⁻¹ K being present in the bulbs and tops, respectively (Lorenz and Maynard, 1988).

Potassium is the nutrient with the greatest influence on produce quality. Foliar K application increases foliar K concentration, fruit sugars, ascorbic acid, and beta-carotene (Jifon and Lester, 2009). In this study, however, rates of K had no effect on onion bulb disorders such as bolting, double bulbs, bulb diseases (Botrytis leaf blight and sour skin), and bulb quality attributes (bulb dry weight, SSC, and pungency). Application of K to deficient soils tends to increase plant resistance to disease by promoting formation of thicker outer cell walls or by enhancing plant vigor (Prabhu et al., 2007). The beneficial effect of K in reducing plant disease is often confined to plants deficient in K (Walters and Bingham, 2007), as found for onions infected with downy mildew (Develash and Sugha, 1977).

Sulfur effects. Sulfur is one of the six essential macronutrients in plants. It is present in the amino acids cysteine and methionine and in several metabolites (Leustek and Saito, 1999). The most important source of S in plants is sulfate (Hawkesford et al., 2012). Allicins are important S-containing compounds of secondary metabolism in onion. They are precursors of compounds responsible of onion pungency (Hawkesford et al., 2012). Sulfur nutrition strongly influences onion pungency; thus, production of sweet onions requires use of a soil with low S content.

Plant growth, and bulb yield and onion bulb quality, as well as bulb S concentration were unaffected by S rates. The effects of S on onion plant growth and yield and bulb quality are inconsistent in the literature. In a field study, S application increased marketable bulb

yield, S uptake, and pungency (pyruvic acid), over no S treatment, although there was no effect on the storage life of onion bulbs (Thangasamy et al., 2013). In another report, S nutrition had no impact on pyruvic acid, dry matter, and total S and sugar content in bulbs of short-day 'Texas Grano 1015Y' onions (Hamilton et al., 1998). One more study shows that SSC, total sugars, pungency (pyruvic acid), and flavor precursor compounds were unaffected by up to 26 kg·ha⁻¹ S in short-day onion cultivars grown in soils with high S content (Lee et al., 2009). Our results do not support previous studies showing increased onion pungency with high S levels in the soil (Hawkesford and De Kok, 2006; Randle and Bussard, 1993). Response of onion to S, however, seems to be cultivar dependent (Randle and Bussard, 1993).

In conclusion, K/S rates (from 56 kg·ha⁻¹ K and 80 kg·ha⁻¹ S to 280 kg·ha⁻¹ K and 264 kg·ha⁻¹ S) had little effect on sweet onion plant growth, bulb yield, and quality. The lack of response of onion plants to K/S rates, even at the lowest rate suggests that some of the K absorbed by plants originated from K already present in the soil before planting. The average K content of sweet onion whole plants was 80 kg·ha⁻¹ K. Thus, our results agree with previous reports indicating that the optimal recommendation for 'Vidalia' onions is 84 kg·ha⁻¹ K (Boyhan et al., 2007). Under our experimental conditions, application of K rates above the recommended value is unnecessary and will likely not improve plant growth, or bulb yield and quality. Regarding S, rates higher than 80 kg·ha⁻¹ S are probably unnecessary and will

not enhance either plant growth or bulb yield or quality.

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