Sweet Onion (*Allium cepa* L.) as Influenced by Organic Fertilization Rate: 2. Bulb Yield and Quality before and after Storage

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Abstract. There is a growing interest in organic fertilizers because of increased demand for organic sweet onions and other vegetables. There are, however, limited studies on sweet onion bulb yield and quality in response to organic fertilization. The objective of this study was to evaluate the effects of organic fertilizer rate on sweet onion bulb yield and bulb quality before and after storage. Experiments were conducted at the Horticulture Farm, Tifton Campus, University of Georgia, in the Winters of 2012–13 and 2013–14. There were five organic fertilization treatments (organic fertilizer 3–2–3 equivalent to 0, 60, 120, 180, and 240 kg-ha⁻¹ N). Total and marketable yields and individual bulb weight increased quadratically with increasing organic fertilization rate and responses failed to reach a plateau. The fraction of extra-large bulb increased with increasing organic fertilization rate. Incidence of onion bolting was maximal at 60 kg-ha⁻¹ N and decreased with increasing organic fertilization rate. The percentage of bulb dry weight was highest in the unfertilized control and decreased with increasing organic fertilization rate. Organic fertilization rate had no consistent impact on bulb soluble solids content (SCC) and pungency (measured as pyruvate concentration) in the two seasons. Total antioxidant capacity (measured as gallic acid equivalents) values were among the lowest at 60 and 120 kg-ha⁻¹ N. In conclusion, onion bulb yields increased with increasing organic fertilization rate, whereas incidences of bulb diseases responded differently to N rate. Botrytis rot was the main cause of postharvest bulb decay in all organic fertilization rates.

Production of organic fruits and vegetables has doubled in the last 10 years in response to growing demand (Dorais and Alsanius, 2015; Engelbrecht et al., 2012). Vidalia onions (*Allium cepa* L.) 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-sulfur soils (<0.001 mg-L⁻¹). There is increased interest in utilization of organic fertilizers because of increased demand for organic sweet onions and other vegetables. There is, however, limited information about application rates of organic fertilizers to vegetable crops.

One of the challenges in organic vegetable production is to achieve a timely nutrient release from organic fertilizers (Dorais and Alsanius, 2015). Most of the fertilizer recommendations for vegetable crops were developed for crop production with synthetic chemical fertilizers. With synthetic chemical fertilizers, there is precise and ready nutrient availability. In contrast, soil nutrient release and availability, particularly that of N, is complex and variable with organic fertilizers, which makes current fertilizer recommendations often not applicable to organic production.

The availability of N may differ depending on source of organic fertilizer and environmental conditions. Insufficient soil N availability is frequent in organic vegetable production because of unpredictable N release. Tomato plants in 20% to 40% compost (yard waste or yard waste plus swine manure) were found to have nutrient deficiencies in less than 1 month after planting, whereas plants in 50% compost had no visible nutrient deficiencies and had yields similar to those of tomatoes in a hydroponic system (Zhai et al., 2009). In a study on the rate of N mineralization from organic fertilizers, after 2 weeks between 47% and 60% of organic N had been mineralized, and after 8 weeks between 60% and 66% had been mineralized; temperatures (10 or 25 °C) had minor effects on rate of N mineralization (Hartz and Johnstone, 2006). In another study, a liquid organic fertilizer containing fishery wastes and seabird guano showed rapid nitrification, with >90% of mineral N in nitrate form after 1 week of incubation at 25 °C or 2 weeks at 15 °C (Hartz et al., 2010). In onion, plant growth and numbers of leaves were reduced with organic fertilizers, whereas bulb yields and soluble solids were similar between organic fertilizers and synthetic inorganic fertilizers (Lee, 2010). The objective of this study was to evaluate the effects of organic fertilization rate on sweet onion bulb yield and quality before and after storage. In a companion article, we report on the effects of organic fertilization rate on plant growth and leaf and bulb mineral nutrition of sweet onion (Díaz-Pérez et al., 2018).

Materials and Methods

Land preparation and planting. Experiments were conducted at the Horticulture Farm, Tifton Campus, University of Georgia, in the Winters 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 of the farm is a Tifton Sandy Loam (a fine loamy-siliceous, thermic Plinthic Kandiodults) with organic matter content of 0.5% and a pH of 6.5. Because of the high rainfall and the low organic matter content of Georgia soils as that of this study, there is very low residual N available for the crop (Kissel and Sonon, 2008). The concentration of macronutrients in the soil before planting in 2012 and 2013 were, respectively, P (39 and 35 mg·kg⁻¹), K (35 and 27 mg·kg⁻¹), Ca (511 and 523 mg·kg⁻¹), Mg (90 and 76 mg·kg⁻¹), and S (21 and 18 mg·kg⁻¹).

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 an in-row 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. The

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Fig. 1. Seasonal trends of maximal, mean, and minimal air temperature and rainfall. Tifton, GA, Winters of 2012–13 and 2013–14.

plants were irrigated with ≈ 4 mm per week in one weekly application from transplanting to the period of rapid bulb enlargement (mid-March). From the period of rapid bulb enlargement to bulb harvest, the plants were irrigated with ≈ 12 mm per week in one to two weekly applications. To minimize nitrate leaching, each irrigation was ended when soil water content was at about field capacity. Soil water content (volumetric) in the 0–12 cm of soil profile was measured with a portable time domain reflectometry (TDR) sensor (CS-620; Campbell Scientific, Logan, UT). The two metallic 12-cm rods of the TDR sensor were inserted vertically within the row between two plants.

Before laying the plastic mulch and before transplanting, N treatments were applied to the soil (only to the bed area) as organic fertilizer (microSTART60 3–2–3; Perdue AgriRecycle, LLC, Seaford, DE). No additional fertilizer was applied after transplanting. Onion seedlings 'Yellow Granex PRR' grown at the Vidalia Onion and Vegetable Research Center, University of Georgia, Lyons, GA, 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 (N rate). The experimental unit consisted of a 6.1-m-long bed. The organic fertilization treatment rates were equivalent to 0, 60, 120, 180, and 240 kg ha⁻¹ N.

Plant diseases and disorders. Incidences of bolting (flower stems), double bulbs, botrytis leaf blight (*Botrytis cinerea* Pers.),

Fig. 2. Total (A), marketable (B), and nonmarketable (C) bulb yield, and individual mature bulb weight (D) as affected by fertilization rate in sweet onion. Tifton, GA, Winters of 2012–13 and 2013–14. Nitrogen was provided by chicken manure organic fertilizer.

Table 1. Disorders, diseases, and quality attributes of sweet onion bulb immediately after harvest as influenced by organic fertilizer rate. Nitrogen was provided by chicken manure organic fertilizer. Tifton, GA, Winter of 2013 and 2014.

Treatment	Bolting (%)	Doubles (%)	Botrytis rot (%)	Sour skin (%)
Fertilizer (kg ha ⁻¹ N) ^a				
0	4.2	0.4	0.0	5.2
60	18.3	0.7	0.6	13.9
120	9.1	1.3	1.5	18.5
180	5.6	1.3	0.9	18.7
240	4.1	1.5	2.4	18.6
Significance	0.010	0.103	0.499	0.090
L ^b	0.264	0.024	0.035	0.005
Q	0.049	0.065	0.110	0.005
Year				
2013	2.9	1.8	0.0	6.5
2014	11.0	0.6	1.6	19.2
Significance	0.002	0.0004	0.048	<0.0001
Interaction				
N × Y	0.009	0.248	0.547	0.233

^aOrganic fertilizer (Perdue) applied before planting.

^bL = linear; Q = quadratic response.

and sour skin [*Pseudomonas cepacia* (Burkholder) Palleroni & Holmes] were determined as percentage of plants with the symptoms.

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

Harvest. The 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 removed; bulbs were left in the field for 48-h curing.

Bulb quality immediately after harvest. After curing, the bulbs were graded by size

Table 2. Postharvest quality attributes of sweet onion bulbs as influenced by organic fertilization rate. Bulbs were stored for 9 weeks in 2013 (2.5 °C and 80% RH) and 15 weeks in 2014 (1.9 °C and 83% RH). Chicken manure organic fertilizer was the source of nitrogen. Values are means of four replications (20 bulbs per experimental unit). Onion plants were grown in Tifton, GA.

Treatment	Initial bulb wt (g)	Wt loss (%)	WLR ^z (% kPa ⁻¹ ·week ⁻¹)	Marketable bulbs (%)	Botrytis rot (%)
Year 2013					
Fertilization rate (kg·ha ⁻¹ N) ^y					
0	93	5.0	0.956	94	
60	248	1.6	0.312	97	
120	312	1.8	0.345	90	
180	318	1.6	0.300	98	
240	308	1.7	0.328	86	
Significance					
L ^x	<0.0001	0.0001	0.0001	0.213	
Q	<0.0001	<0.0001	<0.0001	0.411	
Year 2014					
Fertilization rate (kg·ha ⁻¹ N) ^y					
0	81	9.2	1.053	38	62
60	197	7.7	0.876	38	62
120	265	8.3	0.952	33	67
180	261	8.0	0.921	44	56
240	256	8.1	0.933	46	54
Significance					
L ^x	<0.0001	0.359	0.359	0.472	0.384
Q	<0.0001	0.425	0.425	0.697	0.678

^zWLR = bulb water loss rate.

^yOrganic fertilizer (Perdue) applied before planting.

^xL = linear; Q = quadratic response.

Fig. 3. Bulb dry weight (percentage) as affected by fertilization rate in sweet onion harvested in 2013 and 2014 in Tifton, GA. Nitrogen was provided by chicken manure organic fertilizer.

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 hand-held refractometer (Kernco Instruments Co. Inc., Tokyo, Japan) to measure SSC. Pungency was measured using four bulbs. A 20-μL juice sample was obtained from each bulb. Pyruvic acid is used routinely to measure onion pungency or flavor intensity (Lancaster and Boland, 1990). Total phenols were determined as a measure of total antioxidant capacity of onion bulbs following the Folin-Ciocalteu method (Singleton et al., 1999) and data were expressed as gallic acid equivalents.

Bulb storage. Bulbs (20 marketable bulbs per experimental unit) were stored at the

Vidalia Onion Postharvest Laboratory, UGA Tifton Campus, for 9 weeks in 2013 [2.5 °C, 80% relative humidity (RH), 0.586 kPa of vapor pressure deficit (VPD), 3.8% CO₂, and 10.2% O₂] and 15 weeks in 2014 (1.9 °C, 83% RH, 0.582 kPa VPD, 5% CO₂, and 5% O₂). The 20 bulbs per replication were kept inside a jute sack and weighed before storage. After storage, the bulbs were graded into marketable and cull and their numbers and weights determined. Bulb weight loss was calculated as the percentage of change in bulb weight during storage. Bulb water loss rate (WLR) was calculated by dividing the bulb weight loss by the time (weeks) of storage and by the average VPD. In 2014, the percentages of bulb affected by botrytis rot and sour skin were determined. Quality attributes of bulbs after storage were measured as described previously for bulbs immediately after harvest.

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. Figure 1 shows the seasonal trends of maximal, mean, and minimum air temperature and rainfall in 2012–13 and 2013–14. In both seasons, temperatures were lowest for the first 60 d after transplanting. In 2012–13, average maximum, mean, and minimum temperatures were 19.0, 13.6, and 8.2 °C and cumulative rainfall was 807 mm. In 2013–14, average maximum, mean, and minimum temperatures were 18.6, 13.0, and 7.3 °C and cumulative rainfall was 671 mm.

Bulb yields. Total (Fig. 2A), marketable (Fig. 2B), and nonmarketable bulb yields (Fig. 2C) and individual bulb weight (Fig. 2D) increased quadratically with increasing fertilization rate with only nonmarketable yield reaching a plateau or slight decline at high fertilization rates. In the unfertilized control, most of the bulbs had a medium size. Among the marketable bulbs, because of the increase in bulb weight with increasing fertilization rate, the fraction of extra-large bulb increased with increasing N rate, from ≈23% at 60 kg·ha⁻¹ N to ≈54% of total marketable yield at 240 kg·ha⁻¹ N (Fig. 2A).

Bulb disorders and diseases. Incidence of onion bolting (mean incidence = 7.0%) was maximal at 60 kg·ha⁻¹ N and decreased with increasing fertilization rates (Table 1). The incidences of double bulbs (mean = 1.2%), botrytis rot (mean = 0.8%), and sour skin (mean = 15.0%) increased with increasing fertilization rate. Incidences of bolting, botrytis rot, and sour skin rot were greatest in 2014.

Postharvest bulb quality. Average weight of bulbs used for the postharvest study was lowest at 0 kg·ha⁻¹ N in both 2013 and 2014 and increased with increasing organic fertilization up to 120 kg·ha⁻¹ N with no increases in bulb weight with further increases in organic fertilization rate (Table 2). In both 2013 and 2014, total bulb weight loss (ranges: 1.7% to 5.0% in 2013, and 7.7% to 9.2% in 2014) and WLR were greatest at 0 kg·ha⁻¹ N and they showed little differences among the other organic fertilization rates. In 2013, the percentage of marketable bulbs after storage ranged from 86% to 97%. In 2014, the percentage of marketable bulbs after storage ranged from 33% to 46%, with botrytis rot being the predominant defect of cull bulbs, with incidence ranging from 54% to 67%. In both years, the percentage of marketable bulbs after storage was unaffected by organic fertilization rate. The incidences of bulb sour skin were negligible in both seasons (data not shown).

In both 2013 and 2014, the percentage of bulb dry weight measured immediately after harvest was highest in the unfertilized control and decreased with increasing organic fertilization rate (Fig. 3). The relationship of bulb SSC as a function of organic fertilization rate differed in the 2 years (Fig. 4A and B). In 2013, both before and after a 3-month storage, SSC decreased with increasing organic fertilization rate, whereas in 2014, both before and after storage, SSC had a quadratic response with lowest values at 60 and 120 kg·ha⁻¹ N. Across fertilization rates, bulb SSC decreased after storage in 2013 but not in 2014.

The relationship of bulb pungency (measured as pyruvate concentration) with organic fertilization rate varied by year (Fig. 5A and B). In 2013, pungency (before storage) tended to be reduced at the highest organic fertilization rate. In 2014, both before and after storage, pungency tended to be reduced in the unfertilized control and there were no differences in pungency among the

Fig. 4. Bulb soluble solids content before or after storage as affected by fertilization rate in sweet onion harvested in 2013 (A) and 2014 (B) in Tifton, GA. Nitrogen was provided by chicken manure organic fertilizer. Error bars represent the SE.

other organic fertilization rates. In 2013, after storage, total antioxidant capacity (measured as gallic acid equivalents) was lowest at intermediate organic fertilization rates (60, 120, and 180 kg ha^{-1} N) (Fig. 6A). In 2014, both before and after storage, total antioxidant capacity values were among the lowest at 60 and 120 kg ha^{-1} N (Fig. 6B). Total antioxidant capacity showed increased values after storage.

Discussion

Bulb yields. For sweet onion in Georgia, highest yields are obtained with 150 kg ha^{-1} N applied as synthetic inorganic fertilizer (Boyhan et al., 2007; Díaz-Pérez et al., 2003). With organic fertilizers, N requirements

can be determined, but the amount of fertilizer needed is difficult to calculate because N in organic fertilizers may not be readily available when present in an organic form. Nitrogen in organic form needs to be mineralized before being accessible to plants. It usually takes 3–6 months for N in organic fertilizers to be fully available to crops (Hartz and Johnstone, 2006). In the present study, the fact that plants were chlorotic 5 months after application of organic fertilizer suggests that most of the soil N in mineral form was already taken up by the crop or leached deeper into the soil. In tomato, despite a slower rate of availability and mineralization of nutrients from the organic fertilizers, there was no difference in the yield of red tomatoes from plants treated

with organic fertilizer or nutrient solutions (Toor et al., 2006).

In a 3-year study of poultry litter rates (0–11 t ha^{-1}) on sweet onion, bulb yield increased with organic fertilization rate. In addition, organic-compliant fertilizers, 4N–0.9P–2.5K at 168–280 kg ha^{-1} N, as well as 13N–0P–0K at 168 kg ha^{-1} N and in combination with 9N–0P–7.5K totaling 168 kg ha^{-1} N showed no differences in total or jumbo yields, whereas medium yields generally decreased with increased organic fertilizer rate (Boyhan et al., 2010). In a field onion trial where synthetic chemical fertilizer was applied at a third of the recommended rate of N, P, and K, bulb yield increased with increasing beef cattle manure compost applications of up to 80 t ha^{-1} (Lee, 2012). In the present study, total and marketable yields showed an increasing trend with increasing organic fertilization rate and the response did not reach a plateau or saturation (Fig. 2A and B), suggesting that at rates above the highest used in this study (240 kg ha^{-1} N), there would be a bulb yield increase. This result together with the low N use efficiency at high N fertilization rates (Fig. 6A) support the possibility of N leaching at high N fertilization rates. However, some organic N from the organic fertilizer may remain in the soil at the end of the season.

Bulb disorders and diseases. Onion bolting is enhanced by low temperature conditions (Rabinowitch, 1990), cultivar-dependent, and associated with low N fertilization (Díaz-Pérez et al., 2003, 2004). In the present study, onion bolting was highest at 60 kg ha^{-1} N but, surprisingly, bolting incidence was reduced in the unfertilized control (Table 1). High N fertilization rates are often associated with increased incidences of plant diseases (Marschner, 2012; Walters and Bingham, 2007). Incidences of bulb decay have been reported to increase with N fertilization rate (Díaz-Pérez et al., 2003). In addition to N rate, nitrogen source may also influence bulb rot incidence. Bulb rot incidence was found to be highest with NH_4NO_3 and least with $\text{Ca}(\text{NO}_3)_2$ and NaNO_3 (Batal et al., 1994). In the present study, before storage, sour skin incidence was greatest at intermediate and high N fertilization rates (Table 1), whereas botrytis incidence was low and affected slightly by N rate. This change in response indicates that onion bulb diseases may respond to N rate in a different way.

Postharvest bulb quality. Transpiration accounts for most of the weight loss in most of the horticultural produce (Ben-Yehoshua and Weichmann, 1987; Wills et al., 1998). Excessive weight loss of produce (primarily due to water loss) results in softening and shriveling. The permissible weight loss for many vegetables is $\approx 5\%$ (Burton, 1982; Wills et al., 1998). In the present study, onion bulbs during storage lost 8.5% (average across treatments) of the initial weight; this weight loss had minor effects on bulb appearance. These results are consistent with a report stating that maximum permissible weight loss for onions is 10% (Kays and Paull, 2004).

Fig. 5. Bulb pungency (measured as pyruvate concentration) before or after storage as affected by fertilization rate in sweet onion harvested in 2013 (A) and 2014 (B) in Tifton, GA. Nitrogen was provided by chicken manure organic fertilizer. Error bars represent the SE.

In the present study, the percentage of bulb dry weight decreased with increasing fertilization rate, possibly because of a dilution effect associated with increased bulb growth. Rates of beef cattle compost, in contrast, were found to have no effect on onion bulb dry weight (Lee, 2012).

In conclusion, onion total and marketable yields increased with increasing organic fertilization rate suggesting that at rates above the highest used in this study ($240 \text{ kg ha}^{-1} \text{ N}$), there would be a bulb yield increase. Incidences of bulb diseases responded differently to fertilization rate. Before storage, botrytis rot incidence was

low, whereas after storage, botrytis rot was the main cause of bulb decay in all N rate treatments.

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Fig. 6. Bulb total antioxidant capacity (measured as gallic acid equivalents) before or after storage as affected by fertilization rate in sweet onion harvested in 2013 (A) and 2014 (B) in Tifton, GA. Nitrogen provided by chicken manure organic fertilizer. Error bars represent the SE.

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