Research Reports

Optimizing Sweetpotato Seed Root Density and Size for Slip Production

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Summary. **There is a research gap with respect to documenting the effects of sweetpotato (*Ipomoea batatas*) seed root density and size on transplant yield and quality. Field studies were conducted in 2012 and 2014 to determine the effect of sweetpotato seed root (canner size) density [12, 24, 37, 49, 61, 73, and 85 bushels [bu (50 lb)] per 1000 ft²] on 'Covington' and 'Evangeline' slip production in propagation beds. Another field study was conducted in 2012 and 2013; treatments included canner, no. 1, and jumbo-size 'Covington' roots at 49 bu/1000 ft², to determine the effect of seed root size on slip production. As seed root density increased in the propagation bed, transplant production increased with no change in slip quality as measured by node counts and slip length except for stem diameter. In 2012, the best marketable slip yield was obtained at root densities of 73 and 85 bu/1000 ft². In 2014, marketable slip production of 'Evangeline' increased as seed root density increased at a greater rate than 'Covington'. In 2014, the best seed root density for marketable slip production was 49 to 85 bu/1000 ft² for 'Covington' and 85 bu/1000 ft² for 'Evangeline'. In 2012, potential slip revenues increased with an increase in seed root density up to 73 bu/1000 ft². In 2014, revenue trend was similar for 'Covington' as 2012; however, for 'Evangeline', revenue was greatest at 85 bu/1000 ft². Seed root size had no effect on marketable slip production when using a once-over harvest system. Results suggest growers would use a seed root density from 49 to 85 bu/1000 ft² depending on variety, and any size roots for production of optimum marketable slips. Selection of optimum seed root density also depends on grower needs; e.g., high seed root density strategy will have a higher risk due to the upfront, higher seed costs, but potentially have higher profits at harvest time. Lower seed root density strategy would be a lower initial risk with a lower seed cost, but also potentially have lower net revenues.**

Sweetpotato is an important crop worldwide, valued at over $9.4 billion (Food and Agriculture Organization of the United Nations, 2012). In the United States, sweetpotato production is valued at $698 million in gross farm value [U.S. Department of Agriculture (USDA), 2015a]. North Carolina ranks first in sweetpotato production in the United States with 73,000 acres planted in 2014, which accounts for more than half of the total acreage planted nationwide (USDA, 2015b). 'Covington' sweetpotato, released by the North Carolina Agricultural Research Service in 2005, accounts for 88% of certified seed root acreage in North Carolina, followed by 'Beauregard' and 'Evangeline' at 5% and 3%, respectively (North Carolina Crop Improvement Association, 2014; Yencho et al., 2008). 'Evangeline' sweetpotato was released by the Louisiana Agricultural Experiment Station in 2007 and was reported to have southern root-knot nematode (*Meloidogyne incognita*) resistance, yields that are comparable to 'Beauregard', and an excellent flavor profile (La Bonte et al., 2008). In addition to 'Covington', 'Evangeline' under North Carolina growing conditions had been minimally investigated in terms of production practices and was, therefore, considered an important component in the study.

A sweetpotato crop is established with nonrooted cuttings (slips), which are vegetatively produced in field propagation beds. North Carolina growers use a wide (24 to 73 bu/1000 ft²) range of seed root densities to produce sweetpotato slips (D. Godwin, D. Scott, and J. Jones, personal communication). However, a lack of knowledge exists on what is the optimum seed root density and size for production of sweetpotato slips. Depending on grower's equipment, the propagation beds are elevated about 10 inches and are 36 inches wide (Wilson et al., 1977). Mainly canner size roots (1 to 1.75 inches diameter) are used as seed source for propagation beds (Smith et al., 2009). These seed roots are cured [85 °F, 85% to 90% relative humidity (RH)] for ≈1 week after harvest to heal wounds to the skin

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
0.3048	ft	m	3.2808
0.0929	ft²	m²	10.7639
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
0.4536	lb	kg	2.2046
48.8243	lb/1000 ft²	kg·ha⁻¹	0.0205
1.1209	lb/acre	kg·ha⁻¹	0.8922
28.3495	oz	g	0.0353
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

that occurs during harvest and then stored at 55 to 60 °F and 80% to 85% RH (Edmunds et al., 2008; Kemble, 2013; Steinbauer and Kushman, 1971). Before bedding, the seed roots are presprouted in storage (85 °F, 85% RH) for 20 to 28 d (Kemble, 2013). Sweetpotato seed roots are placed into the propagation beds and then covered with 2 inches of soil (Wilson et al., 1977). Clear polyethylene mulch is then placed over the beds to increase the soil temperature and facilitate sprouting. Mulch is vented after 7 d to prevent an accumulation of carbon dioxide and then removed completely once shoot emergence begins and before bed temperatures become too hot. Once slips reach optimal size (7 to 14 inches), they are cut either by hand or with mechanical cutters, and packed in boxes (1000 slips/box) to transport and plant directly into the production field (Smith et al., 2009). Many commercial growers in North Carolina adopt a once-over harvest strategy, meaning that only one cutting is obtained from slip propagation beds. However, there are some growers that cut slips multiple times, coming back when slips have regrown to optimal size. Adopting a multiple harvest slip production strategy is common in geographical locations that have longer sweetpotato-growing seasons. Australian growers can harvest seedbed cuttings at least four to five times with 4 weeks between harvests (Northern Territory Government, 2005).

At the end of the growing season, when storage roots are harvested, a portion of the roots are saved to use as seed roots for the following year. This process is repeated for a number of years, each of which is called a generation (G). However, clones can slowly decline over each generation due to the accumulation of viruses, pathogens, and mutations (Clark et al., 2002; Villordon and LaBonte, 1996). Therefore, it is recommended to use no older than G-5 (the number indicates number of years in field production) seed root stock (Bryan et al., 2003).

Research is lacking with respect to documenting the effects of sweetpotato seed root density and size on transplant yield and quality. Thus, the primary objective of this research was to identify optimal seed root density and size of 'Covington' and 'Evangeline' that maximize production and quality of slips and return on investment. This project was conducted in direct response to grower interest and with sweetpotato industry funding.

Materials and methods

Field research was conducted in 2012 and 2013 at a commercial farm in Lucama, NC [Wilson County (lat. 35.63°N, long. 78.05°W)], and in 2014, at a commercial farm in Bailey, NC [Nash County (lat. 35.87°N, long. 78.14°W)]. The soil was an Altavista fine sandy loam (fine-loamy, mixed, semi active, thermic Aquic Hapludults) in Lucama, and in Bailey, it was Norfolk, Georgeville, and Faceville soils (fine-loamy, kaolinitic, thermic Typic Kandiudults). Growers targeted pH 6 each year for all these field studies and their sweetpotato beds. In 2012 and 2013, the crop grown in the previous year was soybean (*Glycine max*), while in 2014, the previous crop grown was corn (*Zea mays*) (S. Scott and W. Glover, personal communication). All years 'Covington' seed root stock was G-2 and 'Evangeline' was G-1, which were harvested the previous fall from several seed root producers' commercial farms in Wilson and Nash counties, cured, and stored (Edmunds et al., 2008; Kemble, 2013; Steinbauer and Kushman, 1971).

SEED ROOT DENSITY STUDY. Seed root stock was counted and weighed corresponding to assigned treatment and transported by pallets to the field. Average weight per seed root was 3.4 oz for 'Evangeline' and 6.3 oz for 'Covington' as seed root stock was primarily comprised of (1 to 1.75 inches diameter) canner roots (USDA, 2005). Seed roots were evenly placed in propagation beds by hand on 22 Mar. 2012 and 5 Apr. 2014 at the appropriate seed root density (Fig. 1). The seed root density study was conducted in a randomized complete block design with a two-way factorial (2 × 7) arrangement of sweetpotato variety (Evangeline and Covington) and seed root density (12, 24, 37, 49, 61, 73, and 85 bu/1000 ft^2) with four replicates. Dichloran (Botran; Gowan Company, Yuma, AZ) fungicide was applied to bare earth before seed roots were hand placed into beds, and again on top of seed roots after placement in the bed. Propagation beds were fertilized with 6N–2.6P–14.9K granular fertilizer at 14 lb/1000 ft^2. The bed maintenance and pesticide handling were done in compliance with recommendation for sweetpotato grown in the southeastern United States (Kemble, 2013). Beds were irrigated using two drip lines and covered with clear polyethylene mulch after seed roots were covered with soil. The mulch was removed when sprouts reached the soil surface. As slips in propagation beds grew, they were mowed four or five times before harvesting, theoretically to maximize uniformity and the number of marketable slips for a once-over harvest.

SEED ROOT SIZE STUDY. On 22 Mar. 2012 and 4 Apr. 2013, canner, no. 1, and jumbo-size 'Covington' roots, which averaged 6.3, 8.3, and 23 oz, respectively, were bedded at 49 bu/1000 ft^2 to determine the effect of seed root size on slip production. The study was conducted in a randomized complete block design with four replicates. The 49 bu/1000 ft^2 seed root density rate was considered to be the average seed root density used by commercial farmers. Seed roots were graded according to the USDA and North Carolina Department of Agriculture (USDA, 2005) standard that classify roots into no. 1 (diameter of 1.75 to 3.4 inches and length of 3 to 9 inches), canner (diameter 1 to 1.75 inches), and jumbo (diameter >3.5 inches) roots.

PLOT SIZE AND DATA COLLECTED. Each plot was a 3 ft wide × 20 ft long

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Fig. 1. Seed root density treatments of sweetpotato from low to high in bushels per 1000 ft^2. Seed roots evenly placed by hand into propagation beds. Commercial farms have reported using seed root densities ranging from 24 to 73 bushels/1000 ft^2; one 50-lb (22.68 kg) bushel/1000 ft^2 = 2441.2138 kg·ha^{-1}.

bed spaced 8 ft between row centers. A 3 × 5 ft subsection of each plot was harvested on 4 and 5 Apr. 2012 (seed root density and root size studies), 12 June 2013 (seed root size study), and 17, 18, and 19 June 2014 (seed root density study) by cutting the slips by hand directly above the soil surface. From both seed root density and size studies, slips were measured from cut end to apical meristem and categorized as marketable and unmarketable. Slips less than 5 inches long were not considered marketable based on input from a large commercial sweetpotato grower (D. Scott, personal communication). Cull slips (<5 inches) are considered unmarketable because these slips are many times completely buried during transplanting (slips are inserted into the soil ≈3 to 6 inches deep) and would not survive. In addition, short slips have few nodes so establishment and subsequent storage root production can be limited (Thompson, 2014). The following marketable slips were categorized as marginal (5 to <7 inches), optimal (7 to 14 inches), and extra-long (>14 inches) with the extra-long slips potentially being cut to optimal size or into two slips. Slip quality parameters (slip length, node number, and stem diameter) and individual slip weight were also collected from the seed root density study. Average number of nodes and stem width per slip were determined by measuring 20 optimal size slips 9 to 10 inches long per plot. Nodes were counted from cut end and included the growing point. Stem diameter measurements were taken with calipers twice per slip, turning 45° between measurements. The two measurements were averaged to calculate slip stem diameter. Weight per slip was determined by averaging the weight of 50 optimal (7 to 14 inches) size slips per plot.

Statistical and economic analyses. All data were checked for homogeneity of variance and normality. Data from seed root density study were subjected to analysis of variance using the PROC MIXED procedure of SAS (version 9.4; SAS Institute, Cary, NC) to test for treatment effects and interactions. Seed root size study data were analyzed using PROC GLM (SAS version 9.4). Means were separated using Fisher's protected least significant differences at $P \leq 0.05$ when appropriate. Optimum, marketable, or total slip production data were regressed against seed root density in SigmaPlot 12.0 (Systat Software, San Jose, CA) using either linear equation $Y = a + bX$ or quadratic equation $Y = a + bX + cX^2$, where Y = optimum, marketable, or total slip production and a, b, and c are constants, and X = seed root density. Furthermore, quadratic regression was fit to describe the relationship between individual slip weight and seed root density (quadratic equation $Y = a + bX + cX^2$, where Y = individual slip weight and a, b, and c are constants, and X = seed root density).

Economic analysis was performed to determine the cost-effectiveness of seed root densities for marketable slip production on the 2012 and 2014 seed root density studies. Gross revenue for all slips was assumed to be $40 per box of 1000 plants. Slip pricing represents the standard purchase rate obtained from commercial growers from 2012 to 2014 (J. Jones, personal communication). Seed root cost was valued at $7/bu for G-2 seed stock (J. Jones, personal communication).

Results and discussion

Seed root density study

Slip production. The interaction for year × variety × density was not significant for cull, extra-long, and marginal slip number and individual slip weight; therefore, data were combined for both years (Table 1). However, for optimal, marketable, and total slip production, the year × variety × density interaction was significant, so data are presented by year (Table 1).

Individual slip weight of an optimal slip differed between varieties and decreased with increased seed root density (Fig. 2). A quadratic response shows that average slip weight decreased with increased seed root density and leveled off at the higher seed root densities (Fig. 2). This trend was likely due to intraspecific competition for limited resource (space, light, water, and nutrients) availability per slip at the higher seed root densities (Casper and Jackson, 1997; Wilson and Tilman, 1991). Studies on other crop species, such as switchgrass (*Panicum virgatum*), have demonstrated this same trend of decreased plant weight with higher plant densities due to limited resources (Sanderson and Reed, 2000). 'Covington' slips weighed more than 'Evangeline' at all densities. 'Evangeline' plant weight leveled off near the 61 bu/1000 ft^2 treatment whereas 'Covington' began to level off at the 49 bu/1000 ft^2 treatment (Fig. 2). This difference is likely due to genetic differences between varieties. Varieties can perform differently under the same

Table 1. Probability > F for slip production of sweetpotato for each grade as influenced by seed root density and variety at Lucama and Bailey, NC, in 2012 and 2014, respectively.

	Cull	Marginal	Extra-long	Optimal	Marketable	Total	Wt/slip
Variable				P > F			
Year (Y)	0.003	0.001	0.203	0.006	0.008	<0.001	<0.001
Density (D)	<0.001	<0.001	0.264	<0.001	<0.001	<0.001	<0.001
Variety (V)	<0.001	<0.001	<0.001	<0.001	<0.001	0.007	<0.001
D × V	0.001	<0.001	0.217	0.005	0.023	0.359	<0.001
Y × D	0.001	0.075	0.811	<0.001	<0.001	<0.001	0.064
Y × V	0.451	0.051	0.061	<0.001	<0.001	<0.001	0.074
Y × V × D	0.886	0.248	0.725	<0.001	<0.001	<0.001	0.442

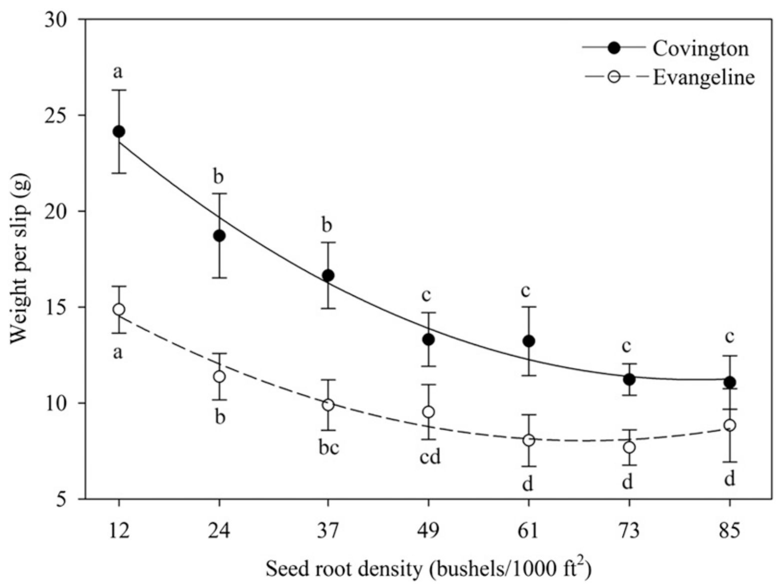

Fig. 2. The influence of sweetpotato seed root density on individual slip weight of optimal slip (7 to 14 inches) combined over both years (2012 and 2014) for 'Covington' and 'Evangeline'. Different letters within a variety indicate statistically significant difference between seed root density based on Fisher's protected least significant differences at $P \leq 0.05$. 'Covington' slip weight: $Y = 28.28 - 0.42X + 0.003X^2$ (R^2 = 0.98), 'Evangeline' slip weight: $Y = 17.6 - 0.28X + 0.002X^2$ (R^2 = 0.96). 1 g = 0.0353 oz; 1 inch = 2.54 cm, one 50-lb (22.68 kg) bushel/1000 ft² = 2441.2138 kg·ha⁻¹.

agroclimatic conditions due to an interaction of genetic makeup and environment (Jilani et al., 2009).

Extra-long slip (>14 inches) production was not influenced by seed root density (Table 2), but there were varietal differences. 'Evangeline' produced more extra-long slips than 'Covington' (3.3 and 1.6 boxes/1000 ft², respectively). Cull and marginal slip production was influenced by the interaction of seed root density and variety. Seed root density did not have an impact on cull slip production for 'Evangeline'; however, for 'Covington', production of cull slips increased with an increase in seed root density (Table 2). Marginal sized slip production increased with an increase in seed root density; however, 'Covington' produced more marginal size slips than 'Evangeline' as seed root density increased (Table 2).

In 2012, the interaction between seed root density and variety (P > 0.05) was not significant for optimal, marketable, or total slip production; therefore, data were combined from both varieties to find the influence of seed root density. The main effect of variety was only significant (P = 0.002) for total slip production where 'Covington' (30 boxes/1000 ft²) produced more than 'Evangeline' (23 boxes/1000 ft²). Within the limits of the seed root density treatments observed in this experiment, a quadratic relationship was observed between optimal, marketable, or total slip production and seed root density (Fig. 3). As seed root density increased, optimal, marketable, or total slip productions increased, and mean separation analysis indicated that significantly higher slip production occurred for seed root density of 73 and 85 bu/1000 ft² compared with all other densities (Fig. 3).

In 2014, the interaction between seed root density and variety was significant for optimal (P < 0.001), marketable (P< 0.001), and total (P= 0.001) slip production; therefore, data are presented by variety (Fig. 4). A linear and quadratic increase for optimal, marketable, or total slip production was observed as seed root density increased for 'Evangeline' and 'Covington', respectively. An interaction between variety and seed root density showed that optimal, marketable, or total slip production for 'Evangeline' increased at a faster rate than 'Covington' (Fig. 4). Mean separation analysis for 'Covington' indicated that optimal and marketable slip production from 49 to 85 bu/1000 ft² were not significantly different, suggesting that increase in seed root density from 49 to 85 bu/1000 ft² did not increase slip production (Fig. 4). Mean separation analysis for 'Evangeline' indicated that optimal, marketable, and total slip production from 49 to 73 bu/1000 ft² were not significantly different; however, at these densities the slip production was lower than 85 bu/1000 ft². This suggests that for 'Evangeline', an increase in seed root density from 49 to 73 bu/1000 ft² did not increase slip production, but at seed root density of 85 bu/1000 ft², slip production increased significantly.

Environmental factors can also have detrimental effects on the survival and/or thriving of slips for root production. Many North Carolina

Table 2. **Slip production of sweetpotato by grade as influenced by seed root density and variety at Lucama and Bailey, NC, in 2012 and 2014, respectively.**

	Cull[y]		Extra-long[y]		Marginal[y]	
Seed root density	'Covington'	'Evangeline'	'Covington'	'Evangeline'	'Covington'	'Evangeline'
Bushels/1,000 ft[2z]	Boxes/1,000 ft²					
12	4 f[x]	3 a	2 a	3 a	2 d	1 c
24	7 ef	4 a	2 a	3 a	3 d	2 c
37	10 de	7 a	2 a	4 a	5 c	2 c
49	13 cd	8 a	1 a	3 a	5 c	2 c
61	15 bc	9 a	2 a	3 a	9 c	3 ab
73	19 ab	9 a	1 a	3 a	11 a	4 a
85	20 a	8 a	1 a	4 a	7 bc	4 a

[z]Data combined from 2012 and 2014; 1 50-lb (22.68 kg) bushel/1000 ft² = 2441.2138 kg·ha⁻¹.
[y]Cull, extra-long, and marginal slips are considered <5 inches, >14 inches, and 5 to <7 inches, respectively; 1 inch = 2.54 cm, 1 box (1000 slips)/1000 ft² = 107.6391 boxes/ha.
[x]Means followed by a different letter within a column are significantly different according to Fisher's protected least significant difference ($P \leq 0.05$).

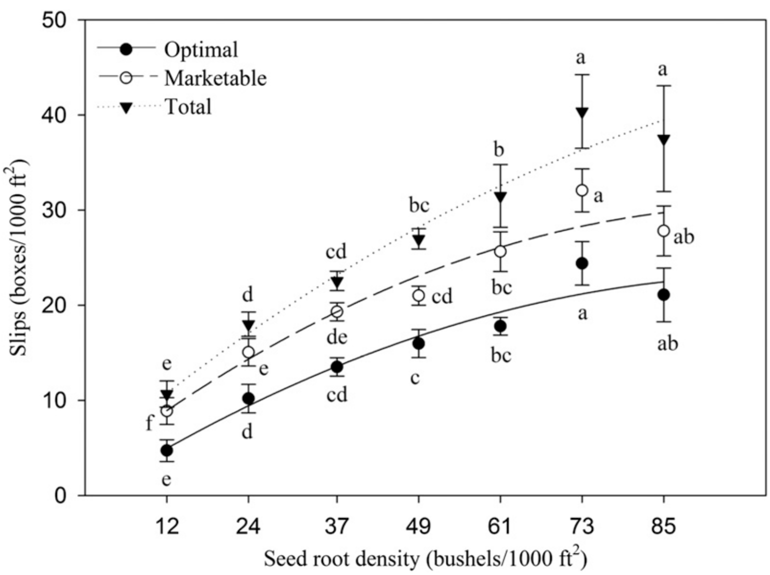

Fig. 3. The influence of seed root density on sweetpotato slip production (optimal, marketable, and total) combined for both 'Covington' and 'Evangeline' at Lucama, NC, in 2012. Different letters within a slip grade indicate a statistically significant difference between seed root density based on Fisher's protected least significant differences at $P \leq 0.05$. Optimal slips: $\Upsilon = -0.17 + 0.45X - 0.002X^2$ ($R^2 = 0.94$), marketable slips: $\Upsilon = 2.74 + 0.54X - 0.003X^2$ ($R^2 = 0.94$), total slips: $\Upsilon = 3.84 + 0.60X - 0.002X^2$ ($R^2 = 0.96$); one box (1000 slips)/1000 ft² = 107.6391 boxes/ha, one 50-lb (22.68 kg) bushel/1000 ft² = 2441.2138 kg·ha⁻¹.

sweetpotato fields are not irrigated. Slips are typically transplanted into production fields and watered simultaneously by the mechanical transplanter, but are then reliant on rainfall. Ample slip tissue above and below the soil surface enables the slip to survive the hot and sometimes dry conditions that are prevalent during North Carolina's growing season. Irrigated slips typically show higher stand percentages vs. nonirrigated slips (Thompson, 2014). It is important to note that while marginal (5 to <7 inches) slips may survive transplanting, the best success for thriving, productive slips are found within the optimal slip size range (7 to 14 inches). A recent study found that slips between 20 and 30 cm consistently provided higher plant stands and yields for 'Covington' sweetpotato than 9.5-cm slips (Thompson, 2014). Limited slip tissue below the soil surface can limit root initiation due to reduced number of nodes (Thompson, 2014). Therefore, fewer nodes will likely lead to a reduction in root set and overall yields. A minimum of three nodes under the soil surface has been recommended (Granberry et al., 1986). Studies on vegetatively propagated cassava (*Manihot esculenta*) have also found that longer transplants result in higher yields (Ekandem, 1962; Rodriguez and Sanchez de Bustamante, 1963).

Extra-long slips have the length necessary to survive, but are sometimes more difficult to handle during transplanting. These slips are typically cut to appropriate length when packed together into boxes after harvest and are, therefore, considered marketable. The best slips are not only the appropriate length but are also straight. Extra-long slips tend to be curved, which can cause problems during transplanting. Extra laborers are then needed to hand-stick the curved or missed slips into the planting rows.

Using total slips as a means for selecting particular varieties for superior slip production would not be advisable. Total slip production includes unusable or cull slips. Optimal slip (7 to 14 inches) production is of utmost consideration in selecting varieties and seed root density, not only for slip production but also for subsequent storage root set in field production. However, extra-long and marginal slips have their own negative points along with benefits; therefore, both of these categories of slips are included as marketable slips. Using marketable slips as a means for selecting particular varieties for superior slip production would be advisable.

Slip quality. The interaction for year × density × variety was not significant for number of nodes per slip, slip diameter, and slip length; therefore, data are combined over both years. The interaction for density × variety was not significant for number of nodes per slip ($P = 0.355$), slip diameter ($P = 0.100$), and slip length ($P = 0.264$). Number of nodes per slip was unaffected by either seed root density ($P = 0.070$) or variety ($P = 0.173$) (data not shown). Number of nodes per slip ranged from 8 to 10 nodes per slip. Differences in slip stem diameter were observed between varieties ($P < 0.001$) and seed root density ($P = 0.006$). 'Covington' slips were larger in diameter (4.62 mm), in contrast to 'Evangeline' (3.67 mm). This difference was likely due to the stocky growth habit of 'Covington'. Larger stem diameter of slips (4.4 mm) were obtained from 12 bu/1000 ft² seed root density compared with all other densities where slip diameter ranged from 4 to 4.2 mm. Slip length was only influenced by variety ($P < 0.001$), and 'Covington' slips were smaller in length (9.3 inches) than 'Evangeline' (9.6 inches). Our hypothesis was that the highest seed root density treatments would show a decrease in slip quality due to increased competition for nutrients, water, light, and space. However, these results indicate that increased seed root density does not have measurable negative impacts on slip quality including node counts, and slip length except on slip diameter at the densities evaluated.

ECONOMIC ASSESSMENT. Gross revenue generated from marketable slip production increased as seed root density increased from 12 to 73 bu/1000 ft² during the year 2012 with yield data for both varieties combined (Table 3). Revenue after subtracting seed root cost ranged from $271 to $772 per 1000 ft² for seed root density treatments (Table 3). Adopting a higher (61 and 73 bu/1000 ft²) seed root density could increase revenue by 17% and 36%, respectively, relative to average commercial (49 bu/1000 ft²) bedding density (Table 3). However, further increase in seed root density to 85 bu/1000 ft² resulted in decreased revenue ($20/1000 ft²) compared with 61 and 73 bu/1000 ft² ($101 and $275/1000 ft², respectively) due mainly to higher seed cost and decrease in slip yield (Table 3).

During 2014, cost-benefit analysis of seed root densities for marketable slip production was presented by varieties due to the yield difference between both varieties (Table 4). 'Covington' revenue after subtracting

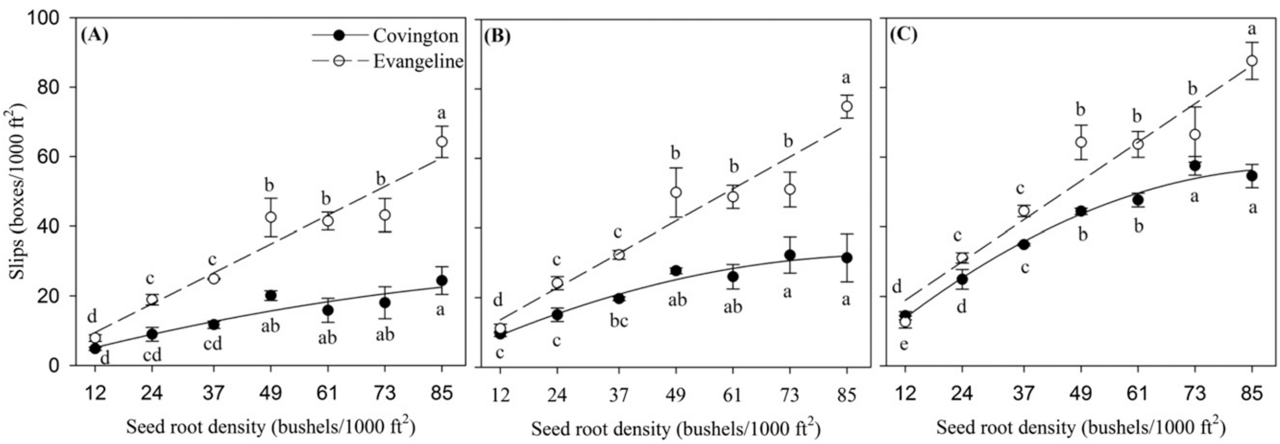

Fig. 4. The influence of seed root density on slip production. (A) Optimal (B) marketable, and (C) total of 'Covington' and 'Evangeline' sweetpotato varieties at Bailey, NC, in 2014. Different letters within a variety indicate statistically significant difference between seed root density based on Fisher's protected least significant differences at $P \leq 0.05$. (A) Optimal 'Covington' slips: $\Upsilon = 0.92 + 0.36X - 0.001X^2$ ($R^2 = 0.86$), optimal 'Evangeline' slips: $\Upsilon = 1.23 + 0.69X$ ($R^2 = 0.93$); (B) marketable 'Covington' slips: $\Upsilon = 2.01 + 0.64X - 0.003X^2$ ($R^2 = 0.96$), marketable 'Evangeline' slips: $\Upsilon = 4.41 + 0.77X$ ($R^2 = 0.93$); (C) total 'Covington' slips: $\Upsilon = 0.51 + 1.18X - 0.006X^2$ ($R^2 = 0.98$), total 'Evangeline' slips: $\Upsilon = 7.75 + 0.93X$ ($R^2 = 0.93$); one box (1000 slips)/1000 ft² = 107.6391 boxes/ha, one 50-lb (22.68 kg) bushel/1000 ft² = 2441.2138 kg·ha⁻¹.

Table 3. Cost-benefit analysis of seed root densities for marketable slip production of sweetpotato at Lucama, NC, in 2012 (combined over varieties).

Seed root density (bushels/1,000 ft²)[z]	Slips (boxes/1,000 ft²)[z]	Gross revenue ($/1,000 ft²)[y]	Seed root cost[x]($/1,000 ft²)	Revenue after seed cost ($/1,000 ft²)[w]	Change in revenue ($/1,000 ft²)[v]	Change (%)
12	8.9	355	84	271	–226	–83
24	15.1	602	168	434	–63	–15
37	19.3	772	259	513	16	3
49	21.0	840	343	497	0	0
61	25.6	1,025	427	598	101	17
73	32.1	1,283	511	772	275	36
85	27.8	1,112	595	517	20	4

[z]1 50-lb (22.68 kg) bushel/1000 ft² = 2441.2138 kg·ha⁻¹, 1 box (1000 slips)/1000 ft² = 107.6391 boxes/ha.
[y]1 box of slips costs $40; marketable slips are considered to be longer than 5 inches (12.7 cm); $1/1000 ft² = $107.6391/ha.
[x]Seed root cost = $7/bushel ($0.31/kg) for G-2 (2 years in field production) seed stock.
[w]Revenue after seed cost = gross revenue – seed root cost.
[v]Change in revenue and percentage change based on median seed root density treatment of 49 bushels/1000 ft².

Table 4. Cost-benefit analysis of seed root densities for marketable slip production of sweetpotato at Bailey, NC, in 2014 (by varieties).

Variety	Seed root density (bushels/1,000 ft²)[z]	Slips (boxes/1,000 ft²)[z]	Gross revenue ($/1,000 ft²)[y]	Seed root cost ($/1,000 ft²)[x]	Revenue after seed cost ($/1,000 ft²)[w]	Change in revenue ($/1,000 ft²)[v]	Change (%)
Covington	12	9.5	381	84	297	–453	–152
Covington	24	15.1	603	168	435	–315	–73
Covington	37	19.7	788	259	529	–221	–42
Covington	49	27.3	1,093	343	750	0	0
Covington	61	27.0	1,080	427	653	–97	–15
Covington	73	32.3	1,291	511	780	30	4
Covington	85	31.4	1,258	595	663	–87	–13
Evangeline	12	11.1	444	84	360	–1297	–360
Evangeline	24	24.2	967	168	799	–858	–107
Evangeline	37	32.3	1,293	259	1,034	–623	–60
Evangeline	49	50.0	2,000	343	1,657	0	0
Evangeline	61	48.9	1,956	427	1,529	–128	–8
Evangeline	73	51.0	2,041	511	1,530	–127	–8
Evangeline	85	74.9	2,996	595	2,401	744	31

[z]1 50-lb (22.68 kg) bushel/1000 ft² = 2441.2138 kg·ha^{-1}, 1 box (1000 slips)/1000 ft² = 107.6391 boxes/ha.
[y]1 box of slips costs $40; marketable slips are considered to be longer than 5 inches (12.7 cm); $1/1000 ft² = $107.6391/ha.
[x]Seed root cost = $7/bushel ($0.31/kg) for G-2 (2 years in field production) seed stock.
[w]Revenue after seed cost = gross revenue – seed root cost.
[v]Change in revenue and percentage change based on median seed root density treatment of 49 bushels/1000 ft².

seed root cost ranged from $297 to $780 per 1000 ft² for the range of seed density treatments (Table 4). Comparatively, revenue after subtracting seed cost was higher for 'Evangeline' than 'Covington', and it ranged from $360 to $2401 per 1000 ft² for same range of seed density (Table 4). For 'Covington', change in revenue for adopting higher than standard seed density was variable, with decreased revenue at 61 bu/1000 ft², a marginal increase of 4% at 73 bu/1000 ft², and a 13% decrease at 85 bu/1000 ft². In the case of 'Evangeline', an increase in seed density up to 73 bu/1000 ft² resulted in decreased revenue, but a further increase in seed density to 85 bu/1000 ft² increased the revenue after subtracting seed cost by 31% (Table 4). This shows that the economic gains from changing seed density could vary with variety of sweetpotato grown.

Seeding propagation beds with higher seed root densities would have a high upfront cost and, therefore, could be considered a high-risk strategy. Seed root costs started from $84 and increased up to $595/1000 ft² for seed root densities that ranged from 12 to 85 bu/1000 ft². Environmental conditions cannot be controlled, so growers need to be cognizant of the financial risk with increased seed root costs associated with higher densities. However, the net benefit from such a strategy could increase profits greatly. Differences between varieties can also play a role in deciding seed root density strategy. Lastly, we only considered increased seed root costs in our economic assessment of changing seed root densities. Thus, our increased potential revenues with increased seed root density do not consider the savings a producer would gain in bedding on less acreage. Savings in pesticide, fertilizer, drip tape, and efficiency of labor may all enhance grower revenue at higher seeding densities (J. Jones, personal communication). One reason behind not adding these costs is that these may vary by grower operation and worker efficiency. The other is to realize that whole seed root planting on beds is a highly mechanized process and these other costs would contribute very minimally with respect to the economics of marketable slip production with increases in seed root density. Thus, our economic assessment provides a conservative value a producer might gain by increasing seed root density.

Seed root size study

The interaction for year × seed root size was not significant for production of slips for any grades including cull, marginal, extra-long, optimal, total, and marketable; therefore, data were combined over both years. Seed root size had little to no effect on slip production. No difference between canner, no. 1, and jumbo roots were observed for cull, marginal, optimal, total, and marketable slip production (Table 5). The only significance found was that jumbo roots produced more extra-long slips than no. 1 or canner seed roots (Table 5). These results likely occurred due to the wider spacing between the jumbo roots in the propagation bed (Fig. 5). This spacing likely results in less plant competition and more space for the slips to vine out horizontally. These results suggest that using larger grades of seed roots for slip production does not increase or decrease yield for a once-over sweetpotato harvest system. In slip production systems where slips are harvested multiple times, larger sized roots may need to be considered since more energy reserves in the root may be required to produce slips over a longer period of time in places like Australia (Northern Territory Government, 2005).

Summary

These studies evaluated slip production in sweetpotato with varying seed root size and densities. Overall, seed root size had no effect on marketable slip production when using a once-over harvest system. Treatments in the seed root density study were designed to include a broad range of densities to account for variations in reported density from the North Carolina commercial sweetpotato industry. Results obtained within the range evaluated indicate that

Table 5. Slip production of sweetpotato by grade as influenced by seed root sizes at Lucama, NC, in 2012 and 2013.

Seed root size[z]	Optimal (7 to 14 inches)[z]	Marginal (5 to <7 inches)	Extra-long (>14 inches)	Cull (<5 inches)	Total	Marketable[y]
	Slips (boxes/1,000 ft^2)[y]					
Canner	15	5	2 b[x]	11	31	20
No. 1	14	4	1 b	8	29	20
Jumbo	12	3	3 a	7	24	17
LSD	12	2	1	8	22	14
P value	0.622	0.139	0.049	0.262	0.498	0.668

LSD = least significant difference.
[z]Data combined from 2012 and 2013; seed roots were graded according to USDA size standards that classify roots into no. 1 (diameter of 1.75 to 3.5 inches and length of 3 to 9 inches), canner roots (diameter 1 to 1.75 inches), and jumbo roots (diameter >3.5 inches); 1 inch = 2.54 cm.
[y]Marketable slips are considered ≥5 inches long; 1 box (1000 slips)/1000 ft^2 = 107.6391 boxes/ha.
[x]Means followed by a different letter within a column are significantly different according to Fisher's protected LSD ($P \leq 0.05$).

Fig. 5. Seed root size by grade of 'Covington' bedded at 49 bushels/1000 ft^2 (119,619.5 kg·ha^{-1}). Average 'Covington' root weight for canner, no. 1, and jumbo size roots was 6.3, 8.3, and 23 oz, respectively; 1 oz = 28.3495 g.

increasing seed root density will also increase overall slip production without a negative effect on slip quality as measured by length and nodes per slip. In 2012, the best marketable slip yield was obtained at 73 and 85 bu/1000 ft^2. In 2014, marketable slip production of 'Evangeline' increased as seed root density increased at a greater rate than 'Covington'. In 2014, the best seed root density for marketable slip yield was 49–85 and 85 bu/1000 ft^2 for 'Covington' and 'Evangeline', respectively.

An even greater increase might be observed at higher seed root densities in 'Evangeline'; however, this requires further study. Slip production would be expected to level off and drop at some point once a seed root density was reached in which more slips could not overcome the limits of resources such as space, light, and water. Research on other crop species, such as fodder radish (*Raphanus sativus* var. *oleiferous*), has shown this quadratic trend, where once the optimum point of seed density and seedling emergence was passed, increased seed density caused a decrease in initial stand and seedling emergence (Oliveira et al., 2011). Another aspect to consider is that increasing seed root density beyond what was evaluated in this study could cause seed root stacking within the beds, which would prohibit the lower seed roots from producing sprouts (J. Jones, personal communication).

Results also indicate that slip production can differ widely between varieties. Seed root density strategies can be tailored to suit grower needs; e.g., high seed root density strategy will have a higher risk due to the upfront, higher seed costs but potentially have higher payoffs at harvest time. Lower seed root density strategy would be a lower initial risk with a lower seed cost but also potentially have lower net revenues. The direct effects of seed root density on slip production, and therefore on revenue, place this production management practice as a very important consideration in the sweetpotato industry. Further research should be conducted to test other commercially grown varieties along with 'Evangeline' and to investigate potential yield increases with increased seed root density. Conversely, an investigation into higher seed root densities could also reveal the point where slip production would level off and possibly even decrease. Lastly, it should be noted that these results represent a once-over harvest slip production system rather than slip production systems that employ two or more harvests as is common with some growers.

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