DENSELY PLANTED OKRA FOR DESTRUCTIVE MACHINE HARVEST SYSTEM

By

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HARVEST SYSTEM

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The purpose of this study was to develop a cultural system which will permit an economical, destructive mechanical okra harvest.

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CHAPTER I

INTRODUCTION

Okra [Abelmoschus esculentus (L.) Moench] is a tropical, annual vegetable which is grown in west Africa, Brazil, India, Turkey, the southern United States and other countries (Martin and Ruberte, 1978). It has economical and commercial significance due to its ability to provide quality, tender, nutritious green fruits during the hot and dry summer season.

Okra has an extended fruiting period. Plants generally set fruit from one flower in a different leaf axil each day (Tanda, 1985). It requires repeated hand harvests at 2 or 3 day intervals for 4-8 weeks (Richardson, 1972) and is very labor intensive. In addition, the pod and other plant parts bear small spines which irritate the skin (Martin and Ruberte, 1978). As a result, it is nearly impossible to get domestic workers who are willing to pick okra.

Okra is well-adapted to the soils and climatic conditions of Oklahoma. About 650 acres of okra are produced in Oklahoma, with a value of almost $ 2 million (Motes, personal communication, 1990). Almost all Oklahoma-grown okra is marketed fresh. Food processing companies, including Stilwell Foods in Stilwell, Oklahoma and Campell Soup (Texas) in Paris, Texas represent significant potential markets for Oklahoma-grown okra. Both of these companies currently import all of their raw okra product from outside of Oklahoma due to an inadequate in-state labor pool to pick the crop in a volume sufficient to sustain a processing plant. Thus, the principal factor limiting expansion of okra acreage in Oklahoma is the lack of sufficient willing and available hand labor to harvest the crop. It is essential to develop a harvest machine for okra to support either the processing companies or fresh markets.

A multi-pass okra harvester designed to remove horticultural mature fruit and associated leaves from the stalk was developed in the 1970's by Clemson University (Richardson, 1972). Sucessful commercialization of the harvester was not achieved even though automatic controls were added and the stripper mechanism improved (Richardson and Craig, 1977). Although the machine successsfully removed the okra fruit, the plant architecture did not permit economical multi-pass harvesting (Richardson, 1977). Therefore, research was initiated in 1992 at Oklahoma State University to develop a system for destructive mechanical harvesting of okra.

The conventional plant spacing of okra is 90 x 23 cm for hand harvest in Oklahoma. However, since okra crops intended for destructive mechanical harvest do not need aisles for worker access, more plants can be planted per unit area compared to conventional hand harvest. Many studies have indicated how various plant species respond to population density. Yields of okra (Shrestha, 1983; Albregts and Howard, 1974; Fatokun and Chheda, 1983), snap bean (Leakey, 1972), soybean (Leakey and Rubaihayo, 1972), cucumber (Wiebe, 1965), and tomatoes (Loughton, 1967; Fery and Janick, 1970; Nicklow and Downes, 1971) have been increased by planting more plants per unit area. Generally, yield per plant decreases as plant population increases (Fery and Janick, 1970; Nichols et al., 1973), but low yield per plant can be compensated for by increasing the number of plants per unit area (Hermann et al., 1990). All investigations on okra spacing were related to hand harvest.

Development of a successful mechanical harvesting system for okra will depend not only on the machine design, but also on some physical properties of okra itself. Some okra cultivars such as Louisiana Green Velvet, C-48 and Emerald have been considered to be fit for a multi-pass harvester (Richardson, 1977).

Objectives of this research

1. Identify a high- density arrangement which concentrates flowering and fruit set.
2. Find an optimum harvest date which leads to a maximum marketable fruit yield per acre with a single harvest.
3. Evaluate the potential for regrowth of cut plants followed by a second harvest.
4. Determine the effect of planting densities on plant architecture of okra.

Justification

The final outcome of this research will be a cultural practice production system for mechanically harvested okra. Once this system (accompanied by a harvester) has been developed, it is expected that existing okra acreage will expand and that several hundred acres of relatively low profit agronomic crops will be replaced with okra.

Processing companies in Oklahoma and neighboring states, which currently import their raw okra product from Mexico and Central America, will be able to vertically integrate and will be able to contract for raw okra product from local growers. A small but definite export market also exists, and Oklahoma growers will be well positioned to hit a market window.

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CHAPTER II

DENSELY PLANTED OKRA FOR DESTRUCTIVE HARVEST

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Abstract: Four okra [Abelmoschus esculentus (L.) Moench] spacing experiments were conducted in Bixby, OK during 1992, 1993, and 1994. Highly dense spacings for destructive harvest were 15 x 15 cm, 23 x 23 cm, and 30 x 30 cm, while conventional spacing for repeated hand harvest was 90 x 23 cm (control). Our objectives were to identify a high density (HD) plant arrangement and a harvest timing which would maximize marketable fruit yield per hectare with a destructive harvest. Within HD treatments, marketable fruit weight increased inconsistently as plant density increased. The 30 x 30 cm spacing was not dense enough for this system. Delaying destructive harvest until many overmature fruit were

present often did not increase marketable fruit yield, and always reduced the proportion of marketable fruit yield to total harvested fruit yield. In all three HD spacings, marketable fruit weight from regrown stems accounted for a large proportion of total marketable yield (up to 60.4%). Overall percentages of marketable yield obtained by destructive harvests of HD plants were low relative to the cumulative marketable yield from control plants. However, the labor-saving potential was high.

Introduction

Okra is grown on about 650 acres in Oklahoma, and the crop value is almost $ 2 million (Motes, personal communication, 1990). The major factor limiting further expansion of okra acreage in Oklahoma is the lack of sufficient willing and available labor for repeated harvest. Food processing companies, including Stilwell Foods in Stilwell, Oklahoma and Campbell Soup (Texas) in Paris, Texas currently import all of their raw okra product from outside of Oklahoma due to inadequate local supplies and high prices partly resulting from costly labor.

The primary efforts to date to mechanize okra harvest took place at Clemson University in the early 1970's, where a multi-pass harvester was developed (Richardson, 1972). All work was done with conventional 90-100 cm (36-40 inches) between-row spacing. Successful commercialization was not achieved because the plant characteristics did not permit economical multi-pass harvesting (Richardson, 1977). Therefore, research was initiated in 1992 at Oklahoma State University to develop a system for destructive mechanical harvesting of okra.

Bradley and Baker (1972), Hammett (1974), Kretchman (1975), and Cantliffe and Phatak (1975) pointed out that plant population per unit area is one of the factors determining yield and efficiency of once-over mechanical harvested pickling cucumber (Cucumis sativus L.). Extensive work has been done on the response of okra to plant population based on repeated hand harvest in various conditions and countries. Sutton and Albregts (1970) tested spacings of okra and found that yield of okra was highest at the closest spacing(122 x 5 cm). Other investigations showed okra spacings of 60 x 20 cm, 60 x 25 cm, 61 x 30.5 cm or 45 x 15 cm gave the higher yields (Kamalanathan et al. 1970; Lee and Leong, 1979; Fatokun and Chheda, 1983; Shrestha, 1983). In contrast, Pinto de Araujo (1982) reported there were no significant increases in yields with increased plant population. In addition, Absar and Siddlque (1982) indicated that a plant spacing as low as 30 x 22 cm could give the highest yield per acre. However, no information has been reported on the optimum plant spacing to maximize yield of destructive-harvested, high-density okra.

Plant uniformity is extremely important for crops which are once-over mechanically harvested (Kretchman, 1975). Cantliffe and Phatak (1975) reported the plant population density may govern uniformity. Richardson (1977) indicated that more uniform plants help reduce losses due to immature and overmature fruit production. The lack of early, uniform stand was a severe problem in okra (Abdefattah et al.,1972; Marsh, 1992; Standifer et al., 1989; Dobbs et al.,1985). Improved uniformity of okra seed germination and seedling emergence was achieved by priming seed in a solid matrix priming agent (such as Super Absorbent or Carri-all)(Mereddy, 1995). Apart from seed treatment, Fatokun and Chheda

(1983), and McFerran et al. (1963) found that planting okra in narrower rows and at higher plant densities reduced crop duration and concentrated fruit on the central flower stalk.

Our objectives of this study were to: 1) identify a high density arrangement which concentrates flowering and fruit set; 2) find an optimum harvest date which leads to a maximum marketable fruit yield per acre with a single harvest; and 3) evaluate the potential for regrowth of cut plants followed by a second harvest.

Materials and Methods

Four field experiments were conducted at the Bixby Research Station, Northeastern Oklahoma during 1992-1994. The soil type was a well-drained, very fine sandy loam (Entisol) which is well-suited for okra cultivation (Lee,1991). 51N-22P-42K, 73N and 36N-16P-30K ($kg \cdot ha^{-1}$) of preplant fertilizer were broadcasted in 1992, 1993 and 1994, respectively. Only N fertilizer was applied in 1993 because adequate P and K were available from fertilization of previous crops. No postplant fertilizers were applied in all years. Weeds were controlled with preplant-incorporated 2, 6-dinitro-N, N,-dipropyl-4-(trifluoromethyl) benzenamine (trifluralin) at 560 $g \cdot ha^{-1}$, and by hoeing if weeds grew during the period of okra growth. Overhead sprinkler irrigation was provided as required to supplement rainfall. Insects were controlled with O,O-dimethyl S-(1,2-dicarboxyethyl) phosphorodithioate (malathion) at 1.4 $kg \cdot ha^{-1}$ as needed. No disease control was used in all years.

Seed of 'Clemson Spineless 80', one of the most popular commercial okra cultivars, was sown with a vacuum metering precision seeding ultranarrow row planter developed by professors Solie and Whitney of the OSU Biosystems and Agricultural Engineering Department. Raw seed was used in 1992 and 1993. Seed which had been solid matrix primed by personnel in the Department of Plant Pathology, Oklahoma State University was used in 1994. Priming was for 3 days after which seeds were allowed to dry back. Dates of planting are shown in Table 2.1 and Table 2.2. Plants were grown on standard 2.1-m-wide beds using a conventional spacing (control) of 90 x 23 cm, and three higher density arrangements: 15 x 15 cm, 23 x 23 cm, and 30 x 30 cm. There were 2 rows per bed for the 90 x 23 cm spacing, and 10, 7, and 5 rows per bed for the 15 x 15 cm, 23 x 23 cm and 30 x 30 cm spacings, respectively. Expt. 1, 2, and 4 were conducted mainly for yield and harvest date; Expt. 3 mainly for yield and regrowth yield potential of cut plants.

A split-block design with 3 replications (Expt. 1, 2) or 4 replications (Expt. 3, 4) was employed. Main plots were spacings, and subplots were harvest dates. Main plots were 8 m long, and subplots were 4 m long. The control did not have subplots. Data areas in control rows were 2.5 m long.

Plants in high-population plots were destructively harvested by hand (simulating a once-over machine harvester) on two sampling dates. The first harvest was made when overmature fruits first were evident (early), while the second harvest was made at least one week later (late) in Expt. 1, 2, 4. The dates of first and second destructive harvests are in Table 2.1. Plants in high-population plots in Expt. 3 were destructively harvested by hand on 7 July 1994, then regrew from stumps to allow two subsequent destructive harvests. The dates of harvests are shown in Table 2.2. At harvest, plants in high population areas were cut off with a lopping shears at a height of $\approx$15 cm above ground level which was below the first branching node in almost all cases. Cut plants were stacked outside the plots, counted, removed from the field and defruited. Fruits were graded into immature (pod<5 cm long), marketable, and overmature categories, counted and weighed. When regrowth occured (Expt. 3), branches were cut off right on top of the stumps. Plants in control plots were repeatedly and non-destructively harvested by hand as needed, up to 3 times per week. One variable which we examined was marketable yield obtained by destructive harvests of the high-population plots expressed as a percent of the total cumulative marketable yield from control plots. Data were analyzed with analysis of variance procedures.

Results

Experiment 1: The interaction of spacing x date on immature fruit weights was significant at $P \leq 0.05$. Immature fruit weights differed among spacings only at early harvest (11 Sept. 1992) (Table 2.3). At early harvest, immature fruit weights in spacings of 15 x 15 cm and 23 x 23 cm were significantly greater than those in the spacing of 30 x 30 cm (at $P \leq 0.01$). Marketable fruit weights increased as plant density increased from 30 x 30 cm to 15 x 15 cm in both early and late harvest. Overmature fruit weights increased as the harvest date was delayed in all spacings. Marketable fruit made up a smaller proportion of total harvested fruit weight with the late harvest than with the early harvest due to an increased weight of overmature fruit at late harvest. The single destructive harvest of the 15 x 15 cm plots on 18 Sept. yielded 33% of the marketable fresh fruit weight obtained by 6.5 weeks of hand harvests in the control (Table 2.3).

Experiment 2: Yields were reduced by heat and drought stress compared to experiment 1 (Table 2.4). Spacing treatments resulted in no significant fruit yield differences. Both immature and overmature fruit weights increased at late harvest, reducing the proportion of total harvested fruit weight due to marketable fruit, as in Expt.1.

Experiment 3: Increasing plant population from 48,500 to 88,100 plants per ha did not increase marketable fruit weight and decreased the proportion of total harvested fruit weight which was marketable due to an increase in overmature fruit weight (Table 2.5). Increasing plant population from 88,100 to 125,300 plants per ha significantly increased the marketable fruit weight (at $P \leq 0.05$) (Table 2.5). Control plots had a long harvest period (12.5 weeks). Marketable fruit weight from regrown stems accounted for a large proportion of total marketable yield in all three spacings, as high as 60.4% (Table 2.6). However, total marketable yield from high-density plots still did not exceed 15% of the control.

Experiment 4: The interaction of spacing x date on immature fruit weights was significant at $P \leq 0.05$ (Table 2.7). Immature fruit weight in spacing of 15 x 15 cm was significantly higher (at $P \leq 0.01$) than those in spacings of 23 x 23 cm and 30 x 30 cm at early harvest . There were no differences in immature fruit weights among spacings at late harvest. Marketable fruit yields were higher at late harvest than at early harvest among all spacings. Overmature fruit weights also increased at late harvest, reducing the proportion of total harvested fruit weight due to marketable fruit as in Expt. 1 and 2.

Discussion and conclusions

The general tendency was that marketable fruit yield increased as the plant density increased in all experiments. This result is in agreement with observed responses of tomato (Lycopersicon esculentum Mill) and pickling cucumber yields to population pressure (Fery and Janick, 1970; Loughton, 1967; Nicklow and Downes,1971; Cantliffe and Phatak,1975). However, it was difficult to determine an optimum density since stands varied from experiment to experiment. Excessive rainfall during stand establishment was a particular problem contributing to stand variability. The 30 x 30 cm spacing yielded the lowest marketable fruit weights and was not dense enough for the destructive harvest system.

Marketable yield components of destructively harvested okra consist of plant population per unit area, marketable pod number per plant and weight per pod. Usually, the weight of each pod is determined by pod size. At a given plant density, number of marketable pods is the key component of total yield. One or two marketable pods per plant at any given harvest was considered desirable (Richardson, 1972). Richardson (1977) also indicated that the key for mechanically harvested okra was plant uniformity. If the expected uniformity of plant density is achieved, it is not difficult to find an optimum date for once-over harvest. In our experiments, changes of marketable yields at both harvest dates were not always consistent. In some cases, marketable fruit yields increased in delayed harvest but not in other cases. Delaying harvest until many overmature fruit were present always reduced the proportion of marketable fruit weight to total harvested fruit weight due to increased overmature fruit weight.

Overall, percentages of marketable yield obtained by destructive harvests of high-population plots were low relative to the cumulative marketable yield from control plots. However, the labor-saving potential was high. Hammett (1974) reported machine harvesters can reduce harvest cost from $600 to 800 per hectare for hand labor to a range of $100 to 200 per hectare depending on use of either a once-over harvester or a multi pick harvester for pickling cucumber. Since marketable fruit weight from regrown stems was a major contributor to total marketable yield from high-density plots in Expt. 3, more work is needed on maximizing yield from regrown stems.

In all experiments, we did not apply any postplant fertilizers. Nutrient, light and water availability are affected by plant density (Cantliffe and Phatak,1975). More competition occurs at both canopy and root level in densely planted crops than widely planted ones. Further research is needed to determine optimum fertilization levels for high-density okra. Also, efforts should be made to identify shade-tolerant cultivars that are suitable for high-density planting. We only used 'Clemson Spineless 80' to do our spacing experiments. A cultivar trial combined with spacing treatments would be a useful follow-up to this study.

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Table 2.1. Planting and harvesting dates of experiments 1,2,4

Experiment	Planting date	Harvest date	
		First	Second
Expt. 1	6/18/92	9/11/92	9/18/92
Expt. 2	6/17/93	9/3/93	9/23/93
Expt. 4	5/24/94	8/26/94	9/6/94

Table 2.2. Planting and harvesting dates of experiment 3

Spacing (cm)	Planting date	Harvest date		
		First destructive harvest	First regrowth harvest	Second regrowth harvest
15 x 15	5/10/94	7/7/94	8/22/94	9/26/94
23 x 23	5/10/94	7/7/94	8/22/94	9/26/94
30 x 30	5/10/94	7/7/94	8/11/94	9/26/94

Table 2.3. Okra fruit yield from once-over, destructive harvests, Expt. 1, 1992

					Harvested fruit	
		Fruit fresh wt ($kg \cdot ha^{-1}$)			Percent by wt of total that was	Marketable fresh wt as a percent of
Spacing	Plants per ha x 10^3	Immature	Marketable	Overmature	marketable	the control
		Early harvest, 11 Sept. 1992				
15 x 15 cm	175.0	438	1911	3985	30	19
23 x 23 cm	88.5	383	1721	3791	30	18
30 x 30 cm	43.2	200	878	1835	31	9
		Late harvest, 18 Sept. 1992				
15 x 15 cm	186.5	117	3136	9723	24	33
23 x 23 cm	103.2	78	1962	10544	16	21
30 x 30 cm	56.8	77	1366	6904	16	14
		Main effects and interactions				
Spacing	**	**	**	NS	NS	**
Harvest date	NS	**	NS	**	*	NS
Spacing x date	NS	*	NS	NS	NS	NS

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

Table 2.4. Okra fruit yield from once-over, destructive harvests, Expt. 2, 1993

Spacing	Plants per ha x 10^3	Fruit fresh wt ($kg \cdot ha^{-1}$) Immature	Marketable	Overmature	Harvested fruit: Percent by wt of total that was marketable	Harvested fruit: Marketable fresh wt as a percent of the control
		Early harvest, 11 Sept. 1992				
15 x 15 cm	174.6	22	319	571	38	5
23 x 23 cm	96.4	5	315	916	25	5
30 x 30 cm	54.0	3	294	828	26	4
		Late harvest, 18 Sept. 1992				
15 x 15 cm	175.4	82	434	3090	12	6
23 x 23 cm	102.4	78	274	2884	9	4
30 x 30 cm	53.2	75	112	1427	6	1
		Main effects and interactions				
Spacing	**	NS	NS	NS	NS	NS
Harvest date	NS	**	NS	*	**	NS
Spacing x date	NS	NS	NS	NS	NS	NS

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

Table 2.5. Cumulative okra fruit yields from three destructive harvests, Expt. 3, 1994

					Harvested fruit	
Spacing	Plants per ha x 10^3	Fruit fresh wt ($kg \cdot ha^{-1}$) Immature	Marketable	Overmature	Percent by wt of total that was marketable	Marketable fresh wt as a percent of the control
15 x 15 cm	125.3a[z]	439	4247a	6184a	39b	15
23 x 23 cm	88.1b	417	3574b	5768a	37b	12
30 x 30 cm	48.5c	345	3615b	4044b	45a	13
			Main effect of spacing			
Spacing	**	NS	*	*	**	NS

[z] If main effect is significant, mean separation in columns by Duncan's MRT, $P \leq 0.05$.

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

Table 2.6. Percentage of regrowth marketable yield to total marketable harvested yield, Expt. 3, 1994

Spacing	First destructive harvest (kg · ha^{-1})	Regrowth destructive harvest(kg · ha^{-1})			Total marketable yield (kg · ha^{-1})	Percent of total regrowth yield
		First	Second	Total		
15 x 15 cm	2687.0	1337.6	222.8	1560.4	4247	36.7
23 x 23 cm	1933.5	1423.2	216.9	1640.1	3574	45.9
30 x 30 cm	1433.1	131.8	2050.1	2181.9	3615	60.4

Table 2.7. Okra fruit yield from once-over, destructive harvests, Expt. 4, 1994

Spacing	Plants per ha x 10^3	Fruit fresh wt ($kg \cdot ha^{-1}$) Immature	Marketable	Overmature	Harvested fruit: Percent by wt of total that was marketable	Marketable fresh wt as a percent of the control
		Early harvest, 11 Sept. 1992				
15 x 15 cm	212.2	278	1760	3206	33	9
23 x 23 cm	106.0	199	1239	3684	25	6
30 x 30 cm	57.4	177	898	1906	33	4
		Late harvest, 18 Sept. 1992				
15 x 15 cm	199.4	77	1875	10504	15	9
23 x 23 cm	93.8	59	2070	10692	16	10
30 x 30 cm	56.2	47	1737	8511	17	9
		Main effects and interactions				
Spacing	**	**	NS	*	NS	NS
Harvest date	NS	*	*	**	**	*
Spacing x date	NS	*	NS	NS	NS	NS

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

CHAPTER III

EFFECT OF DENSE SPACING OF OKRA ON PLANT ARCHITECTURE

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Abstract: Four okra [Abelmoschus esculentus (L.) Moench] experiments were conducted in the field during 1992, 1993 and 1994. Some characteristics of plant architecture were recorded. Overall plant heights were not affected by plant density. Branching decreased and the position of the first marketable fruit attachment moved up as plant density increased. Higher fruit position and reduced branching at higher plant densities were favorable to mechanical harvest. Marketable pods per plant at a given destructive harvest were relatively consistent among spacing treatments.

Introduction

The conventional plant spacing of okra in Oklahoma is 90 x 23 cm with wide aisles between rows to facilitate repeated hand harvesting. This plant arrangement is not necessarily efficient for mechanization of okra harvest, especially for a destructive mechanical harvest. Although an okra plant may produce a total of 20 or more pods during the growing season, a given plant at any given harvest bears only one or two marketable pods (Richardson,1972). A dense plant population was an important factor for maximizing yield with a once-over harvest in other fruit-type vegetables such as pickling cucumber (Cucumis sativus L.) and processing tomato (Lycopersicon esculentum Mill) (Hammett, 1974; Cantliffe and Phatak, 1975; Kretchman, 1975; Zahara, 1970).

Plant density can significantly influence plant architecture. McFerran et al. (1963) indicated that closer spacing of 'Clemson Spineless' okra decreased the amount of branching on the plants, concentrating the pods on the central flower stalk. Hermann et al. (1990) conducted an experiment in West Berlin which focused on plant architecture of okra. They also used 'Clemson Spineless' with three spacings of 80 x 7.8 cm, 80 x 15.6 cm and 80 x 31.3 cm, and observed that days from planting to first flower, number of leaves, leaf size, and number of generative nodes per plant were significantly reduced as planting density increased. Densely spaced plants were taller only at the early stages. By the end of experiment less densely spaced plants were taller since differences in the numbers of internodes by far outweighed the influence of internode length on plant height. Other experiments also showed that the number of branches per plant decreased as the plant density increased, consistent with what McFerran et al. (1963) observed (Fatokun and Chheda, 1983; Lee and Leong, 1979; Absar and

Siddlque, 1982). Another common observation was that the number of pods per plant decreased as plant density increased (Hermann et al., 1990; Fatokun and Chheda, 1983; Shrestha, 1983; Kamalanathan et al., 1970; Lan Chow Wing and Rajkomar, 1982; Absar and Siddlque, 1982).

Some disagreements existed among experiments. Abdul and Aarf (1986), Absar and Siddlque (1982), and Lee and Leong (1979) reported that there was an increase in plant height with an increase in plant density, while Gupta et al. (1981), and Lan Chow Wing and Rajkomar (1982) indicated there was no significant effect of plant spacing on plant height. Contrary to Hermann et al. (1990), Shrestha (1983) found that plant spacing did not affect days to first harvest.

Previous studies all were based on hand harvests and have not involved the response of plant architecture of okra to highly dense spacings for destructive mechanical harvest. Marshall (1984), Palevitch and Levy (1984), and Cooksey et al. (1994) stated that plant morphology of pepper (Capsicum annuum L.) affected the efficiency of mechanical harvest. Denser planting of pepper favored mechanical harvesting through favorable changes in plant morphology (Marshall, 1984; Palevitch and Levy, 1984). Our objectives were to determine the responses of okra plant architecture to highly dense plant arrangements, and to consider the implications of these responses for destructive mechanical harvest.

Materials and Methods

Four field experiments were conducted at the Bixby Research Station, Northeastern Oklahoma during 1992-1994. The soil type was a well-drained, very fine sandy loam (Entisol) which is well-suited for okra cultivation (Lee, 1991). 51N-22P-42K, 73N and 36N-16P-30K (kg · ha^{-1}) of preplant fertilizer were broadcasted in 1992, 1993 and 1994, respectively. Only N fertilizer was applied in 1993 because adequate P and K were available from fertilization of previous crops. No postplant fertilizers were applied in all years. Weeds were controlled with preplant-incorporated 2, 6-dinitro-N, N,-dipropyl-4-(trifluoromethyl) benzenamine (trifluralin) at 560 g · ha^{-1}, and by hoeing if weeds grew during the period of okra growth. Overhead sprinkler irrigation was provided as required to supplement rainfall. Insects were controlled with O,O-dimethyl S-(1,2-dicarboxyethyl) phosphorodithioate (malathion) at 1.4 kg · ha^{-1} as needed. No disease control was used in all years.

Seed of 'Clemson Spineless 80', one of the most popular commercial okra cultivars, was sown with a vacuum metering precision seeding ultranarrow row planter developed by professors Solie and Whitney of the OSU Biosystems and Agricultural Engineering Department. Row seed was used in 1992 and 1993. Seed which had been solid matrix primed by personnel in the Department of Plant Pathology, Oklahoma State University was used in 1994. Priming was for 3 days after which seeds were allowed to dry back. Dates of planting are shown in Table 3.1. Plants were grown on standard 2.1-m-wide beds using a conventional spacing (control) of 90 x 23 cm, and three higher density arrangements: 15 x 15 cm, 23 x 23 cm, and 30 x 30 cm. There were 2 rows per bed for the 90 x 23 cm spacing, and 10, 7, and 5 rows per bed for the 15 x 15 cm, 23 x 23 cm and 30 x 30 cm spacings, respectively.

A split-block design with 3 replications (Expt. 1, 2) or 4 replications (Expt. 3, 4) was employed. Main plots were spacings, and subplots were harvest dates. Main plots were 8 m long, and subplots were 4 m long.

Plants in high-population plots were destructively harvested by hand (simulating a once-over machine harvester) on two harvest dates for yield responses. Plants for plant architecture were sampled at the time of fiirst destructive harvest, which occurred when overmature fruits first were evident in high density plots. In 1992 and 1993, samples were taken within plots, while in 1994, samples were taken from among extra plants at the ends of plots. Control plots also were sampled using extra plants outside the areas undergoing repeated hand harvests. Five or six plants were sampled from each plot in each experiment. Sampling dates are shown in Table 3.1. Plants were cut off at soil level and brought to the lab for measurement. Overall height, height of branches, number of branches, height to first bloom and pod pattern were recorded for each plant. Analysis of variance procedures were used to analyze the data.

Results

Experiment 1: Overall plant heights were not affected by plant density (Table 3.2). However, the position of the first bloom or fruit attachment significantly moved up in the 15 x 15 cm spacing compared to the spacings of 30 x 30 cm and 90 x 23 cm. At the time of sampling, the position of first marketable fruit attachment on plants in the 15 x 15 cm and 23 x 23 cm spacings was much higher than on plants in the 30 x 30 cm and 90 x 23 cm spacings. Both marketable and total fruit number per plant had no differences among spacing treatments. The branch number per plant decreased as plant density increased.

Experiment 2: Overall plant heights, positions of first bloom or fruit attachment and first marketable fruit attachment, and marketable and total fruit number per plant did not show differences among treatments (Table 3.3). Fruit numbers per plant were low due to extremely hot and dry weather. The branch number per plant decreased as plant spacing increased, as in 1992.

Experiment 3: Overall plant heights and marketable fruit number per plant did not differ among treatments, while the positions of first bloom or fruit attachment and first marketable fruit attachment moved up as plant density increased (Table 3.4). Total fruit number and the branch number per plant decreased as plant density increased.

Experiment 4: Overall plant heights were not affected by plant density, as in previous experiments (Table 3.5). However, the position of the first bloom or fruit attachment and the first marketable fruit attachment moved up as plant density increased. Fruit number and branch number per plant decreased as plant density increased, especially when comparing high density plants to control plants.

Discussion and Conclusions

In all experiments, results indicated that overall plant heights were not affected by plant density. This finding is consistent with the observations of okra made by Gupta et al. (1981), and Lan Chow Wing and Rajkomar (1982). Branch number per plant decreased as plant density increased, also in agreement with many previous works (McFerran et al, 1963; Lee and Leong, 1979; Absar and Siddlque, 1982; Fatokun and Chheda, 1983). The position of the first bloom or fruit attachment and the position of the first marketable fruit attachment tended to move up as plant density increased. Richardson (1972) pointed out that the number of marketable pods per plant at any harvest was relatively constant. We obtained a similar result in that the number of marketable pods per plant were not significantly influenced by spacing except in Expt. 4. This showed the yield potential of densely planted okra for destructive machine harvest. As mentioned above, the higher fruit position and reduced branching obtained at higher plant densities should favor mechanical harvest by reducing stem and leaf material in the harvest bins.

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Table 3.1. Planting and sampling dates of experiments

Experiment	Planting date	Sampling date
1	6/18/92	9/11/92
2	6/17/93	9/3/93
3	5/10/94	7/7/94
4	5/24/94	8/26/94

Table 3.2. Plant architecture data from 11 Sept. 1992 harvest, Expt. 1

	Height (cm) from soil to:					
				Fruit no./ plant[z]		
Spacing	Highest plant part	First bloom or fruit attachment	First marketable fruit attachment	Marketable	Total	No. of branches/ plant[z]
15 x 15 cm	158	136a[y]	136a	0.7	1.8	0.0c
23 x 23 cm	160	127ab	135a	0.9	2.8	0.4c
30 x 30 cm	158	115b	115b	1.0	3.1	4.0b
90 x 23 cm	153	116b	116b	0.9	2.9	7.9a
			Main effect of spacing			
Spacing	NS	**	**	NS	NS	**

[z]Square root transformation applied to raw data; back- transformed means are shown.
[y]If main effect is significant, mean separation in columns by Duncan's MRT, P≤ 0.05.
[NS,**]Nonsignificant or significant at P≤ 0.01, respectively.

Table 3.3. Plant architecture data from 3 Sept. 1993 harvest, Expt. 2

	Height (cm) from soil to:			Fruit no./ plant^z		
Spacing	Highest plant part	First bloom or fruit attachment	First marketable fruit attachment	Marketable	Total	No. of branches/ plant^z
15 x 15 cm	78	71	38	0.2	0.2	0.2d^y
23 x 23 cm	75	56	42	0.1	0.6	1.8c
30 x 30 cm	63	45	35	0.0	0.6	3.6b
90 x 23 cm	58	38	33	0.2	0.7	7.8a
			Main effect of spacing			
Spacing	NS	NS	NS	NS	NS	**

^{z}Square root transformation applied to raw data; back- transformed means are shown.
^{y}If main effect is significant, mean separation in columns by Duncan's MRT, P≤ 0.05.
^{NS,**}Nonsignificant or significant at P≤ 0.01, respectively.

Table 3.4. Plant architecture data from 7 July 1994 harvest, Expt. 3

Spacing	Height (cm) from soil to: Highest plant part	First bloom or fruit attachment	First marketable fruit attachment	Fruit no./ plant[z] Marketable	Total	No. of branches/ plant[z]
15 x 15 cm	53	35a	40a	0.9	2.3c	0.0d
23 x 23 cm	52	26b	35b	1.2	3.5b	0.5c
30 x 30 cm	55	25bc	34b	1.3	4.2a	1.1b
90 x 23 cm	49	22c	29c	1.3	4.6a	3.6a
			Main effect of spacing			
Spacing	NS	**	**	NS	**	**

[z]Square root transformation applied to raw data; back- transformed means are shown.
[y]If main effect is significant, mean separation in columns by Duncan's MRT, P≤ 0.05.
[NS,**]Nonsignificant or significant at P≤ 0.01, respectively.

Table 3.5. Plant architecture data from 26 Aug. 1994 harvest, Expt. 4

Spacing	Height (cm) from soil to: Highest plant part	Height (cm) from soil to: First bloom or fruit attachment	Height (cm) from soil to: First marketable fruit attachment	Fruit no./ plant[z] Marketable	Fruit no./ plant[z] Total	No. of branches/ plant[z]
15 x 15 cm	148	138a[y]	150a	0.3c	0.8c	0.0c
23 x 23 cm	151	127ab	132ab	0.9bc	2.6b	0.2bc
30 x 30 cm	148	117b	127b	1.0b	3.5b	1.1b
90 x 23 cm	138	98c	103c	3.8a	9.5a	9.3a
			Main effect of spacing			
Spacing	NS	**	**	**	**	**

[z]Square root transformation applied to raw data; back- transformed means are shown.
[y]If main effect is significant, mean separation in columns by Duncan's MRT, P≤ 0.05.
[NS,**]Nonsignificant or significant at P≤ 0.01, respectively.

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