Densely Planted Okra for Destructive Harvest: III. Effects of Nitrogen Nutrition

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Abstract. Research was conducted to develop a cultural system that would permit a destructive mechanical okra [*Abelmoschus esculentus* (L.) Moench] harvest. Okra grown at a highly dense (HD) plant population of 25 × 23 cm and destructively harvested by machine was compared with control plants spaced at 90 × 23 cm and repeatedly and non-destructively harvested by hand. The control N fertilization regime was 45 kg·ha⁻¹ of N preplant, followed by one or two topdressings, each with 22 kg·ha⁻¹ of N. Treatments applied to HD plots were designed to be multiples of the control N fertilization levels. Preplant fertilizer was added such that the sum of residual soil N plus the added fertilizer would total to 45, 90, or 135 kg·ha⁻¹ of N for the standard, intermediate, and highest rates, respectively. Topdressing rates were 22, 44, or 66 kg·ha⁻¹ of N for standard, intermediate, and highest, respectively. Topdressing was timed to follow a mechanical harvest of the HD plots. Since there was only one mechanical harvest in the two 1995 studies, topdress N treatments did not affect yields from mechanical harvest in that year. Nitrogen treatments had few effects on fruit yield per hectare of HD okra, even when stem N concentrations equaled or exceeded those of control plants. The highest N rate tended to delay fruit production. Increasing N rates did not affect the marketable fruit yield obtained by mechanical harvest of HD plants expressed as a percentage of the total cumulative marketable fruit yield from control plants. Physiological factors appear to be limiting the potential for densely planted okra in a destructive mechanical harvest system rather than horticultural factors such as N nutrition.

Recommended rates of N fertilization for okra vary greatly. Windham (1966) recommended from 27 to 54 kg·ha⁻¹ of N for 'Clemson Spineless' okra, depending on soil type. Other N recommendations for maximum okra fruit yield included 112 kg·ha⁻¹ (Ahmad and Tulloch-Reid, 1968), 135 kg·ha⁻¹ (Asif and Greig, 1972), and 67 kg·ha⁻¹ (Shrestha, 1983). Majanbu et al. (1985) recommended either 35 or 70 kg·ha⁻¹ of N for okra, depending on cultivar. Majanbu et al. (1986) noted that the optimum rate of N for okra plant dry matter production (100 kg·ha⁻¹) was higher than that for maximum edible fruit yield (50 kg·ha⁻¹).

However, these previous studies on N nutrition in okra involved conventionally spaced, hand-harvested plants. Our work to develop a cultural system that would permit a destructive mechanical okra harvest involved high plant populations (some ≥105,000 plants/ha). Therefore, the objective of the present study was to determine whether N nutrition was limiting the yield potential of densely planted, destructively harvested okra.

Materials and Methods

Experiments were conducted in 1995 and 1996 at the Vegetable Research Station in Bixby, Okla., on a Severn very fine sandy loam [coarse-silty, mixed (calcareous), thermic Typic Udipluvial] with an average organic C concentration of 4 g·kg⁻¹ at a depth of 0 to 15 cm. Each experiment occupied a different field at the station, and followed a rotational crop of soybean [*Glycine max* (L.) Merr.] grown and harvested in the previous year. An additional experiment was conducted in 1995 at the Plant Pathology Farm in Stillwater, Okla., on a Norge loam (fine-silty, mixed, active, thermic Udic Paleustoll) (organic C concentration was not determined). The field in Stillwater was cropped to okra from May to Oct. 1994 and had been fallowed since that time. Weeds were

controlled with preplant-incorporated trifluralin [2,6-dinitro-*N,N*-dipropyl-4-(trifluoromethyl) benzenamine] at 560 g·ha⁻¹ (Bixby) or 840 g·ha⁻¹ (Stillwater) and by hoeing. Insects were controlled with malathion [*O,O*-dimethyl *S*-(1,2-dicarboxyethyl) phosphorodithioate] at 1.4 kg·ha⁻¹ as needed. No foliar disease control products were applied. Overhead sprinkler irrigation was provided to supplement rainfall based on subjective observations of plants and soils.

Seeds of 'Clemson Spineless 80' okra were sown in beds that were 2.1 m wide and not raised, using a vacuum-metering, ultranarrow-row precision planter developed by two of the authors (Solie and Whitney). Planting geometries were 25 cm between rows and 23 cm between plants within rows, with six rows per bed, in HD plots and 90 cm between rows and 23 cm between plants within rows, with two rows per bed, in the controls. Plots were 10 m long and were separated from each other by at least 3 m (Stillwater) or 4 m (Bixby) in all directions to minimize the chance of soluble soil N movement between plots. Plots were arranged in randomized complete blocks with three (Bixby, 1995) or four (Bixby, 1996; Stillwater, 1995) replications.

Soil samples were taken before planting in the spring of each year at a depth of 0 to 15 cm. The control N fertilization level was 67 kg·ha⁻¹ in 1995, achieved by combining residual soil N and applied fertilizer to total 45 kg·ha⁻¹ of N preplant and by one topdressing with 22 kg·ha⁻¹ of N. The control N fertilization level was 89 kg·ha⁻¹ in 1996, achieved by combining residual soil N and applied fertilizer to total 45 kg·ha⁻¹ of N preplant and by two topdressings, each with 22 kg·ha⁻¹ of N. Treatments applied to HD plots were designed to be multiples of the control N fertilization levels. Preplant fertilizer was added such that the sum of residual soil N plus the added fertilizer would total to 45, 90, or 135 kg·ha⁻¹ of N for the standard, intermediate, and highest rates, respectively. Topdressing rates were 22, 44, or 66 kg·ha⁻¹ of N for standard, intermediate, and highest, respectively. Topdressing was timed to follow a mechanical harvest of the HD plots, and all plots (control and HD) were topdressed at the same time. The N fertilizer used was urea in all cases except for the preplant application at Bixby in 1995, when a complete fertilizer (13%N–5.7%P–10.8%K) was used.

Plants in HD plots were destructively harvested once overmature fruit became evident, using an experimental machine developed by Oklahoma State Univ. Plants in the 1996 study regrew enough to allow a second destructive harvest. A sickle bar on the machine cut the plants at an average of ≈15 to 20 cm above ground level over the full 10 m per plot. A gathering reel deposited the cut plants onto a conveyor belt that transported them to a collection bin. The entire apparatus was mounted on a frame adapted from a self-propelled sprayer. Bins were unloaded at the end of each plot. Stalks were defruited by hand and fruits (pods) were collected in bags for later grading and data recording. Fruits were graded into immature (pods <5 cm long), marketable, and

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overmature (pods ≥ 5 cm long with palpable fiber development) categories, then weighed. Plants in control plots were repeatedly and non-destructively hand harvested up to three times per week. Data areas in control rows were 2.5 m long.

Four plants per plot were sampled shortly before mechanical harvest to determine height (distance from the soil to the highest plant part), N concentration in stems, and defruited dry weight at Stillwater in 1995 and at Bixby in 1996. Control plant samples were taken outside the areas chosen to undergo repeated hand harvests. After heights were measured, plants were cut at soil level. Stem samples for N concentration were taken by removing the top 15 cm (1995) or 10 cm (1996) of each plant, then using the next 30 cm (1995) or 20 cm (1996) of central axis stem tissue after removing any fruit or leaves from that section. Stem sections were washed in distilled water and dried (along with the rest of the defruited plant material) for ≥ 7 d at 50 °C before weighing. Stem sections then were ground with a Wiley mill to pass a 2-mm screen and analyzed for N by dry combustion.

Bixby, 1995. A preplant soil test indicated 19N–154P–271K (kg·ha⁻¹). Fertilizer was applied and incorporated on 19 May as follows: control and standard = 26N–11P–21K (kg·ha⁻¹); intermediate = 71N–31P–58K (kg·ha⁻¹); highest = 116N–51P–95K (kg·ha⁻¹). Seeds were sown on 15 June (there was a delay in planting due to persistent rains). Plants in HD plots were destructively harvested by machine on 18 Aug. Plants were topdressed on 23 Aug. A total of 27 harvests were made in control plots starting on 4 Aug. and ending on 9 Oct. A sampling only for N concentration in stems was made on 13 Oct.

Stillwater, 1995. A preplant soil test indicated 25N–131P–361K (kg·ha⁻¹). Fertilizer was applied and incorporated on 14 June as follows: control and standard = 20 kg·ha⁻¹ of N; intermediate = 65 kg·ha⁻¹ of N; highest = 110 kg·ha⁻¹ of N. Seeds were sown on 16 June. Four plants per plot were sampled on 28 Aug., after which plants in HD plots were destructively harvested by machine. Plants were topdressed on 1 Sept. A total of 14 harvests were made in control plots starting on 13 Aug. and ending on 5 Oct.

Bixby, 1996. A preplant soil test indicated 10N–111P–272K (kg·ha⁻¹). Fertilizer was applied and incorporated on 9 May as follows: control and standard = 35 kg·ha⁻¹ of N; intermediate = 80 kg·ha⁻¹ of N; highest = 125 kg·ha⁻¹ of N. Seeds were sown on 20 May. Four plants per plot were sampled on 12 July. Plants in HD plots were destructively harvested by machine on 15 July. Plants were topdressed on 19 July. Regrowth was sufficient to justify a second destructive mechanical harvest of plants in HD plots on 26 Aug. Plants were topdressed on 6 Sept., but no further harvests were made in HD plots. A total of 32 harvests were made in control plots starting on 9 July and ending on 25 Sept.

Statistical analysis. Each experiment was analyzed separately. Data were evaluated by analysis of variance procedures. Trend analysis

was used to test for linear and quadratic effects of N rate within the three N treatments applied to the densely planted okra. Least squares means were used to compare the control to the three HD treatments.

Results and Discussion

Increasing N rates from standard to highest had no significant effect on total marketable, overmature, cull, and overall total fruit yields of densely planted okra in all three experiments (Tables 1, 2, and 3). This occurred even when stem N concentrations of densely planted okra equaled (Stillwater, 1995) or exceeded (Bixby, 1996) those of control plants (Table 4). McFerran et al. (1963) found that different rates of sidedressed N had no effect on 'Clemson Spineless' okra grown at three different within-row spacings. Albregts and Howard (1974) grew okra at three plant populations with two rates of N–P–K and concluded that the fertility levels they tested did not affect the yield-plant density response. Several researchers have reported that the major yield response of okra to N comes with the first increment above a zero-N baseline, with limited yield benefits from higher N rates (Ahmad and Tulloch-Reid, 1968; Asif and Greig, 1972; Fatokun and Chheda, 1983).

The highest N rate tended to delay fruit production. This was most evident in the quadratic decrease in marketable fruit weight as N rate increased at first harvest in the 1996

experiment (Table 3). Ahmad and Tulloch-Reid (1968) stated that N fertilizer rates above 112 kg·ha⁻¹ adversely affected okra yield. Majanbu et al. (1986) found that 100 kg·ha⁻¹ of N disproportionately enhanced okra vegetative growth at the expense of fruit development.

We chose to focus on N nutrition because levels of P and K in our soils already were well above those recommended for okra production in Oklahoma (Motes et al., 1982). Asif and Greig (1972) had a similar situation and reported no favorable influence of P or K on okra yield. We further tested our assumption that supplemental P and K were unnecessary by using a complete fertilizer for preplant fertilization at Bixby in 1995, and there were no significant effects on fruit yield from the densely spaced plants (Table 1).

Stands in densely planted plots exceeded those in control plots each year, as expected (Table 4). Some seedlings were lost to hail in early June 1996. Thus, HD stands were not quite double those of the control in 1996, which may help explain why stem N concentrations of plants from the intermediate and highest treatments exceeded those of control plants in that year (Table 4). Stem N concentrations increased linearly with N rates in two out of three of our studies (Table 4). Others (Asif and Greig, 1972; Majanbu et al., 1986) have reported similar results. Nitrogen treatments had no effect on height or dry weight of densely spaced plants (Table 4). Majanbu et al. (1986) noted inconsistent effects on height

Table 1. Fruit yield response of destructively harvested, densely planted (25 × 23 cm) okra to fertilizer treatments, Bixby, Okla., 1995.

Treatment ^a	Fruit fresh wt (kg·ha ⁻¹)					Marketable fresh fruit wt as a percent of the control
	Immature	Marketable ^b	Overmature	Cull	Total	
Standard	46	184**	4466	157	4853	2.1
Intermediate	43	351**	5429	145	5968	3.9
Highest	45	313**	5024	214	5596	3.9
<i>Contrasts within treatments</i>						
N linear	NS	NS	NS	NS	NS	NS
N quadratic	NS	NS	NS	NS	NS	NS

^aA preplant soil test indicated 19N–154P–271K (kg·ha⁻¹). Preplant fertilizer treatments were: standard = 26N–11P–21K (kg·ha⁻¹); intermediate = 71N–31P–58K (kg·ha⁻¹); highest = 116N–51P–95K (kg·ha⁻¹).

^bControl plants were spaced at 90 × 23 cm, received 26N–11P–21K (kg·ha⁻¹) preplant and 22 kg·ha⁻¹ of N topdressed, and were repeatedly harvested by hand. The mean marketable fruit yield from the control was 9554 kg·ha⁻¹. Within this column, means followed by the ** symbol differed from the control at $P \leq 0.01$ by least squares.

NS=Non-significant at $P \leq 0.05$.

Table 2. Fruit yield response of destructively harvested, densely planted (25 × 23 cm) okra to N treatments, Stillwater, Okla., 1995.

N treatment ^a	Fruit fresh wt (kg·ha ⁻¹)					Marketable fresh fruit wt as a percent of the control
	Immature	Marketable ^b	Overmature	Cull	Total	
Standard	260	1496**	1644	26	3426	17.9
Intermediate	224	1102**	1748	20	3094	13.2
Highest	204	1032**	1349	22	2606	12.3
<i>Contrasts within N treatments</i>						
N linear	*	NS	NS	NS	NS	NS
N quadratic	NS	NS	NS	NS	NS	NS

^aA preplant soil test indicated 25N–131P–361K (kg·ha⁻¹). Preplant N fertilizer treatments were: standard = 20 kg·ha⁻¹; intermediate = 65 kg·ha⁻¹; highest = 110 kg·ha⁻¹.

^bControl plants were spaced at 90 × 23 cm, received 20 kg·ha⁻¹ of N preplant and 22 kg·ha⁻¹ of N topdressed, and were repeatedly harvested by hand. The mean marketable fruit yield from the control was 8437 kg·ha⁻¹. Within this column, means followed by the ** symbol differed from the control at $P \leq 0.01$ by least squares.

NS=Non-significant or significant at $P \leq 0.05$, respectively.

Table 3. Fruit yield response of densely planted (25 × 23 cm) okra to N treatments at each of two destructive harvests, Bixby, Okla., 1996.^z

N treatment ^y	Fruit fresh wt (kg·ha ⁻¹)											Total marketable fresh fruit wt as a percent of the control
	Immature		Marketable ^y			Overmature		Cull		Total		
	H1	H2	H1	H2	Total ^x	H1	H2	H1	H2	H1	H2	
Standard	58	276	418	789	1206**	603	4860	38	248	1116	6174	9.1
Intermediate	58	260	436	740	1176**	614	4349	41	282	1149	5631	8.9
Highest	58	277	301	735	1036**	427	4598	47	300	833	5910	7.9
<i>Contrasts within N treatments</i>												
N linear	NS	NS	**	NS	NS	NS	NS	NS	NS	*	NS	NS
N quadratic	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS

^xH1 = first machine harvest, 15 July. H2 = second machine harvest, 26 Aug.

^yA preplant soil test indicated 10N–111P–272 K (kg·ha⁻¹). Preplant N fertilizer treatments were: standard = 35 kg·ha⁻¹; intermediate = 80 kg·ha⁻¹; highest = 125 kg·ha⁻¹. Topdress N fertilizer treatments on 19 July were: standard = 22 kg·ha⁻¹; intermediate = 44 kg·ha⁻¹; highest = 66 kg·ha⁻¹.

^zControl plants were spaced at 90 × 23 cm, received 35 kg·ha⁻¹ of N preplant, 22 kg·ha⁻¹ of N topdressed on 19 July and 22 kg·ha⁻¹ of N topdressed on 26 Aug., and were repeatedly harvested by hand. The mean marketable fruit yield from the control was 13,217 kg·ha⁻¹. Within this column, means followed by the ** symbol differed from the control at $P \leq 0.01$ by least squares.

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

Table 4. Further comparisons of densely planted (25 × 23 cm) okra to a conventionally spaced (90 × 23 cm) control.^z

Treatment ^y	Plants per ha × 10 ³			Stem N concn (%)			Ht (cm) from soil to highest plant part		Defruited dry wt (g/plant)	
	Bix95 ^x	Stw95 ^x	Bix96 ^x	Bix95	Stw95	Bix96	Stw95	Bix96	Stw95	Bix96
Control	41.5	43.3	41.1	2.7	2.5	3.1	106	31	126	39
Standard	109.0**	109.4**	76.7**	1.2**	1.9*	3.4	138**	36	54**	21**
Intermediate	109.8**	105.2**	77.0**	1.8**	2.0*	3.9**	137**	36	56**	25**
Highest	108.6**	105.1**	75.6**	2.2**	2.2	4.4**	137**	35	55**	26**
<i>Contrasts within standard, intermediate, and highest fertilizer treatments</i>										
N linear	NS	NS	NS	**	NS	**	NS	NS	NS	NS
N quadratic	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

^xWithin columns, means followed by the * or ** symbols differed from the control at $P \leq 0.05$ or 0.01, respectively, by least squares.

^ySee text and preceding tables for details of control fertilization rates and fertilizer treatments.

^zLocation/year abbreviations: Bix95 = Bixby, 1995; Stw95 = Stillwater, 1995; Bix96 = Bixby, 1996.

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

but increased shoot dry weight from N applications on conventionally spaced okra. The high plant populations in our studies inconsistently affected plant height, as others have noted (Gupta et al., 1981; Hermann et al., 1990). Control plants also were heavier than densely spaced plants (Table 4), as we had found in other studies (Wu et al., 2003b).

A key finding was that increasing N rates did not increase the marketable fruit yield obtained by mechanical harvest of the densely spaced plants, expressed as a percentage of the total cumulative marketable yield from control plants (Tables 1, 2, and 3). This is evidence that N nutrition does not limit the potential for densely planted okra in a destructive mechanical harvest system. Unfortunately, percentages of marketable yield obtained by destructive harvests of high-population plots were low relative to the cumulative marketable yield from control plots in the present studies (Tables 1, 2, and 3) and in other studies (Wu et al., 2003a). Physiological factors, primarily the lack of a concentrated marketable fruit set (Düzyaman, 1997), appear to be limiting the potential for densely planted okra in a destructive mechanical harvest system rather than horticultural factors such as N nutrition.

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