In-row Plant Spacing and Date of Harvest of 'Beauregard' Sweetpotato Affect Yield and Return on Investment

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Abstract. The effects of plant spacing (15, 23, 31, and 38 cm) and date of harvest on yield and economic return of 'Beauregard' sweetpotato [*Ipomoea batatas* (L.) Lam.] were studied. For comparison, 'Jewel' was included at one spacing. As in-row plant spacing decreased, yield of U.S. No. 1, canners, and total marketable root production increased when plants were harvested 103 days or later after transplanting. The yield of jumbo roots generally increased with in-row spacing because of less plant-to-plant competition. Total marketable and No. 1 grade yields of 'Beauregard' at the closest spacing (15 cm) were greater than those of 'Jewel'. 'Beauregard' roots sized more quickly than 'Jewel' roots regardless of spacing. The optimal time for harvesting 'Beauregard' was 100 to 110 days after transplanting, while acceptable yields could be obtained as early as 90 days after transplanting depending on market prices. Economic analysis of 'Beauregard' spacing data indicated that 23 cm would be the preferred spacing if a late harvest was anticipated, while the 15-cm spacing would be best if harvested at ≈ 110 days after transplanting. Thus, sweetpotato growers should place 'Beauregard' at an in-row spacing of 15 or 23 cm, depending on projected date of harvest, on or before 10 June, to obtain the best yields with the highest return on investment.

Sweetpotato is produced in great quantity in North Carolina. The state ranks first in number of hectares ($\approx 14,000$ to $15,000$ planted annually) and first in total value ($\approx \$56$ to $\$79$ million) (North Carolina Agricultural Statistics, 1996) for sweetpotato production in the United States. 'Jewel' was released by North Carolina State Univ. in 1969 (Pope et al., 1971) and was the dominant clone grown in the United States until 'Beauregard' was released by the Louisiana Agricultural Experiment Station in 1987 (Rolston et al., 1987). Sweetpotato growers in North Carolina were surveyed by mail in 1991 to determine their variety preferences; results indicated that 'Jewel' and 'Beauregard' were being grown on 67% and 27% of the sweetpotato acreage in

the state, respectively (Toth et al., 1996). Since 1991, the percentage of 'Beauregard' acreage in North Carolina has been increasing because of consumer preference in many markets. Sweetpotato plantings in North Carolina are made beginning in early May and usually completed by late June (Wilson et al., 1989). At least 75% of the annual acreage was planted by 7 June from 1987 to 1992 (North Carolina Dept. of Agriculture, 1993).

The effects of in-row spacing have been studied for several sweetpotato clones, and the recommended spacing for most clones is 23 to 40 cm (Rubatzky and Yamaguchi, 1997; Swader et al., 1992). Typically, as the in-row spacing for sweetpotatoes increases, the total root yield decreases, while the yield of larger-size (jumbo) roots increases (Anderson et al., 1945). Yields of 'Nemagold', 'Goldrush', and 'Kandee' usually increased when in-row spacing decreased from 53 to 38 cm (Petersen, 1961), but yields of 'Orlis' were unaffected. Based on yield, the recommended plant spacings for several sweetpotato clones are: 'Nancy Hall', 38 cm (Price, 1930); 'Little Stem Jersey', 20 cm (Zimmerley, 1935); 'Unit 1 Porto Rico', 31 cm (Miller and Kimbrough, 1936); and 'Maryland Golden', 38 cm (Stark and Scott, 1955). Recommended in-row plant spacings for 'Porto Rico' ranged from 20 to 41 cm depending on yield and/or cost of production (Anderson and Randolph, 1943; Anderson et al., 1941; Curry, 1943; Woodard, 1932; Zimmerley, 1935). Most growers use recom-

mended plant spacings of 25 to 28 cm for 'Jewel' to obtain high yields (Wilson et al., 1989). However, unpublished results (H. Covington, personal communication) indicated that plant spacings of 23 cm for 'Jewel' gave highest yields.

Sweetpotato growers face the challenge of producing a profitable crop with increasing costs of production. To be financially successful, growers must increase marketable yields while minimizing production costs and risks. Sweetpotato plants represent significant production costs. The economic analysis of various sweetpotato plant spacing treatments can be useful in determining the benefits and costs associated with each plant spacing. One way to make economic comparisons among treatments is to develop a partial budget economic analysis (Estes et al., 1986), which evaluates comparative input and output measures for each alternative treatment relative to the control practice. The standard North Carolina practice consists of using 'Beauregard' planted at an in-row interval of 31 cm on a shaped bed 1.1 m wide (Wilson et al., 1989).

As indicated previously, sweetpotato clones may differ considerably in optimal plant spacing requirements. There are no previous refereed publications concerning cultural management and economic studies on 'Beauregard' sweetpotato. These studies concentrated on determining the optimum in-row plant spacing for obtaining the highest yields, highest economic returns, and best root quality of 'Beauregard' under North Carolina conditions. At the time this study was initiated, 'Jewel' was the predominant variety grown in North Carolina (Toth et al., 1996) and was included in two tests for comparison with 'Beauregard'.

Materials and Methods

Three tests were conducted over a 2-year period (1991 and 1992) in North Carolina with the purpose of determining optimal plant spacings for 'Beauregard' sweetpotato. Sweetpotatoes were graded according to U.S. Dept. of Agriculture (U.S. Dept. of Agriculture, 1981) and North Carolina Dept. of Agriculture (Sweetpotato Grade Booklet, 1979) standards, which classify harvested product into No. 1 roots (diameter of $4.4 \text{ cm} \leq 8.9 \text{ cm}$ and length of $7.6 \text{ cm} \leq 22.9 \text{ cm}$), canner roots (diameter of $2.5 \leq 4.4 \text{ cm}$), jumbo roots (diameter $> 8.9 \text{ cm}$), and cull roots (malformed or distorted roots).

Expt. 1, Meadow, 1991. A test was conducted on-farm in Meadow, N.C., in 1991 to compare the effects of three plant spacings (15, 23, and 31 cm) on yields of 'Beauregard' with those of 'Jewel' at a plant spacing of 25 cm. Plants were transplanted 30 May. The statistical design was a randomized complete block with four treatments and four replications. Plots were 7.6 m in length and rows were formed on 1.2-m centers. The soil type was a Norfolk loamy sand (fine loamy, siliceous, thermic typic Paleudult). Recommended cultural and pest management practices (North Carolina State Univ.—College of Agriculture and Life Sciences, 1991; Toth et al., 1996;

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Wilson et al., 1989) were followed through the completion of harvest. At 132 days after transplanting (DAT), the middle 6.1 m of row was harvested from the plots.

Expt. 2, Clinton, 1992. The experiment was conducted at the Horticultural Crops Research Station in Clinton, N.C., to compare the yields of 'Beauregard' at four plant spacings (15, 23, 31, and 38 cm) with those of 'Jewel' at a spacing of 23 cm. The test was a split-plot arrangement with six harvest dates as main plots and the five treatments as subplots. The treatments were replicated four times. Plots were 12.2 m in length and rows were formed on 1.1-m centers. The soil type was a Orangeburg loamy sand (fine loamy, siliceous, thermic typic Paleudult). Plants were transplanted 3 June and harvested on 25 Aug. (83 DAT), 4 Sept. (93 DAT), 14 Sept. (103 DAT), 23 Sept. (112 DAT), 2 Oct. (121 DAT), and 12 Oct. (131 DAT). Cultural and pest management practices were followed as described previously. At harvest, data were collected from the middle 9.1 m of row.

Expt. 3, Coharie, 1992. The effect of in-row plant spacings on 'Beauregard' yields were compared at five harvest dates at Millstream Farms in Coharie, N.C. The soil type was a Norfolk loamy sand (described previously). At planting, 45 kg·ha⁻¹ of 0N-46P-0K and 224 kg·ha⁻¹ of 0N-0P-60K were broadcast. The statistical design was a split-plot arrangement with four replications. The main plots were the five harvest dates [26 Aug. (90 DAT), 4 Sept. (99 DAT), 15 Sept. (110 DAT), 24 Sept. (119 DAT), and 9 Oct. (134 DAT)]. Subplots were the four in-row plant spacings (15, 23, 31, and 38 cm). Planting occurred on 28 May. Plots were 9.1 m in length and rows were formed on 1-m centers. Cultural and pest management practices were followed as described previously. At harvest, 7.6 m of row was harvested from the middle of each plot.

Statistical analysis. For all experiments, yields of graded roots were recorded and analyzed using the SAS GLM procedure (SAS Institute, 1989). For 1991 and each experiment and harvest date in 1992, regression analysis was performed on 'Beauregard' plant spacing vs. root grade (Tables 1 and 3). To avoid presenting a model for each harvest date, plant spacing, and root grade (44 total models), an overall regression model is presented for each root grade by combining plant spacing and harvest date data.

Economic analysis. Although production practices differed slightly among experiments, major costs included the purchase of plants, the use of machinery, equipment, and labor in planting and harvesting, and yield-related factors, such as the number of bulk bins needed and the quantity of shipping containers used. Partial budgets were constructed for the 1991 experiment conducted in Meadow (Table 2), for 112 and 131 DAT harvests of the 1992 experiment conducted in Clinton (Table 2), and for the 110 and 134 DAT harvests of the 1992 experiment conducted in Coharie (Table 2). The last harvest date (131 and 134 DAT for the 1992 Clinton and Coharie locations, respectively) was chosen for economic analysis,

Table 1. Effect of plant spacing on yields (t·ha⁻¹) of sweetpotato harvested 132 d after transplanting (DAT) in 1991.²

Clone/plant	Spacing(cm)	No. 1	Canner	Jumbo	Cull	Total marketable	Total
'Beauregard'	15	17.0	11.3	1.0	5.6	29.3	34.9
	23	12.9	7.1	6.2	3.8	26.2	30.0
	31	9.0	9.1	2.5	4.9	20.6	25.5
'Jewel'	25	11.3	11.5	3.8	0.8	26.6	27.4
LSD(<i>P</i> < 0.05)		5.1	2.2	4.0	3.9	7.7	9.0

²Means for four replications. Least significant difference (LSD) presented to allow comparisons of 'Jewel' with the different 'Beauregard' spacings. A linear relationship best explained yields of U.S. No. 1 grade roots: y (yield of No. 1 'Beauregard' roots) = $24.92 - 0.523$ (plant spacing), $r^2 = 0.99$, $P = 0.0068$; and total marketable yield: $y = 42.07 - 0.603$ (plant spacing), $r^2 = 0.99$, $P = 0.045$. No linear or quadratic response was associated with plant spacing on the yield of canners, jumbos, culls, or total marketable yield of 'Beauregard'.

Table 2. Partial budget, net economic value and benefit-cost index values² for two (1991) or three (1992) alternative, in-row spacings of 'Beauregard' sweetpotato and one in-row spacing for 'Jewel' sweetpotato (Expt. 1, 1991 and Expt. 2, 1992) harvested 132 (Expt. 1, 1991), 112 and 131 (Expt. 2, 1992), or 110 and 134 (Expt. 3, 1992) days after transplanting (DAT).

	'Beauregard'						'Jewel'			
Partial budget	15	23					25			
<i>Expt. 1, 1991</i>										
Added revenue	4019	2894					1649			
Reduced cost	71	12					0			
Net positive effect	4090	2906					1649			
Reduced revenue	413	154					0			
Added cost	1211	823					555			
Net negative effect	1624	977					555			
NEV ^y	2466	1929					1094			
BCIV ^x	1.52	1.97					1.97			
			'Beauregard'						'Jewel'	
	15		23		38		23			
Partial budget	112	131	112	131	112	131	112	131		
<i>Expt. 2, 1992</i>										
Added revenue	5570	8137	2058	1506	28	1025	285	884		
Reduced cost	0	27	0	4	657	198	876	975		
Net positive effect	5570	8164	2058	1510	685	1223	1161	1859		
Reduced revenue	0	412	1072	8	3408	1409	4297	4235		
Added cost	1671	1876	444	642	0	81	373	355		
Net negative effect	1671	2288	1516	650	3408	1490	4670	4590		
NEV ^y	3899	5876	542	860	-2723	-267	-3509	-2731		
BCIV ^x	2.33	1.57	0.36	1.32	0	0	0	0		
			'Beauregard'							
	15		23		38					
Partial budget	110	134	110	134	110	134				
<i>Expt. 3, 1992</i>										
Added revenue	2102	2914	510	2297	1210	1071				
Reduced cost	0	94	12	0	241	241				
Net positive effect	2102	3008	522	2297	1451	1312				
Reduced revenue	522	2090	330	688	1584	2021				
Added cost	1138	961	476	655	80	27				
Net negative effect	1660	3051	806	1343	1664	2048				
NEV ^y	442	-43	-284	954	-213	-736				
BCIV ^x	0.26	0	0	0.71	0	0				

²The 31-cm spacing (data not shown) represents the base value (0) with which all other spacings are compared.

³NEV (Net economic value) is the summation of net positive effects (those that add revenues or reduce costs) and net negative effects (those that reduce revenues or add costs).

⁴BCIV (benefit-cost index value) is calculated by dividing the marginal return (net positive effect) by the marginal cost (net negative effect) and subtracting 1.0. The BCIV provides an indirect and simplified measure of marginal return on investment by treatment (e.g., a BCIV of 2.5 indicates that a gain of \$2.50 is achieved for every \$1 invested).

because these harvest times were the most conservative estimate from an economic point of view, while the middle harvest (112 and 110 DAT for the 1992 Clinton and Coharie locations, respectively) was chosen because these harvest times represented the time when most commercial growers harvest 'Beauregard' sweetpotatoes. For all partial budget calcula-

tions, we assumed that gross revenues for all No. 1 grade sweetpotatoes generated \$481.25/MT, jumbo grade \$275/MT, and canner grade \$77/MT. Gross revenues were obtained by multiplying marketable yield × grade × the assumed price. Prices represent the uncured season average obtained from eastern *North Carolina Market News* reports in 1991 and

1992. Additional 'Beauregard' or 'Jewel' sweetpotato plants were valued at the standard 1992 commercial purchase rate of \$25/1000 plants. Bulk field bins were valued at \$45 each and had an expected useful life of 5 years, resulting in an annual expense of \$9 each. Additional shipping containers (18.1-kg boxes) were valued at their bulk purchase rate of \$0.75 each. We also assumed that planting machinery, equipment, and field labor time increased with plant density. A linear relationship was assumed between harvesting equipment, machinery, and labor time and yield. Machinery and equipment were valued at \$10/h while labor was valued at \$6/h.

Results

Expt. 1, Meadow, 1991. U.S. No. 1 grade roots and total root yield of 'Beauregard' decreased as spacing increased (Table 1). A linear relationship with spacing best explained these results. No linear or quadratic effects of plant spacing on the yield of canners, jumbos, culls, or total marketable roots were found. This suggests that greater total yields of 'Beauregard' were obtained primarily from an increase in No. 1 roots at closer plant spacings.

Yield of No. 1 roots was greater for 'Beauregard' at 15 cm than for 'Jewel' at 25 cm. No. 1, total, and total marketable yields of 'Beauregard' at in-row plant spacing of 23 or 31 cm were similar to those of 'Jewel'. 'Beauregard' produced more cull roots at most plant spacings than did 'Jewel'.

All alternative spacings increased the net economic value (NEV) per hectare relative to the control practice of planting at 31 cm (Table 2). The 15-cm spacing resulted in the greatest NEV with an increase of \$2466/ha. The 23-cm spacing of 'Beauregard' and the 25-cm spacing of 'Jewel' also increased the NEV when compared with the 31-cm spacing of 'Beauregard', with NEV gains of ~\$1900 and \$1100/ha, respectively. Benefit-cost index value (BCIV) estimates indicated that the lowest NEV treatments ('Jewel' at 25 cm and 'Beauregard' at 23 cm) provided identical BCIVs of 1.97. The 15-cm plant spacing, which generated the greatest total yield and the largest NEV estimate, provided a positive but smaller return per dollar invested than did 'Jewel' at 25 cm and 'Beauregard' at 23 cm.

Expt. 2, Clinton, 1992. By the third harvest (103 DAT), No. 1 root yields increased as in-row spacing decreased (Fig. 1A, Table 3). Yield of 'Jewel' No. 1 roots (at 23 cm only) did not differ from yields of 'Beauregard' at the 23-, 31-, and 38-cm spacings on most harvest dates (Fig. 1A). However, yields of 'Beauregard' at the 15-cm spacing were greater than those of 'Jewel' regardless of harvest date, the exception being 83 DAT. The yield of cull roots was not affected by plant spacing (data not shown).

'Jewel' produced a greater yield of canner roots than did 'Beauregard' in all cases except the 15-cm in-row spacing at the 93 DAT harvest (Fig. 1B). This indicates that roots of 'Jewel' at 23 cm either do not size as quickly as do those of 'Beauregard', or that 'Jewel'

Table 3. Regression analysis for linear (L) and quadratic (Q) responses for each harvest date and root grade of 'Beauregard' plant spacings for two experiments conducted during 1992.

DAT ²	No. 1		Canner		Jumbo		Total	
	L	Q	L	Q	L	Q	L	Q
<i>Expt. 2, Clinton</i>								
83	NS	NS	0.60**	0.62**	NS	NS	NS	NS
93	NS	NS	0.43**	0.57**	NS	NS	NS	NS
103	0.47**	0.48*	0.48**	0.56**	0.53**	0.53**	NS	NS
112	0.56**	0.56**	NS	NS	NS	NS	0.42**	0.43*
121	0.62**	0.62**	0.36*	0.36*	NS	NS	0.39**	0.39*
131	0.65**	0.78***	0.48**	0.49*	NS	NS	0.31*	0.42*
<i>Expt. 3, Coharie</i>								
90	NS	NS	0.55***	0.57***	NS	NS	0.11*	NS
99	0.12*	0.13*	0.59***	0.60***	0.28***	0.30**	0.12*	0.14*
110	0.16**	0.16*	0.22**	0.22**	0.31***	0.36***	NS	NS
119	0.33***	0.34***	0.18**	0.19**	0.42***	0.42***	0.12*	0.15*
134	0.20**	0.21**	0.30***	0.35***	0.30***	0.30**	NS	NS

²DAT = number of days after transplanting.

NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.0001, respectively.

Fig. 1. Clinton, 1992. Effect of four different plant spacings (PS) on yield over six harvest dates for 'Beauregard' sweetpotato compared with 'Jewel' at 23 cm.

(A) Yield of No. 1 roots; y ('Beauregard' root yield) = $-104.75 + 1.97(\text{DAT}) - 0.0062(\text{DAT})^2 + 1.2(\text{PS}) - 0.0013(\text{PS})^2 - 0.01549(\text{DAT})(\text{PS})$; $R^2 = 0.92$, $P = 0.0001$. LSDs ($P < 0.05$) for comparison of 'Jewel' with different 'Beauregard' spacing treatments were 3.9, 5.6, 7.0, 8.5, 7.1, 5.5 for the 83, 93, 103, 112, 121, and the 131 DAT harvests, respectively.

(B) Yield of canner roots; y ('Beauregard' root yield) = $13.114 - 0.027(\text{DAT}) - 0.00015(\text{DAT})^2 - 0.438(\text{PS}) + 0.0038(\text{PS})^2 + 0.00122(\text{DAT})(\text{PS})$; $R^2 = 0.73$, $P = 0.0001$. LSDs ($P < 0.05$) for comparison of 'Jewel' with different 'Beauregard' spacing treatments were 1.1, 1.8, 1.4, 1.9, 1.8, and 1.0 for the 83, 93, 103, 112, 121, and the 131 DAT harvests, respectively.

(C) Yield of jumbo roots; y ('Beauregard' root yield) = $-28.114 + 0.338(\text{DAT}) + 0.000057(\text{DAT})^2 - 0.2108(\text{PS}) + 0.00355(\text{PS})^2 + 0.001289(\text{DAT})(\text{PS})$; $R^2 = 0.93$, $P = 0.00001$. LSDs ($P < 0.05$) for comparison of 'Jewel' with the different 'Beauregard' spacing treatments were 1.1 (NS), 2.6, 3.7, 7.1, 9.1, and 11.0 for the 83, 93, 103, 112, 121, and the 131 DAT harvests, respectively.

(D) Yield of marketable roots; y ('Beauregard' root yield) = $-117.78 + 2.24(\text{DAT}) - 0.0061(\text{DAT})^2 + 0.572(\text{PS}) + 0.0054(\text{PS})^2 - 0.01274(\text{DAT})(\text{PS})$; $R^2 = 0.95$, $P = 0.0001$. LSDs ($P < 0.05$) for comparison of 'Jewel' with the different 'Beauregard' spacing treatments were 4.3 (NS), 4.3, 11.6 (NS), 9.8, 12.1, and 8.7 for the 83, 93, 103, 112, 121, and the 131 DAT harvests, respectively.

yield or sizing capacity is inherently lower compared with 'Beauregard'. 'Beauregard' produced more canner roots at the closest plant spacing (15 cm), for all harvests except 112 DAT (Fig. 1B, Table 3).

'Jewel', at 23 cm, produced few jumbo-sized roots in this experiment, especially up to 112 DAT (Fig. 1C). 'Beauregard' yielded more jumbo roots than did 'Jewel' (23 cm), except for the first harvest (83 DAT), when few or no jumbo roots were produced by either clone. In-row spacing did not affect the yield of 'Beauregard' jumbo roots except at 103 DAT (Table 3), although yields appeared to be higher in later harvests (121 and 131 DAT) at the widest in-row spacing (38 cm) (Fig. 1C).

For the last three harvest dates, marketable yields of 'Beauregard' increased as in-row spacing decreased (Fig. 1D, Table 3). Marketable yield of 'Jewel' did not differ from that of 'Beauregard' at any plant spacing on the first or third harvest dates (83 and 103 DAT) (Fig. 1D). Based on marketable yields, 'Beauregard' at the 15-cm spacing outyielded 'Jewel' (23 cm) at 93, 112, 121, and 131 DAT. Yields at the wider in-row spacings were not significantly better for 'Beauregard' than for 'Jewel' at 23 cm; however, yields of 'Beauregard' tended to be greater regardless of in-row spacing.

When 'Beauregard' was harvested at 131 DAT, the NEV for the 15-cm spacing was nearly \$5900/ha greater than that for the 31-cm spacing (Table 2). At in-row spacing of 38 cm for 'Beauregard' and 23 cm for 'Jewel', NEVs were less than values for 'Beauregard' at the 31-cm spacing, indicating that these treatments were economically inferior to the current practice. The 23-cm spacing of 'Beauregard' increased NEV at 131 DAT much less than did the 15-cm in-row spacing treatment (\$860 vs. \$5876/ha, respectively). At 131 DAT, the 15-cm spacing returned more for every additional dollar invested than did the 23-cm spacing (\$1.57 vs. \$1.32, respectively).

Economic analysis of the 112 DAT data revealed a similar pattern. Spacings of 15 cm and 23 cm for 'Beauregard' resulted in net economic gains, relative to the 31-cm spacing, (\$3899 and \$542/ha, respectively). At the 23-cm in-row spacing, an economic cost of \$1516 resulted in a revenue gain >\$2050/ha, or an estimated BCIV of 0.36. Similar calculations for the 15-cm spacing gave an estimated BCIV of 2.33.

Expt. 3, Coharie, 1992. The yields of cull roots in 1992 were not affected by plant spacing on most harvest dates (data not shown). At 99 DAT or later, the closer the plant spacing, the greater the yield of 'Beauregard' No. 1 grade roots (Fig. 2A, Table 3). Considering all harvest dates, the yields of canner roots increased as plant spacing decreased (Fig. 2B, Table 3), whereas yields of jumbos decreased, with the exception of 90 DAT (Fig. 2C, Table 3). Total marketable yields increased as harvest was delayed (Fig. 2D). Total marketable yields were less affected by plant spacing than were other root grades (Table 3).

Partial budget calculations were influenced

Fig. 2. Coharie, 1992. Effect of four different plant spacings (PS) on yield over five harvest dates (DAT) for 'Beauregard' sweetpotato.

(A) Yield of No. 1 roots; y (root yield) = $-158.776 + 2.834$ (DAT) $- 0.00951$ (DAT) 2 + 0.7937 (PS) + 0.00011 (PS) 2 $- 0.0099$ (DAT) (PS); $R^2 = 0.59$, $P = 0.0001$.

(B) Yield of canner roots; y (root yield) = $69.5036 - 0.8918$ (DAT) + 0.00346 (DAT) 2 $- 0.7765$ (PS) + 0.0048 (PS) 2 + 0.00298 (DAT) (PS); $R^2 = 0.45$, $P = 0.0001$.

(C) Yield of jumbo roots; y (root yield) = $32.217 - 0.5528$ (DAT) + 0.00243 (DAT) 2 $- 1.0437$ (PS) + 0.00459 (PS) 2 + 0.00966 (DAT) (PS); $R^2 = 0.59$, $P = 0.0001$.

(D) Yield of total marketable roots; y (root yield) = $-77.928 + 1.7815$ (DAT) $- 0.00541$ (DAT) 2 $- 1.0707$ (PS) + 0.0095 (PS) 2 + 0.0033 (DAT) (PS); $R^2 = 0.68$, $P = 0.0001$.

by DAT (Table 2). At the late harvest (134 DAT), spacing 'Beauregard' at 23 cm increased revenues $\approx$ \$950 above economic costs (reduced revenues and added costs) compared with the 31-cm spacing. The closest in-row spacing (15 cm) increased gross revenues almost \$3000 at 134 DAT, but the combination of reduced jumbo grade and added plant costs increased economic costs >\$3000. Thus, the 15-cm spacing was slightly inferior to the 31-cm spacing. However, partial budget calculations for the 110 DAT data were slightly different from those for 134 DAT. 'Beauregard' harvested 110 DAT indicated that the 15-cm spacing was superior, with a NEV estimate of \$442/ha. With an economic investment of \$1600, additional revenues >\$2100 were obtained and the BCIV estimate was 0.26. The 23-cm plant spacing resulted in \$510 in added gross revenue at 110 DAT but added plant costs and reduced jumbo grade yield resulted in a net negative effect of \$806.

Discussion

The popularity of 'Beauregard' among North Carolina sweetpotato growers in the 1990s has increased dramatically, primarily because of its high yields and market acceptance. 'Beauregard' is ready for harvest earlier

(100–110 DAT) and yields more (Rolston et al., 1987) than 'Jewel', which is a 120-d cultivar (Pope et al., 1971). In many cases, 'Beauregard' yielded more than 'Jewel' (at 23 cm only) in our tests when compared at the closer plant spacing used for 'Beauregard'. The roots of 'Beauregard' sized much more quickly than did those of 'Jewel' (23 cm) (Fig. 1C). Acceptable yields of 'Beauregard' might be obtained as early as 90 DAT, given high market prices.

The recommended in-row plant spacing for most sweetpotato clones is 23 to 40 cm in-row (Rubatzky and Yamaguchi, 1997; Swiader et al., 1992), but closer spacings (23–31 cm) appear to reduce the number of jumbos produced and hence increase overall yields (Swiader et al., 1992). Other researchers (Anderson et al., 1945; Peterson, 1961) also found that yields of sweetpotatoes generally increased as in-row plant spacing was reduced. From our tests, higher marketable yields of 'Beauregard' can be achieved with closer plant spacings. Our data indicated that the closest spacing evaluated (15 cm) gave the highest root yields. Closer plant spacings increased the yields of No. 1 grade roots. This is the most desired grade size and gives the grower the greatest monetary return. Jumbo root production increased with wider plant

spacings because of less competition among plants. This finding agrees with those of several other investigators (Anderson et al., 1941; Petersen, 1961; Swiader et al., 1992), who found that closer plant spacings reduced the number of jumbo grade roots produced and increased the overall yields of sweetpotatoes.

In most cases, the widest spacing tested for 'Beauregard' (38 cm) produced relatively low yields (except for jumbo grade yields). Based on economic analyses, the 38-cm spacing was always inferior to the 31-cm spacing. The closer in-row spacings (15 and 23 cm) increased total root yield and marginal return on investment compared with the wider spacings tested. However, the number of days until harvest determined which spacing (either 15 or 23 cm) was best. Data for marginal return on investment (BCIV) indicated that the choice of plant spacing depends on the projected date of harvest. Planting 'Beauregard' at an in-row interval of 23 cm would be the preferred strategy if a late harvest was anticipated, while the 15-cm spacing would be best for harvesting at ≈ 110 DAT.

For the 1991 spacing test (harvested 132 DAT), high added revenues were obtained with the 15-cm plant spacing ('Beauregard' only), but a smaller BCIV estimate was realized because of higher added costs (\$1211/ha) associated with this spacing. Additional plants, extra labor for plant establishment, and increased harvesting and selling expenses contributed to the added cost. The other spacings ('Beauregard' at 23 cm, and 'Jewel' at 25 cm) provided \$1.97 in added revenue while the 15-cm spacing provided ('Beauregard' only) only \$1.52 in added revenue for every \$1 in added costs. Thus, the 15-cm spacing could be characterized as a high benefit, high cost treatment strategy while the wider plant spacings ('Beauregard' at 23 cm, and 'Jewel' at 25 cm) are moderate revenue, low-cost strategies. An economic analysis of the 1992 spacing test in Clinton, N.C., indicated that the 15-cm spacing was superior to all other treatments regardless of harvest date (112 or 131 DAT); however, the 15-cm spacing was only slightly better than the 23-cm spacing at the 131 DAT

harvest. For the 1992 Coharie, N.C., experiment, the 15-cm spacing was the only treatment at the 110 DAT harvest that was superior to the 31-cm spacing, while at the 134 DAT, the 23-cm spacing was the superior treatment.

For sweetpotato fields planted before 10 June in North Carolina, we recommend that growers adjust their transplanters to 15- to 23-cm spacing, depending on projected date of harvest. An abnormally cool or extended drought during the growing season might result in reduced sizing at the previously recommended in-row spacings. Over 70% of the acreage is traditionally planted by 10 June (North Carolina Dept. of Agriculture, 1993). Most sweetpotatoes in North Carolina are grown at in-row plant spacings of ≈ 30 cm. However, some sweetpotato growers are adopting the practice of transplanting at 20- to 25-cm in-row spacings and have obtained improved root quality, root yields, and revenues with these spacings.

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