Optimizing Sweetpotato Production for Fresh and Processing Markets through Plant Spacing and Planting-harvest Time

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ADDITIONAL INDEX WORDS. bulk harvest, cost-benefit, cultural practices, *Ipomoea batatas*, marginal analysis

SUMMARY. Consumption of sweetpotato (*Ipomoea batatas*) has increased in the past decade in part because of its nutritional and health attributes, and because of the availability and convenience of processed products. The sweetpotato processing industry is expanding and supplying more sweetpotato products than ever before. Unlike the medium-sized roots (U.S. no.1) preferred for fresh market, large (jumbo) roots is accepted and in certain cases desired by the processing industry, and overall yield is preferred over strict sizing requirements and aesthetic appeal. Therefore, this study investigated the yield increase and grade proportions in response to plant spacing and extension of the growing period to improve profitability of the production system. Experiments with ‘Beauregard’ and ‘Evangeline’ sweetpotato were conducted in Mississippi and Louisiana during 2010 and 2011. Treatments consisted of a combination of early and late planting date and delay in harvest, in-row plant spacing, and row width. Yield increase was inconsistent with delaying harvest and appears to depend on environmental conditions at harvest late in the season. Marketable yield was consistently greater in early plantings than late plantings. Yield of U.S. no.1 grade was unaffected by delaying harvest regardless of planting date. Delaying harvest in early plantings contributed to increase jumbo-sized roots and marketable yield. The economic assessment of delaying harvest in early plantings indicated a gain in net benefit either when hand harvested for fresh market or field run bulk harvested for processing. Row width and in-row plant spacing had only a marginal effect on yield of canner grade (small-sized roots). The economic assessment of changing plant density indicated no gain in net benefit, which indicates that choice of plant density can depend on other factors.

Sweetpotatoes are grown in the United States primarily for the fresh market, which demands attractive medium-sized roots of uniform shapes that are free from

blemishes. This class brings the highest price. In contrast, the processing sector can use storage roots of all sizes, but in the sweetpotato fry industry, they prefer large roots because the recovery is greater (longer and more consistent fry length than with medium-sized roots). In addition, shape is not as critical as for fresh market, and total yield within their quality expectations is more important than the proportion of U.S. no.1 (medium size). The U.S standards for grades of sweetpotato are U.S. Extra

no.1 with roots 1-3/4 to 3-1/4 inches diameter, 3 to 9 inches long that are less than 18 oz; U.S. no.1 with roots 1-3/4 to 3-1/2 inches diameter, 3 to 9 inches long that are less than 20 oz; U.S. no.1 Petite (or canner) with roots 1-1/2 to 2-1/4 inches diameter and 3 to 7 inches long; and U.S. no.2 consisting of roots larger than 1-1/2 inches diameter, unless otherwise specified, with a maximum weight of 32 oz [U.S. Department of Agriculture (USDA), 2005]. The commercial grade known as jumbo is larger than U.S. no.1 in diameter and/or length, and falls in the U.S. no.2 category. The market for jumbo and canner grades is primarily the processing industry. Because of the differences in size and quality standards for the processing industry vs. the fresh market, diverse production strategies may be necessary to optimize returns.

In the United States, sweetpotato is produced mainly in the southern states and the west coast with over 130,000 acres planted in 2012 (USDA, 2013a). Mississippi and Louisiana ranked second and fourth in the nation for sweetpotato acreage with 24,000 acres and 10,000 acres planted in 2012, respectively. In addition, Mississippi and Louisiana ranked third and fourth, respectively, in the nation for sweetpotato crop value with over \$62.6 million and \$33.3 million in gross farm value in 2012 (USDA, 2013b). The acreage and production of sweetpotato could increase even further because demand and per capita consumption are increasing (46% in the past decade) mainly due to two factors: the perceived nutritional and health attributes, and the availability and convenience of value-added processed products (Nalley et al., 2005; USDA, 2011; Woolfe, 1992).

Sweetpotato growers are quickly adjusting to processor's demands to

This article is based on work supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, under project no. MIS-145060, the Mississippi Agriculture and Forest Experiment Station, the Louisiana State University Agricultural Center, the Mississippi Sweet Potato Council, and the Louisiana Sweet Potato Advertising and Development Commission.

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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
45.3592	cwt	kg	0.0220
112.0851	cwt/acre	kg·ha ⁻¹	0.0089
0.3048	ft	m	3.2808
2.54	inch(es)	cm	0.3937
0.4536	lb	kg	2.2046
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

make the crop more widely available. The main objective of fresh market growers is U.S. no.1, but they supply processors with large roots for processed products to improve profitability. Therefore, an approach to increase root yield must be examined to satisfy the greater processing demand while maintaining yield of U.S. no.1 grade for fresh market. In contrast, some producers are targeting the processing sector exclusively with field-run bulk-harvest contracts; however, to be profitable, yield must increase and production costs must be reduced considerably in comparison with production intended for the fresh market. Achieving a higher total yield is critical given the lower price paid by the processors for field-run harvest. Therefore, this study focused on determining yield increases and changes in grade proportions in response to plant spacing and extension of the growing period to improve profitability of the production system intended for either fresh market or the processing industry.

Sweetpotato producers targeting fresh market venues strive to achieve a large percentage of U.S. no.1 grade roots, while minimizing small and jumbo grade roots. Growers are challenged to time-harvesting operations to reduce the number of unwanted roots and maximize marketing potential and profit. Growing roots to increase larger roots and tonnage while maintaining U.S. no.1 yield can create a larger window of success considering that the roots essentially can grow as long as environmental conditions are favorable. In addition, our assumption that a delay in harvest reduces U.S. no.1 yield may be incorrect and producers targeting the fresh market may realize a yield gain by increasing jumbo yield. There is a need to examine different planting and harvest dates, plant spacing, and row widths to determine the best combination to increase the number of large roots and overall tonnage while maintaining U.S. no.1 yield.

It is generally thought that high plant densities result in small storage roots, and as plant density decreases, the number of large roots increases (Rubatzky and Yamaguchi, 1997). Most growers use row widths ranging from 38 to 42 inches to produce sweetpotato in the United States. However, the difference, if any, between various

row widths has not been evaluated with current commercial varieties. Extension publications from the main sweetpotato production states have no specific row width recommendations except California where a double-row system on 80-inch beds is used to accommodate the drip irrigation system (Boudreaux, 2009; Schultheis et al., 2005; Stoddard et al., 2013; Thompson et al., 2002). Row width of 3-1/5 to 4 ft is recommended in Alabama (Kemble et al., 2006). In-row plant spacing recommendations are available in all states, but vary somewhat among states and varieties, and range from 8 to 16 inches. In-row plant spacing has been reported to influence yield of U.S. no.1; however, varieties responded differently to spacing and planting-harvest time (Mulkey et al., 1994; Schultheis et al., 1999). In addition, the study in North Carolina reported that 'Beauregard' planted at 15 or 23 cm increased net economic value compared with wider in-row spacing (Schultheis et al., 1999). To our knowledge, in-row plant spacing has not been evaluated at different row widths with current commercial varieties.

The objective of this study is to determine the importance of planting and harvest dates, and plant spacing in 'Beauregard' and 'Evangeline' sweetpotato to improve yields and economic benefit. Most of the research in the United States with varieties destined for food consumption has been directed to optimize U.S. no.1 root grade toward the fresh market sector. Consequently, studies with the objective of increasing total tonnage of root grades destined for processing are lacking. Furthermore, no information is available in the United States about the response to in-row plant spacing and row width combinations at different planting-harvest dates to increase tonnage and determine changes in the proportion of root grades. Storage root grades differ in value and therefore influence gross income and profitability.

Materials and methods

Field research was conducted at the Pontotoc Ridge-Flatwoods Experiment Station—Mississippi State University [Pontotoc, MS (lat. 42°1'N, long. 93°38'W)] and at the Louisiana State University Agricultural Center—Sweet Potato Research

Station [Chase, LA (lat. 32°6'N, long. 91°42'W)] in Summer 2010 and 2011. In Mississippi, the soil type was a Falkner silt loam (fine-silty, mixed, thermic Typic Ochraqualfs) and in Louisiana it was fine-silty, mixed, active, thermic Typic Glossaqualfs. 'Beauregard' and 'Evangeline' sweetpotato, G-1 (generation 1) in Mississippi and G-0 in Louisiana from the foundation seed stock in each state were used. 'Beauregard' was selected because it is the main variety used in Louisiana and Mississippi. 'Evangeline' was recently released at the time of this investigation and information about plant cultural practices needed to be defined. Field preparation activities, including fertilizer rates, herbicide, and insecticide applications, were similar in each year for each state (Boudreaux, 2012; Thompson et al., 2002). There was no supplemental irrigation supplied in Mississippi, but in Louisiana supplemental overhead irrigation was supplied with a traveling irrigation sprinkler if a rainfall event did not occur. In-season supplemental irrigation was based on soil moisture of 30% to 50% of field capacity at 6-inch depth. For the soil type used in the study, 16% volumetric water content represents 50% of field capacity.

In Mississippi, the experimental design for each year was a split-split plot with harvest date [days after planting (DAP)] as the main effect (plot), in-row plant spacing as subplot (plot), and variety as sub-subplot with four replications. Each experimental unit (sub-subplot) consisted of three 20-ft rows and the center row was harvested for evaluation. Plant spacing was 40 inches between rows and there were three in-row planting distances: 12, 16, and 20 inches. Planting was on 15 June 2010 and 9 June 2011. Storage roots were harvested on 13 Oct. 2010 (120 DAP) and 2 Nov. 2010 (140 DAP). To avoid cold temperatures by the end of the season and since yields were not different between both harvest dates in 2010, harvest was earlier in 2011: 16 Sept. 2011 (99 DAP) and 17 Oct. 2011 (130 DAP). Plots were harvested using a single-row mechanical chain harvester. After harvest, storage roots were cured for 7 d (85 °F and 80% to 85% relative humidity) and stored until evaluation. After 2 months, storage roots were classified using a modification

of the U.S. standards for grades of sweetpotatoes (USDA, 2005). U.S. no.1 grade consisted of roots 2 to 3-1/2 inches diameter and 3 to 9 inches long, canner grade consisted of roots 1-1/2 to 2 inches diameter and 3 to 7 inches long, and jumbo grade was anything larger than U.S. no.1.

In Louisiana, treatments consisted of a combination of two planting dates (early and late) and two harvest dates (early and late). The planting-harvest combinations were as follows: EE [early planting (1 June 2010 and 7 June 2011) with early harvest (4 Oct. 2010 and 10 Oct. 2011)], EL [early planting with late harvest (19 Oct. 2010 and 25 Oct. 2011)], LE [late planting (30 June 2010 and 8 July 2011) with early harvest (2 Nov. 2010 and 10 Nov. 2011)], and LL [late planting with late harvest (17 Nov. 2010 and 25 Nov. 2011)]. Treatments were replicated four times. In addition, two row widths (38 and 42 inches) and two in-row plant spacing (12 and 16 inches) were evaluated. The two varieties were planted in two-row plots (30 ft long) with 10-ft alleys between plots. For each treatment combination, one row of each plot was harvested at 125 DAP (early harvest) and the remaining row was harvested at 140 DAP (late harvest) with a single-row mechanical chain harvester. After harvesting, roots were separated into U.S. no.1, jumbo, or canner grades as described above and weighed.

Data from both locations were analyzed similarly. Yield for each grade, the combined yield of U.S. no.1 + jumbo grades and total marketable yield (all three grades) as well as the proportion of U.S. no.1 and U.S. no.1 + jumbo grades were determined and compared among treatments. The proportion of U.S. no.1 grade and the combination of U.S. no.1 + jumbo grades are presented as percentages, but the data were transformed [arcsin (square root)] for statistical analysis to stabilize the variances. Statistical analyses were conducted with SAS statistical software (version 9.2 for Windows; SAS Institute, Cary, NC). Analysis of variance was performed by Proc Mixed and differences among means were adjusted by Tukey's multiple range test ($P \leq 0.05$). Data are presented by variety and also by year due to interaction.

Cost-benefit and marginal analyses were performed for each variety each year and location to evaluate the gain in net economic benefit and the marginal rate of return of the alternative practice/technologies (International Maize and Wheat Improvement Center, 1988). The change (gain/loss) in net benefit (change in gross benefit – change in costs that varied) and the changes in costs incurred by modifying plant density and delaying harvest time was based on current sweetpotato prices and estimated costs for field operations in Mississippi for 2013 (Hood et al., 2012). The change in gross benefit was determined by the difference in total gross benefit between the standard practice and the alternative practice/technology (e.g., early and late harvest). Total gross benefit for each practice/treatment was calculated by the addition of the individual gross benefits (yield $\times$ price) from each grade. Prices for sweetpotato grades after subtracting, cleaning, packing, and marketing costs were \$12 per 50-lb bushel (bu) for U.S. no.1, \$6.5 and \$3.5 per hundred-weight (cwt) for jumbo and canner, respectively, and \$15/cwt for field-run U.S. no.1 + jumbo. The change in costs that varied was determined by the difference in the costs that varied between the standard practice and the alternative practice/technology. Costs that varied when changing plant density were estimated based on a linear relationship with the estimated planting costs (\$29 per 1000 plants and \$98.13/acre for the use of the planter, labor, and miscellaneous planting costs) for 1 acre planted at 42 $\times$ 16 inches plant spacing, which is the most common plant spacing in Mississippi (Hood et al., 2012). Costs that varied when delaying harvest were also estimated based on a linear relationship with the estimated harvest costs [\$2.40/bu for hand harvest, hauling, and storage of a 330 bu/acre sweetpotato yield for fresh market (Hood et al., 2012), and \$2.44/cwt for mechanical bulk harvest, hauling, and storage for processing of a 500 cwt/acre potato (*Solanum tuberosum*) yield (Carlson et al., 2008)]. The marginal rate of return was determined by the ratio between the change in net benefit and the change in costs that varied, and indicates the gain/loss in net benefit obtained per additional dollar invested in the alternative practice/technology.

Results

In Mississippi, sweetpotato yield was similar in 2010 and 2011, but marketable yield was higher in 'Beauregard' than 'Evangeline' both years with 616 over 520 bu/acre and 596 over 498 bu/acre in 2010 and 2011, respectively (Tables 1 and 2). 'Beauregard' U.S. no.1 and canner yields in 2010, and jumbo and canner yields in 2011 were higher than 'Evangeline'. Consequently, the combination of U.S. no.1 + jumbo grades and total marketable yields were higher by 30% and 18% in 2010 and by 16% and 20% in 2011, respectively. In addition, the proportion of U.S. no.1 and the combination of U.S. no.1 + jumbo grades of 'Beauregard' sweetpotato were larger than 'Evangeline' in 2010, but not in 2011. In Louisiana, yields were different between years and varieties (Table 3). Variety interactions were not significant at $P \leq 0.05$, but interactions occurred between years for canners and marketable yield in 'Beauregard', and for U.S. no.1, U.S. no.1 + jumbo, and marketable yield in 'Evangeline'. 'Beauregard' marketable yield was 1446 and 865 bu/acre for 2010 and 2011, respectively, and 'Evangeline' marketable yield was 865 and 699 bu/acre for 2010 and 2011, respectively (data not presented).

HARVEST DELAY. Delaying harvest from 120 to 140 DAP in Mississippi had no effect on any yield category in 2010; consequently, data were pooled together for analysis (Table 1). There were no differences detected in yield of U.S. no.1 and jumbo grades due to in-row plant spacing in both varieties. There was interaction between variety and plant spacing for the canner grade in 2010, so spacing analysis was conducted separately for each variety. Canner yield was higher at 12 inches in-row spacing in 'Beauregard' sweetpotato, but not in 'Evangeline'. Although marketable yield was not different among the in-row spacing tested for each variety in 2010 (Table 1), there was no interaction and the combined yields resulted in higher yield at 12 inches than 16 and 20 inches in-row spacing (data not shown). In 2011, there were no differences among in-row plant spacing, but yield differences due to harvest time were detected as well as harvest time by variety

Table 1. Sweetpotato yield in response to in-row plant spacing (harvest time combined) without irrigation at Pontotoc, MS, in 2010.

Variety	In-row spacing (inches) ^z	U.S. no.1 (bu/acre) ^y	Jumbo (bu/acre)	U.S. no.1 + Jumbo (bu/acre)	Canner (bu/acre)	Marketable (bu/acre)	U.S. no.1 (%)	U.S. no.1 + Jumbo (%)
Beauregard	12	386	189	575	120 a ^x	695	56	83
	16	354	135	489	70 b	559	64	87
	20	363	170	533	60 b	593	62	90
	Significance	NS	NS	NS	***	NS	NS	NS
	Correlation (<i>r</i>)				-0.67			
Evangeline	12	301	165	467	120	587	55	78
	16	214	144	358	105	463	47	76
	20	257	149	406	104	510	53	78
	Significance	NS	NS	NS	NS	NS	NS	NS
Beauregard		368	165	532	83	616	61	87
Evangeline		258	153	410	110	520	51	77
Significance		***	NS	***	**	**	**	***

^z1 inch = 2.54 cm.

^yU.S. no.1 roots are 2 to 3-1/2 inches diameter, 3 to 9 inches long, straight, uniform roots free of blemishes; canner roots are 1-1/2 to 2 inches diameter, 3 to 7 inches long; jumbo roots are larger than U.S. no.1; one 50-lb (22.7 kg) bushel/acre = 56.0426 kg·ha⁻¹.

^xMeans within columns followed by different letters are significantly different from each other by Tukey's multiple range test at *P* ≤ 0.05.

NS, *, **, *** Nonsignificant and significant at *P* ≤ 0.01 and 0.001, respectively.

Table 2. Sweetpotato yields in response to delayed harvest (in-row plant spacing combined) without irrigation at Pontotoc, MS, in 2011.

Variety	Planting-harvest time (DAP) ^z	U.S. no.1 (bu/acre) ^y	Jumbo (bu/acre)	U.S. no.1 + Jumbo (bu/acre)	Canner (bu/acre)	Marketable (bu/acre)	U.S. no.1 (%)	U.S. no.1 + Jumbo (%)
Beauregard	99	262	93	356	89	445	62	70
	130	301	362	663	218	881	34	69
	Significance	NS	***	**	*	***	***	NS
Evangeline	99	244	98	342	96	438	59	68
	130	285	221	507	110	617	46	74
	Significance	NS	*	*	NS	NS	*	NS
Beauregard		276	186	462	134	596	52	70
Evangeline		252	145	397	101	498	54	70
Significance		NS	*	*	*	**	NS	NS

^zPlanting-harvest time: Planting date was 9 June 2011; harvest dates were 16 Sept. 2011 and 17 Oct. 2011 [99 and 130 d after planting (DAP), respectively].

^yU.S. no.1 roots are 2 to 3-1/2 inches diameter, 3 to 9 inches long, straight, uniform roots free of blemishes; canner roots are 1-1/2 to 2 inches diameter, 3 to 7 inches long; jumbo roots are larger than U.S. no.1; 1 inch = 2.54 cm, one 50-lb (22.7 kg) bushel/acre = 56.0426 kg·ha⁻¹.

NS, *, **, *** Nonsignificant and significant at *P* ≤ 0.05, 0.01, and 0.001, respectively.

interactions (Table 2). In 'Beauregard', yield of jumbo and canner grades, but not of U.S. no.1 grade, increased 289% and 144%, respectively, from 99 to 130 DAP. In 'Evangeline' sweetpotato, only yield of jumbo grade increased by 126% from 99 to 130 DAP. Consequently, U.S. no.1 + jumbo grades increased by 86% and 48% from 99 to 130 DAP in 'Beauregard' and 'Evangeline', respectively, but total marketable yield increased by 97% only in 'Beauregard' sweetpotato. In contrast, the yield proportion of U.S. no.1 grade was reduced in both varieties (Table 2).

In Louisiana, yields were different among planting and harvest date combination (EE, EL, LE, and LL) in both years (Table 3). In general, yield of early plantings were higher than late plantings with 'Beauregard' both years, but only in 2011 with

'Evangeline'. Early planting in 'Beauregard' increased U.S. no.1 yields by 21% and 115% in 2010 and 2011, respectively, regardless of the harvest date. For 'Evangeline', differences were found only in 2011 where EL U.S. no.1 yield was 38% and 170% higher than EE and the late plantings (LE and LL), respectively. In 2010, jumbo yield of 'Beauregard' increased by 128% in EL over the next planting-harvest combination (EE). In 2011, jumbo yield of EL was not different from EE, but EL was 195% higher than the late planting yields (LE and LL). For 'Evangeline', EL jumbo yield was higher than EE and the late plantings at least by 164% in 2010, and in 2011, early plantings were 6.8-fold higher than late plantings regardless of harvest time. For 'Beauregard', yield of U.S. no.1 + jumbo in EL was the same as EE in 2010, but 47%

higher than the late planting yields. In 2011, yield of U.S. no.1 + jumbo in early plantings was 118% higher than late plantings regardless of harvest time. For 'Evangeline', EL was at least 20% higher than EE and the late plantings in 2010, but in 2011, EL was 32% higher than EE and at least 195% higher than the late plantings. In contrast, 'Beauregard' canner yields were increased by 75% in the late plantings in 2010, but were inconsistent in 2011. For 'Evangeline', late planting canners were also higher than early plantings by 63% in 2010, but in 2011, EL was 39% higher than EE and 156% higher than LL. 'Beauregard' marketable yields were the same among the various planting and harvest dates in 2010, but in 2011, EL was 25% higher than EE and 78% higher than the late planting dates. For Evangeline', EL marketable

Table 3. Sweetpotato yield in response to planting-harvest time (row width and in-row spacing combined) with supplemental sprinkler irrigation at Chase, LA, in 2010 and 2011.

Variety	Yr	Planting-harvest combination ^z		U.S. no.1 (bu/acre) ^y	Jumbo (bu/acre)	U.S. no.1 + Jumbo (bu/acre)		Canner (bu/acre)	Marketable (bu/acre)	U.S. no.1 (%)	U.S. no.1 + Jumbo (%)	
		Group	DAP			(bu/acre)	(bu/acre)					
Beauregard	2010	EE	125	957 a ^x	156 b	1,114 ab	314 b	1,428	67 a	77 a		
		EL	140	968 a	356 a	1,324 a	254 b	1,578	61 ab	84 a		
		LE	125	791 b	112 b	902 b	475 a	1,378	57 b	65 b		
		LL	140	792 b	86 b	878 b	522 a	1,399	55 b	60 b		
	2011	EE	125	700 a	41 ab	742 a	230 b	972 b	71 a	75 a		
		EL	140	798 a	112 a	910 a	305 a	1,216 a	65 ab	73 a		
		LE	125	364 b	33 b	386 b	286 ab	684 c	51 c	54 b		
		LL	140	333 b	38 b	371 b	219 b	589 c	56 bc	61 b		
	Significance 2010 × 2011				**	**	**	*	**	NS	NS	
	Evangeline	2010	EE	125	701	141 b	842 b	296 b	1,138 b	61	73 b	
			EL	140	791	373 a	1,164 a	251 b	1,415 a	55	82 a	
			LE	125	871	98 b	969 ab	429 a	1,398 a	62	68 b	
LL			140	819	79 b	898 ab	463 a	1,362 ab	59	64 b		
2011		EE	125	475 b	94 a	569 b	272 b	841 b	55	66 a		
		EL	140	655 a	98 a	753 a	377 a	1,130 a	58	65 a		
		LE	125	242 c	14 b	255 c	252 b	507 c	46	48 b		
		LL	140	167 c	3 b	170 c	147 c	317 d	49	50 b		
Significance 2010 × 2011				**	**	**	**	***	NS	**		
Significance Beauregard × Evangeline				***	NS	***	NS	***	***	***		

^zEE = early planting (1 June 2010, 7 June 2011), early harvest (4 Oct. 2010, 10 Oct. 2011); EL = early planting, late harvest (19 Oct. 2010, 25 Oct. 2011); LE = late planting (30 June 2010, 8 July 2011), early harvest (2 Nov. 2010, 10 Nov. 2011); and LL = late planting, late harvest (17 Nov. 2010, 25 Nov. 2011); DAP = days after planting.

^yU.S. no.1 roots are 2 to 3-1/2 inches diameter, 3 to 9 inches long, straight, uniform roots free of blemishes; canner roots are 1-1/2 to 2 inches diameter, 3 to 7 inches long; jumbo roots are larger than U.S. no.1; 1 inch = 2.54 cm, one 50-lb (22.7 kg) bushel/acre = 56.0426 kg·ha⁻¹.

^xMeans within columns followed by different letters are significantly different from each other by Tukey's multiple range test at $P \leq 0.05$.

NS, *, **, *** Nonsignificant and significant at $P \leq 0.05$, 0.01, and 0.001, respectively.

yield in 2010 was 24% higher than EE, but similar to the late plantings. However, in 2011 EL was 34%, 123%, and 256% higher than EE, LE, and LL, respectively. The proportion of 'Beauregard' U.S. no.1 as a fraction of the total marketable yield in EE only was larger than the late plantings both years; however, the proportion of U.S. no.1 + jumbo for both early plantings was larger than the late plantings regardless of harvest time both years. For 'Evangeline', the proportions of U.S. no.1 were the same for all planting-harvest combinations both years. In contrast, the proportion of U.S. no.1 + jumbo for EL was larger than all other treatments in 2010 and the proportions of both early plantings were larger than the late plantings in 2011 (Table 3).

PLANT DENSITY. Yields were also analyzed according to in-row plant spacing (12 and 16 inches) for yield by grade for each variety (Table 4). Differences in yield between both in-row spacing were found only in canner grades. In 2010, 'Beauregard' yielded 17% higher in the 12-inch in-row spacing than the 16 inches.

No difference was found in 2011. For 'Evangeline', canner yields at 12 inches were 6% and 25% higher than 16 inches in 2010 and 2011, respectively. The effects of in-row spacing on the proportions of U.S. no.1 grade and U.S. no.1 + jumbo were inconsistent. In 2010, only the 'Beauregard' U.S. no.1 proportion was higher at 16 inches. In contrast, U.S. no.1 and U.S. no.1 + jumbo proportions of 'Evangeline' were increased at 16 inches in 2011. No other differences were found in either year. The effect of increasing row width from 38 to 42 inches on yield was also investigated by variety (Table 5). The only differences were found in 2010 with canner grade of both varieties. Canner yield was 28% and 35% higher for 'Beauregard' and 'Evangeline', respectively, in the 42 inches row width. No other grade and yield proportion was different in both years.

ECONOMIC ASSESSMENT. The cost-benefit analysis of changing plant density resulted in no changes in the net benefit because U.S. no.1, jumbo, and marketable yields were not different among row width and in-row plant spacing (Tables 1, 4,

and 5), and the variability in gross and net income were greater than the changes in costs that varied (data not presented). The cost-benefit and marginal analyses of delaying harvest time were conducted with the data from early plantings in Louisiana both years and the 2011 study in Mississippi because of the yields in the late plantings were mostly the same (Tables 2, 3, and 6). Overall, delaying harvest in early plantings increased yields and therefore increased gross income as well as costs that varied. Depending on the harvest system, hand harvest for fresh market or field-run bulk harvest for processing, changes in gross income ranged from \$677 to \$2415 per acre. Changes in costs that varied were consistently lower for bulk harvest and ranged from 36% to 71% of the corresponding hand harvest. The changes in net benefit due to delaying harvest were positive in all early plantings. In general, the gains in net benefit were higher for the bulk-harvest system ranging from \$1034 to \$2022 per acre than the hand-harvest system, which ranged from \$315 to \$1663 per acre. This reduced

Table 4. Sweetpotato yield in response to in-row plant spacing (row width and planting-harvest time combined) with supplemental sprinkler irrigation at Chase, LA, in 2010 and 2011.

Variety	Yr	In-row spacing (inches) ^z	U.S. no.1 (bu/acre) ^y	Jumbo (bu/acre)	U.S. no.1 + jumbo (bu/acre)	Canner (bu/acre)	Marketable (bu/acre)	U.S. no.1 (%)	U.S. no.1 + jumbo (%)
Beauregard	2010	12	873	181	1,055	422	1,476	58	70
		16	880	174	1,054	361	1,415	62	73
	Significance		NS	NS	NS	*	NS	*	NS
	2011	12	533	54	587	277	864	60	65
		16	565	58	617	244	866	61	66
	Significance		NS	NS	NS	NS	NS	NS	NS
Evangeline	2010	12	818	170	988	371	1,359	59	71
		16	774	175	949	349	1,298	59	73
	Significance		NS	NS	NS	*	NS	NS	NS
	2011	12	369	57	427	291	718	48	53
		16	400	47	447	233	680	57	62
	Significance		NS	NS	NS	***	NS	**	**

^z1 inch = 2.54 cm.

^yU.S. no.1 roots are 2 to 3-1/2 inches diameter, 3 to 9 inches long, straight, uniform roots free of blemishes; canner roots are 1-1/2 to 2 inches diameter, 3 to 7 inches long; jumbo roots are larger than U.S. no.1; one 50-lb (22.7 kg) bushel/acre = 56.0426 kg·ha⁻¹.

NS, *, **, *** Nonsignificant and significant at $P \leq 0.05$, 0.01, and 0.001, respectively.

Table 5. Sweetpotato yield in response to row width (in-row spacing and planting-harvest time combined) with supplemental sprinkler irrigation at Chase, LA, in 2010 and 2011.

Variety	Yr	Row width (inches) ^z	U.S. no.1 (bu/acre) ^y	Jumbo (bu/acre)	U.S. no.1 + jumbo (bu/acre)	Canner (bu/acre)	Marketable (bu/acre)	U.S. no.1 (%)	U.S. no.1 + jumbo (%)
Beauregard	2010	38	841	172	1,013	343	1,356	60	72
		42	912	184	1,096	440	1,535	60	71
	Significance		NS	NS	NS	*	NS	NS	NS
	2011	38	517	57	568	243	817	60	65
		42	581	55	636	278	913	62	67
	Significance		NS	NS	NS	NS	NS	NS	NS
Evangeline	2010	38	819	171	990	306	1,297	62	74
		42	772	174	947	413	1,360	57	69
	Significance		NS	NS	NS	*	NS	NS	NS
	2011	38	358	57	415	257	672	48	54
		42	411	47	459	267	726	56	61
	Significance		NS	NS	NS	NS	NS	NS	NS

^z1 inch = 2.54 cm.

^yU.S. no.1 roots are 2 to 3-1/2 inches diameter, 3 to 9 inches long, straight, uniform roots free of blemishes; canner roots are 1-1/2 to 2 inches diameter, 3 to 7 inches long; jumbo roots are larger than U.S. no.1; one 50-lb (22.7 kg) bushel/acre = 56.0426 kg·ha⁻¹.

NS, * Nonsignificant and significant at $P \leq 0.05$, respectively.

gain in net benefit was reflected in the marginal rate of return. For bulk harvest the marginal rate of return was consistently 5.15, but for the hand-harvest system varied from 0.50 to 2.40. In addition, the gains in net benefit and the marginal rate of return were reduced in Mississippi, and considering the longer time harvest was delayed, 31 d compared with 15 d in Louisiana, the gains and rate are comparatively lower.

Discussion

The yield response to planting and harvest combinations as well as

the in-row plant spacing treatments in Mississippi and Louisiana were comparable and data are validated because the same varieties were used. In Mississippi, the late planting in combination with early and late harvest conducted in 2010 were comparable to the LE and LL planting-harvest combination in Louisiana (Tables 1 and 3). The lack of yield response to delayed harvest in the late plantings may be most likely due to cold temperatures late in the season. The planting-harvest combinations investigated in Mississippi in 2011 were comparable to the EE and EL planting-

harvest combinations in Louisiana where yield increased with a delay in harvest under favorable temperature regimes (Tables 2 and 3). Although actual yields of 'Beauregard' were higher than 'Evangeline' in this study, the yield responses to the treatments were similar in both varieties and states. This may differ with other varieties and locations.

HARVEST DELAY. Extending the growing period in sweetpotato allows the storage roots to grow larger resulting in increased tonnage of marketable roots (Tables 2 and 3). In most grade categories, the early planting date and

Table 6. Cost-benefit and marginal analyses of delaying harvest time in early planted sweetpotato production for fresh and processing markets.

Variety	Yr	Location ^z	Harvest delay (d)	Change in gross income ^y		Change in costs that varied ^y		Change in net benefit ^y		Marginal rate of return ^y	
				Hand harvest (\$/acre) ^x	Bulk harvest (\$/acre) ^x	Hand harvest (\$/acre)	Bulk harvest (\$/acre)	Hand harvest (\$/acre)	Bulk harvest (\$/acre)	Hand (\$/acre)	Bulk (\$/acre)
Beauregard	2010	LA	15	677	1,575	362	256	315	1,319	0.87	5.15
	2011	LA	15	1,538	1,260	585	205	953	1,055	1.63	5.15
	2011	MS	31	1,567	2,308	1,047	375	520	1,933	0.50	5.15
Evangeline	2010	LA	15	1,755	2,415	664	393	1,091	2,022	1.64	5.15
	2011	LA	15	2,357	1,380	693	224	1,663	1,156	2.40	5.15
	2011	MS	31	922	1,234	430	201	492	1,034	1.14	5.15

^zLA = Chase, LA; MS = Pontotoc, MS.^yChange in gross income = gross income late harvest – gross income early harvest. Change in costs that varied = harvest costs of the late harvest – harvest costs of the early harvest. Change in net benefit = Change in gross income – change in costs that varied. Marginal rate of return = change in net benefit ÷ change in costs that varied.^xHand harvest = conventional hand harvest to select U.S. no.1 storage roots for fresh market and canner and jumbo roots for processing; bulk harvest = field-run mechanical bulk harvest of U.S. no.1 and jumbo roots for processing; \$1.00/acre = \$2.4711/ha.

late harvest date combination was regarded as the best combination to maximize tonnage (Tables 2 and 3). Recent research suggests that it is extremely important to get transplants planted as early as possible during the growing season, but not until soil temperature is above 65 °F (Villordon et al., 2010). Typically, anything planted in July in the southern U.S. region adjacent to the Gulf of Mexico does not perform as well as those planted before July, as high temperatures have been shown to reduce storage root formation (Ravi and Indira, 1999; Reddy et al., 2013). Delaying harvest is thought to achieve higher yield and more jumbo roots because sweetpotato is indeterminate and continues growing under adequate environmental conditions (Loebenstein and Thottappilly, 2009). In this study, the average increase in marketable yield in the early plantings when harvest was delayed 15 to 31 d ranged from 10 to 16 and 6 to 19 bu/acre per day for ‘Beauregard’ and ‘Evangeline’, respectively (Tables 2 and 3). However, the lack of response when harvest was delayed into November in Mississippi in 2010 (data not shown) and the LL combination in comparison with LE in Louisiana (Table 3) indicates that extending the harvest too late in the season is ineffective and possibly detrimental due to cold temperatures. EL marketable and jumbo grades were the top yields in both varieties regardless of year and location (Tables 2 and 3). These results reinforce the importance of getting transplants out as early as possible (Villordon et al., 2010). The increase in marketable yield as well as tonnage of larger roots produced by using the EL combination may significantly increase revenue for producers growing for both the fresh market as well as the processing sector.

This study demonstrated no loss in U.S. no.1 yield by delaying harvest as long temperatures are adequate. The canner grade roots appear to have sized into U.S. no.1 roots and the U.S. no.1 roots into jumbo grade roots because no reduction was observed in U.S. no.1 yield in Mississippi and Louisiana regardless of variety and year. In general, yield of Jumbo grade increased with early planting and late harvest, but not with late planting and late harvest in the season (Tables 2 and 3). An increased

jumbo yield is especially valuable for the processing sector because it is available at a reduced price. Sweetpotato is indeterminate in growth and these results demonstrate that a longer growth period allows additional bulking without a compromise in the yield grade desired for fresh market. Thus, a producer targeting the fresh market can maintain their supply and realize a gain with a longer growing period by increasing their supply to the processing industry. This data implies little consequence in U.S. no.1 yield if an unforeseen delay in harvest occurs as long as growing conditions are adequate; however, an extended delay (beyond adequate environmental conditions) may be risky and negatively affect the entire crop. Similarly, growing sweetpotato and delaying harvest in sweetpotato weevil-infested areas would be a risky business.

PLANT DENSITY. In-row plant spacing had a slight and inconsistent effect on canner yield only regardless of the variety (Tables 1 and 4). In 2010, ‘Beauregard’ responded with a higher canner yield at 12 inches than 16 inches in both states; however, there was no difference in 2011. ‘Evangeline’ canner yield was the same in Mississippi, but higher at 12 inches in Louisiana both years. Yield of U.S. no.1 grade was reported to increase as plant spacing decreases to 15 cm; however, differences were not pronounced for spacing between 31 and 38 cm (Schultheis et al., 1999). Higher canner yield were the only observed differences to plant spacing, yet the canner grade yield is the most inconsequential of all grades. Spacing at 16 or 20 inches appears to be a more advantageous spacing to adopt with ‘Beauregard’ and ‘Evangeline’ because reducing plant population per acre subsequently may reduce input costs. Similar to in-row plant spacing, only canner yield responded, also inconsistently, to changes in row width for both varieties (Table 5). Yield at 42 inches was higher than that at 38 inches in 2010 only. However, the canner grade is not considered a reliable tool in estimating the success of a crop. No additional differences were detected for any other category during 2010 or 2011. Therefore, the 42-inch row width may be recommended to decrease the number of plants per acre and maximize cost efficiency. In addition, the

wider row width may have value in nonirrigated acreage, if water is a limiting resource.

ECONOMIC ASSESSMENT. Changing plant density within the range tested in this study resulted in no changes in the economic benefit. Because the most valuable sweetpotato grades and gross income were not different among the plant densities (Tables 1, 4, and 5) and the variability in gross income was greater than the changes in costs that varied (data not presented), the net income was the same rendering no economic gain. In Mississippi, the most common planting distance is 42 × 16 inches, so increasing plant density would only increase planting cost without a gain in net benefit. However, in North Carolina reducing in-row plant spacing to 6 or 9 inches was reported to increase yield of ‘Beauregard’ U.S. no.1 roots and the net economic value (Schultheis et al., 1999). Similarly, ‘Beauregard’ planted at 9 inches in Louisiana resulted in the highest yield of U.S. no.1 when planted from mid-May to mid-June but no economic analysis was performed (Mulkey et al., 1994).

Delaying harvest time in early planted crop resulted in a net economic gain. Growers need to be cognizant of the market demands and adjust their practices accordingly to meet market expectations. Prices received by growers depend on the particular grade and market, and the difference in prices is a factor in the net benefit and marginal rate of return when delaying harvest (Table 6). The positive marginal rate of return indicates that for every additional dollar invested in delaying harvest, a proportional gain is attained and the net benefit of the crop is improved. On average, the increase in the estimated net benefit by delaying harvest 15 d in Louisiana was \$634 and \$1377 per acre for ‘Beauregard’ and ‘Evangeline’, respectively, when hand harvested for fresh market, and \$1187 and \$1589 per acre, respectively, when bulk harvested for processing after paying for all production and harvest costs (Table 6). The higher gain in net benefit and marginal rate of return of the bulk-harvest system for processing suggests that it has more room to improve than the hand-harvest system for fresh market. Similarly, the higher gain in net benefit and marginal return in ‘Evangeline’

suggests that the response was more sizable than ‘Beauregard’. Therefore, delaying harvest is an important factor to take in consideration when maximizing yield for specific markets.

In summary, this study evaluated storage root yield in sweetpotato when delaying harvest at different plant spacing and row widths. Treatments were designed to increase overall tonnage and large roots and reduce costs. Results indicate that early planting and late harvest date combination results in increased tonnage, particularly of jumbo roots while maintaining the valuable U.S. no.1 size roots. The increase in yield resulted in a gain in net benefit either for fresh market or for processing. This is important not only for producers growing strictly for a processor but for fresh market growers who intend to supply both the fresh market and the processing sector as well. Delaying harvest (as long as environmental conditions are favorable) to allow the crop to size did not negatively impact U.S. no.1 productivity, but it does extend the time the crop is susceptible to flooding and frost damage. Altering plant spacing and row width did not increase yield in this study, and these practices may be determined by other factors in the grower’s operation. Future research should examine fertility as well as irrigation requirements in varied production intervals to optimize total yield and the consequences to the various grades.

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