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

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Additional index words. mineral nutrients, potassium thiosulfate, postharvest, Vidalia onion, plastic mulch, drip irrigation

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 a region that includes at least parts of 20 counties, where there are mild winters and low-S soils

Received for publication 2 Aug. 2016. Accepted for publication 18 Oct. 2016.

Financial support was provided by the Vidalia Onion Committee and the Georgia Agricultural Experiment Stations.

Our sincere gratitude to Nélida Bautista and Alberto Alvarado Chávez for their invaluable technical support. We appreciate the thorough review of the manuscript by George Boyhan and Tim Coolong, and by the anonymous reviewers. Mention of trade names in this publication does not imply endorsement by the University of Georgia of products named, nor criticism of similar ones not mentioned.

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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 on 13 May 2013 and 12 May 2014. Onions 20% of the necks had collapsed (tops down), on 13 May 2013 and 12 May 2014. Onions

**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).

**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.

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

| Treatment | Root (g/plant) | Seasonal | Mature plant | Significance |
|-----------|----------------|----------|--------------|--------------|
| K/S (kg·ha⁻¹)³ | Root | Bulk | Shoot | Root | Bulk | Shoot | L | Q |
| 56/80 | 0.84 | 6.12 | 6.61 | 1.44 | 25.43 | 13.45 | 0.508 | 0.837 |
| 112/126 | 0.60 | 4.10 | 5.06 | 0.97 | 18.97 | 11.59 | 0.477 | 0.319 |
| 168/172 | 0.87 | 5.35 | 6.99 | 1.72 | 24.31 | 14.53 | 0.79 | 5.71 |
| 224/218 | 0.79 | 5.10 | 6.19 | 1.19 | 26.04 | 13.28 | 0.82 | 5.70 |
| 280/264 | 0.82 | 5.70 | 5.92 | 1.02 | 20.91 | 10.57 | 0.50 | 0.95 |

**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)³ | N | P | K | Ca | Mg | S | B | Fe | Cu | Mn | Zn |
|----------------|---|---|---|----|----|---|---|----|----|----|----|
| 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 |

**Conclusion**

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

| Treatment | Marketable 1,000/ha | Marketable t ha⁻¹ | Total 1,000/ha | Total t ha⁻¹ | Bulb wt (g) |
|-----------|---------------------|-------------------|----------------|---------------|-------------|
| K/S (kg ha⁻¹) | | | | | |
| 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 = 0.014 0.695 0.372 0.778 <0.0001 <0.330
Q = 0.690 0.390 0.759 0.363 0.374
Year (Y) 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.

'K/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 (ms) |
|-----------|-------------|-------------|-----------------|--------------|----------------|--------|-------------|
| K/S (kg ha⁻¹) | | | | | | | |
| 56/80 | 6.0 | 1.0 | 6.0 | 7.2 | 8.7 | 7.5 | 2.8 |
| 112/126 | 4.8 | 1.5 | 5.4 | 11.7 | 8.8 | 7.4 | 2.4 |
| 168/172 | 4.8 | 1.3 | 4.8 | 10.3 | 8.7 | 7.5 | 3.0 |
| 224/218 | 5.2 | 0.7 | 5.2 | 13.4 | 8.9 | 7.9 | 3.2 |
| 280/264 | 4.8 | 1.1 | 4.8 | 12.1 | 9.2 | 7.5 | 2.6 |

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) 0.36 | 0.18 | 0.36 0.18 0.36 0.18 0.36 0.18

| Treatment | Pyruvate (ms) | Botrytis rot (%) | Sour skin (%) | Bulb dry wt (%) | SSC (%) | Pyruvate (ms) |
|-----------|--------------|-----------------|--------------|----------------|--------|-------------|
| K/S (kg ha⁻¹) | | | | | | | |
| 112/126 | 0.0008 | 0.457 | <0.0001 | <0.0001 | 0.018 | n.d. |
| 168/172 | 0.0008 | 0.457 | <0.0001 | <0.0001 | 0.018 | n.d. |
| 224/218 | 0.0008 | 0.457 | <0.0001 | <0.0001 | 0.018 | n.d. |
| 280/264 | 0.0008 | 0.457 | <0.0001 | <0.0001 | 0.018 | n.d. |

Significance
K/S × 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.

'K/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 immediately after harvest (2.83 mM pyruvate equivalent) than after 3-month storage (6.10%). Bulb SSC increased with increasing bulb dry weight (R² = 0.566; P < 0.0001). Pungency was lower immediately after harvest (6.83%) than after 3-month storage (6.10%). Bulb SSC increased with increasing bulb dry weight (R² = 0.566; P < 0.0001).

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 to respond to K. The presence of K in plant tissues is known as "luxury consumption" and occurs when K supply is plentiful in the plant and cell turgor pressure, and controls stomatal function (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 midseason plant shoots of sweet onion varies from 3.5% to 5.5% at sufficiency range (Bryson and Mills, 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 for 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 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 (Boylan 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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