High Planting Density Twin-row Arrangement Produces Favorable Bulb Size Distribution in Short-day Onion

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Abstract. Twin-row planting arrangements are commonly used in agronomic crops to improve production and enhance disease management, but little information exists on their application in onion production. This study evaluated the impact of twin-row arrangements at high planting density on yield and bulb size distribution of short-day onion ('Sweet Magnolia'). Treatments combined within-row and between-row distances and the number of rows per bed top to achieve the desired planting arrangement and resultant planting densities. Treatments were four single rows of plants per bed top spaced 6 inches × 12 inches (within by between row), four single rows spaced 4 inches × 12 inches, or four twin rows (eight rows in total) spaced 6 inches × 4 inches among twins with 12 inches between twin-row pairs from middle to middle, resulting in planting densities of 58,000, 87,000 (commercial standard), and 116,000 plants per acre, respectively. Onion total and marketable yields increased while bulb size decreased as planting density rose. The twin-row high planting density was equivalent to the commercial standard in both total and marketable yield. Most important, twin rows had a favorable bulb size distribution, with both the highest yield and percentage of jumbo bulbs (≥3 inches in diameter) at 998.3 40-lb bags per acre and 80.2%, respectively. Culls decreased with increased planting density with no difference between twin-row high planting density and the commercial standard. Significant bolting was observed in 2024 at high planting density in conjunction with cooler weather. Our data indicate that twin-row planting arrangements do not outperform the commercial standard planting density in marketable yield but have potential applications for targeting specific bulb sizes by altering the bulb size distribution to favor smaller bulbs.

Onions (*Allium cepa*) are a highly valued vegetable crop in the United States; 133,000 acres are devoted to onion cultivation, worth just over $1.5 billion US Department of Agriculture, National Agricultural Statistical Service 2023. In Georgia, onions are worth $178 million and contribute 13% of the total value brought by vegetables (University of Georgia, Center for Agribusiness and Economic Development 2024). Georgia is known for the Vidalia onion, which is valued for its sweet taste and low pungency. This onion is a yellow granex type exclusively cultivated in the Vidalia region of Georgia, a federally designated area well suited for sweet, short-day onions because of its environment: loamy sand soils with low sulfur content and mild winters (Boyhan and Torrance 2002).

Each onion plant only produces one onion bulb. Thus, planting density is crucial to optimize yields and bulb size. Currently, most growers plant Vidalia onions in four single rows per bed top with 4 to 6 inches between plants to reach rates of 58,000 to 87,000 plants per acre (University of Georgia 2017). Increasing planting density can increase yield in onions but also decrease bulb size (Brewster 2008). This presents a challenge because bulb size distribution is an important factor of onion yield: consumers prefer jumbo bulbs (≥3 inches in diameter), which bring the highest premium at the market and are a priority for growers (Ibiapina de Jesus 2023). Typically, growers change the spacing between plants within a row to reach their target planting density, but decreasing the space below 4 inches (10 cm) would likely restrict the growth of larger bulbs. This has been reported in short-day onions: Leskovar et al. (2012) noted significant decreases in jumbo bulbs when decreasing in-row space from 4 to 3.2 inches, and Stofella (1996) also reported a reduction of bulbs ≥3 inches in diameter from 6 to 3 inches in-row space.

Twin-row planting arrangements are a common technique for agronomic crops that can be used to increase planting density by placing rows more closely together instead of decreasing plant space within the row. In soybeans, it can increase yield over single-row beds (Bruns 2011), and in peanuts, it increases yield as well as enhances disease management (Balkcom et al. 2010), but little information exists regarding its effect in onions. Because each onion plant produces a single bulb, using a twin-row planting arrangement that does not put plants closer than 4 inches to increase planting density may improve yields without reducing desirable onion sizes. The goal of this research was to increase production efficiency, yields, and profitability using equipment growers already have. Applying this technique to onions can be implemented using existing equipment (tractor, sprayers, and spreaders); only the hole punch needs to be modified, without altering standard management practices or reducing the in-row space below 4 inches. This study evaluated the effects of a high plant density twin-row planting arrangement on yield and yield components of Vidalia onion.

Materials and methods

Site selection and study design. The study was conducted at the University of Georgia Vidalia Onion and Vegetable Research Center (VOVRC), located in Lyons, GA, USA, during the winter growing seasons of 2023 and 2024 (32°00′59″N, 82°13′12″W). This region is ideal for Vidalia onion production due to the loamy sand soils with low sulfur content and warm, humid weather with an average annual rainfall of 46 inches (University

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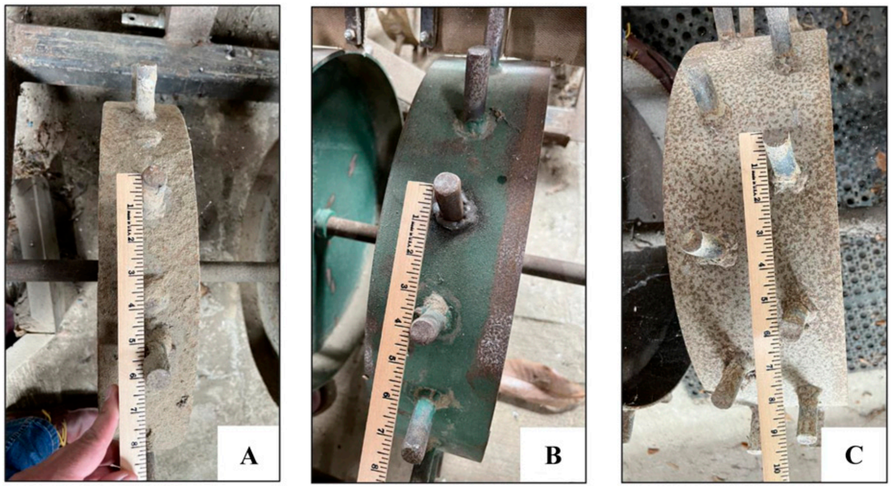

Fig. 1. Images of hole-punching attachments used for single and twin-row onion planting arrangements pictured with a wooden yardstick in inches for scale. (A) Single row wheel attachment with 6 inches between spokes. (B) Single row wheel attachment with 4 inches between spokes. (C) Twin-row wheel attachment with 6 inches between spokes and 4 inches between twins. 1 inch = 2.54 cm.

of Georgia Weather Network 2024; US Department of Agriculture, National Resources Conservation Service 2013).

Trials were arranged in a randomized complete block design (RCBD) with three treatments and four replications. Treatments combined within-row, between-row spacing, and number of rows per bed to achieve the desired planting arrangements and resultant plant population densities. Hole punch wheels with three spoke configurations (shown in Fig. 1) were mounted at four wheels per bed top and spaced 12 inches from wheel middle to middle to form main rows. Configurations were four rows of plants spaced 6 inches within-row (Fig. 1A), four rows of plants spaced 4 inches within-row (Fig. 1B), or four staggered twin-rows (eight rows total) spaced 6 inches within the row and 4 inches between twin-rows on the same hole puncher (Fig. 1C), resulting in planting densities of 58,000, 87,000, and 116,000 plants per acre, respectively (Table 1). Treatment plots were 20 ft long and 6 ft center to center.

The variety studied was 'Sweet Magnolia' (Seminis, St Louis, MO, USA), chosen based on superior crop performance and common use by growers in Georgia. Sixty-day-old bare ground seedlings were transplanted in the first week of December and harvested in the last week of April. Fertilizer, irrigation, and pesticide management were followed according to University of Georgia guidelines for onions. At harvest, onion bulbs were undercut with a rotating bar when 40% to 50% of the tops had fallen over. These bulbs were allowed to field-dry for 5 d before trimming roots and tops. They were then stored in plastic mesh bags and cured in a dryer at 90 °F for 48 h.

Data collection. Each plot's total bulb weight was recorded post-cure on a per-plot basis. Bulbs that were diseased, misshapen, or hollow-necked were considered culls and removed before sizing. The remaining marketable onions were sized by USDA grading standards for Granex-type onions (US Department of Agriculture, Agricultural Marketing Service 2014) using a commercial perforated conveyor belt grader (Haines Equipment Inc, Avoca, NY, USA) and bulb weights were recorded for each size by plot. Size categories were based on minimum bulb diameter with medium = 2 inches, jumbo = 3 inches, and colossal = 3.75 inches. In 2024, the number of bolting plants in each plot was recorded after observing substantial bolting in the field, which was absent in 2023.

Statistical analysis. Yield and yield parameters were analyzed using a Mixed Model in JMP Pro version 17 (SAS Institute Inc., Cary, NC, USA) to determine significant differences between single-row low and standard planting density and twin-row high planting density treatments at $\alpha = 0.05$, with treatment as a fixed effect and year and block as random effects. Bolting in 2024 was analyzed similarly, excluding year from the model. Post hoc separation of means was determined using Tukey's honestly significant difference. Supplemental figures were generated in RStudio version 2024.04.02 (RStudio, PBC, Boston, MA, USA).

Table 1. List of treatments by planting arrangement, planting density, rows per bed top, and corresponding spacing of onions for trials in 2023 and 2024.

Planting arrangement	Planting density (plants/acre)[i]	Rows per bed	Spacing (inches) In row	Spacing (inches) Between row[ii]
Single row	58,000	4	6	12
Single row	87,000	4	4	12
Twin row	116,000	8 [iii]	6	12[iv]

[i] 1 acre = 0.4047 ha.
[ii] Between-row distance is measured from middle to middle of the hole punch wheel attachment.
[iii] Four twin rows = eight rows total.
[iv] Distance between twins on the same wheel attachment is 4 inches with 12 inches between twin rows. See Fig. 1C.

Results

Yield response to planting density. Both total and marketable yields increased with planting density (Table 2; Supplemental Fig. 1). The twin row high planting density had a significantly higher total yield than the lowest planting density ($P = 0.0146$). Planting using a twin-row configuration at 116,000 plants/acre yielded significantly higher 40 lb bag/acre (1846) than planting in single rows at 58,000 plants/acre (1465). The total yield for the commercial standard density of single rows at 87,000 plants/acre (1684) was not significantly different from the other two treatments ($\alpha = 0.05$).

Marketable yield followed a similar pattern, with a significantly higher yield from the twin-row 116,000 plants/acre plots than the 58,000 plants/acre plots in single rows ($P = 0.0017$). No significant differences existed in marketable yield between the commercial standard

Table 2. Total, marketable, and cull yield of onion by weight and percentage of marketable and cull bulbs relative to total yield at each planting arrangement and density in 2023 and 2024 combined. Values represent descriptive means ± standard error.

Planting arrangement	Planting density (plants/acre)	Yield (40 lb bag/acre)[i]				
		Total	Marketable	Cull	% Marketable	% Cull
Single row	58,000	1465.0 ± 136.32 b[ii]	644.9 ± 88.9 b	820.2 ± 114.8 a	45.0 ± 4.7 b	55.0 ± 4.7 a
Single row	87,000	1684.5 ± 194.1 ab	991.4 ± 81.9 ab	693.1 ± 125.8 ab	60.9 ± 3.0 a	39.1 ± 3.0 b
Twin row	116,000	1846.2 ± 173.9 a	1245.5 ± 137.0 a	600.7 ± 85.6 b	66.7 ± 4.5 a	33.3 ± 4.5 b

[i] 40 lb bag/acre = 98.84 lb/ha or 18.14 kg/ha.
[ii] Letters following means represent separation by Tukey's honestly significant difference test within the column, with unique letters indicating a significant difference at $P \leq 0.05$.

and the high and low planting density treatments ($\alpha = 0.05$) (Table 2).

In 2024, plots with the highest planting density experienced significantly more bolting (seed-stem formation) at 15.9% (Table 3). The proportion of marketable to cull bulbs increased substantially with planting density, with the percentage of marketable bulbs rising from 45% at the low density to 60.9% and 66.7% ($P = 0.0034$) for the 87,000 plants/acre commercial standard and high planting density, respectively (Table 2; Supplemental Fig. 2). There was no significant difference in culls between the single-row commercial standard and the twin-row high planting density.

Bulb size distribution in response to planting density. The relative contribution of each bulb size category to the marketable yield was also affected by planting density. The proportion of jumbo- and medium-sized bulbs was the largest, and the fraction of colossal bulbs was the smallest, with twin-row 116,000 plants/acre plots (Table 4; Supplemental Figs. 3 and 4). Jumbo bulbs were a significant contributor to marketable yield (40 lb bag/acre) for 58,000 plants/acre plots at 290.4 (45.0%), and the largest contributor for both commercial standard 87,000 plants/acre and twin-row 116,000 plants/acre plots at 608.0 (61.3%) and 998.3 (80.1%), respectively, with statistical differences between each group ($P < 0.0001$). Medium bulb yields (40 lb bag/acre) were highest in twin-row 116,000 plants/acre plots at 88.5 (7.1%) and statistically distinct from the group of single-row low and commercial standard density plots with yields of 6.8 (1.0%) and 15.9 (1.6%), respectively ($P < 0.0001$).

Yields (40 lb bag/acre) for colossal bulbs were highest in the single-row 58,000 and 87,000 plants/acre plots at 347.7 (53.9%) and 367.5 (37.1%). The twin-row high planting density had lower yields of colossal bulbs at 158.8 (12.7%) than the commercial standard but was not significantly different from the single-row low planting density plots ($P = 0.032$). The single-row low and commercial standard plant density plots were not significantly different.

Discussion

Yield and planting density. Twin-row planting arrangements are a common technique for agronomic crops that can increase yield and enhance disease management. Our goal was to apply twin-row planting to Vidalia onions as a form of precision agriculture and evaluate the impact at a high planting density. We observed total and marketable yields increase with planting density. However, although the twin-row high planting density had higher total and marketable yields than the low planting density, it was equivalent to the commercial standard for both yield categories. Because each plant produces one bulb, these yield increases were primarily due to increasing plant numbers. Mixed results were found in Spanish sweet onions. Stoffella (1996) saw yields increase with planting density at rates ranging from 101,000 to 608,000 plants per acre, whereas Caruso et al. (2014) reported no effect of planting density on yield for rates of 524,000, 672,000, and 941,000 plants per acre. In contrast with these studies is a report from Brazil where short-day onions showed a quadratic yield response to plant spacing (dos Santos et al. 2018). In our study, cull bulbs also decreased with planting density, and there was no difference between the twin-row high planting density and the commercial standard. This contrasts with Stoffella (1996), where culls were <9% and unaffected by planting density. Because we applied the same rate of fertilizer across planting densities, one possible explanation for the higher number of culls at low planting densities is excess available nitrogen (N), which has been associated with bulb decay in Vidalia onions (Diaz et al. 2003).

Bulb size distribution and planting density. Bulb sizes generally decreased as planting density increased, with significant differences in size distribution. Jumbo and medium bulbs increased with planting density, and the twin-row high planting density plots had both the highest yield and percentage of these bulbs. Results for colossal bulbs were mixed. Colossal bulbs tended to decrease as planting density increased, but the differences between the lowest planting density and the other treatments were not significant. This is generally consistent with previous reports on short-day onions: Stoffella (1996), Leskovar et al. (2012), Caruso et al. (2014), and dos Santos et al. (2018) all observed decreasing bulb sizes as planting density increased. Varietal and environmental

Table 3. Percentage of bolted onion plants by planting arrangement and density in 2024. Values represent descriptive means ± standard error.

Planting arrangement	Planting density (plants/acre)[i]	Bolted plants (%)
Single row	58,000	0.5 ± 0.3 b[ii]
Single row	87,000	2.1 ± 0.6 b
Twin row	116,000	15.9 ± 1.3 a

[i] 1 acre = 0.4047 ha.
[ii] Letters following means represent separation by Tukey's honestly significant difference test within the column, with unique letters indicating a significant difference at $P \leq 0.05$.

Table 4. Contribution of onion bulb size by weight to the marketable yield by planting arrangement and density in 2023 and 2024 combined. Values represent descriptive means ± standard error.

Planting arrangement	Planting density (plants/acre)[ii]	Yield (40 lb bag/acre)[i]		
		Colossal[iii]	Jumbo	Medium
Single row	58,000	347.7 ± 61.9 ab[iv]	290.4 ± 30.7 c	6.8 ± 2.3 b
Single row	87,000	367.5 ± 59.7 a	608.0 ± 52.0 b	15.9 ± 2.3 b
Twin row	116,000	158.8 ± 28.0 b	998.3 ± 119.8 a	88.5 ± 10.1 a

[i] 40 lb bag/acre = 98.84 lb/ha or 18.14 kg/ha.
[ii] 1 acre = 0.4047 ha.
[iii] Size categories were based on the minimum diameter of bulbs: Colossal = 3.75 inches, Jumbo = 3 inches and Medium = 2 inches. 1 inch = 2.54 cm.
[iv] Letters following means represent separation by Tukey's honestly significant difference test within the column, with unique letters indicating a significant difference at $P \leq 0.05$.

factors also influence the effect of planting density on yield and bulb sizes.

Boyhan et al. (2009) observed decreased bulb sizes for Vidalia onions at rates from 31,680 to 110,880 plants per acre but noted significant varietal and environmental interactions when comparing bulb-size distributions. Although marketable yield is important, bulb size distribution is critical for maximizing profits from Vidalia onions. Jumbo bulbs are generally more valuable than medium and colossal bulbs and are considered more desirable by growers (Ibiapina de Jesus 2023).

In 2024, the twin-row high planting density plots also experienced significant bolting. Bolting is a complex process but can be induced by low temperatures (50 to 59 °F) late in the season (March–April) and enhanced by smaller bulbs (Brewster 2008). Cool weather and smaller bulb sizes at the high planting density may help explain the increased bolting observed in the 2024 trial.

Conclusions

This study evaluated the impact of a twin-row arranged high planting density in the production of Vidalia onion in Georgia USA. We found that yield increased with planting density. Twin-row high planting density total and marketable yields were equivalent to the commercial standard planting density. Bulb size decreased as planting density increased, and the marketable size distribution also changed substantially across planting densities; twin-row planting arrangements had the highest proportion of jumbo and medium bulbs. Culls also decreased as planting density increased, and there was no difference between twin-row high and commercial standard plant populations. We also observed bolting at high planting density, but this can also be influenced by variety and cold weather. Our data indicate twin-row planting arrangements can potentially be used to increase production of high-value bulb sizes in short-day onions.

References cited

Balkcom KS, Arriaga FJ, Balkcom KB, Boykin DL. 2010. Single- and twin-row peanut production within narrow and wide strip tillage systems. Agron J. 102(2): 507–512. https://doi.org/10.2134/agronj2009.0334.

Boyhan GE, Torrance RL. 2002. Vidalia onions—Sweet onion production in southeastern Georgia. HortTechnology. 12(2): 196–202. https://doi.org/10.21273/HORTTECH.12.2.196.

Boyhan GE, Torrance RL, Cook J, Riner C, Hill CR. 2009. Plant population, transplant size, and variety effect on transplanted short-day onion production. HortTechnology. 19(1):145–151. https://doi.org/10.21273/HORTTECH.19.1.145.

Brewster JL. 2008. Onions and other vegetable alliums (2nd ed). CABI, Wallingford, UK.

Bruns HA. 2011. Comparisons of single-row and twin-row soybean production in the Mid-South. Agron J. 103(3):702–708. https://doi.org/10.2134/agronj2010.0475.

Caruso G, Conti S, Villari G, Borrelli C, Melchionna G, Minutolo M, Russo G, Amalfitano C. 2014. Effects of transplanting time and plant density on yield, quality and antioxidant content of onion (*Allium cepa* L.) in southern Italy. Sci Hortic. 166:111–120. https://doi.org/10.1016/j.scienta.2013.12.019.

Diaz PJC, Purvis AC, Paulk JT. 2003. Bolting, yield, and bulb decay of sweet onion as affected by nitrogen fertilization. J Am Soc Hortic Sci. 128(1):144–149.

dos Santos JP, Grangeiro LC, Sousa VdFLd, Gonçalves FdC, Franca FDd, Cordeiro CJX. 2018. Performance of onion cultivars as a function of spacing between plants. Rev Bras Eng Agríc Ambient. 22(3):212–217. https://doi.org/10.1590/1807-1929/agriambi.v22n3p212-217.

Ibiapina de Jesus H. 2023. Nitrogen fertilization strategies for short-day onion (*Allium cepa*) production in Georgia (PhD Diss). University of Georgia, Athens, GA, USA.

Leskovar DI, Agehara S, Yoo K, Pascual-Seva N. 2012. Crop coefficient-based deficit irrigation and planting density for onion: growth, yield, and bulb quality. HortScience. 47(1):31–37. https://doi.org/10.21273/HORTSCI.47.1.31.

Stoffella PJ. 1996. Planting arrangement and density of transplants influence sweet Spanish onion yields and bulb size. HortScience. 31(7):1129–1130. https://doi.org/10.21273/HORTSCI.31.7.1129.

University of Georgia Weather Network. 2024. Georgia weather—Automated Environmental Monitoring Network page. http://www.georgiaweather.net/mindex.php?variable=PR&site=VIDALIA. [accessed 1 Nov 2024].

University of Georgia. 2017. Georgia Onion Production Guide. University of Georgia Cooperative Extension Bulletin. Bulletin 1198.

University of Georgia, Center for Agribusiness and Economic Development. 2024. 2022 Georgia Farm Gate Value Report. University of Georgia Cooperative Extension Bulletin. Report #AR-24-01. https://caed.uga.edu/content/dam/caes-subsite/caed/publications/annual-reports-farm-gate-value-reports/2022%20Farm%20Gate%20Value%20Report.pdf. [accessed 5 Nov 2024].

US Department of Agriculture, Agricultural Marketing Service. 2014. United States Standards for Grades of Bermuda-Granex-Grano Type Onions. https://www.ams.usda.gov/grades-standards/bermuda-granex-grano-type-onions-grades-and-standards. [accessed 28 Mar 2025].

US Department of Agriculture, National Agricultural Statistics Service. 2023. USDA/NASS QuickStats Ad-hoc Query Tool. https://quickstats.nass.usda.gov/results/3A657E29-8801-342F-ACF4-126851280D31. [accessed 3 May 2025].

US Department of Agriculture, National Resources Conservation Service. 2013. Official Series Description—IRVINGTON Series. https://soilseries.sc.egov.usda.gov/OSD_Docs/I/IRVINGTON.html. [accessed 1 Nov 2024].