Yield, Time of Maximum CO₂ Exchange Rate, and Leaf-area Index of 'Clemson Spineless' Okra Are Affected by Within-row Spacing

W.F. Whitehead¹ and B.P. Singh

Agricultural Research Station, Fort Valley State University, Fort Valley, GA 31030-4313

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Abstract. A 2-year field study was conducted to determine the effects of within-row spacing (WRS) on CO₂ exchange rate (CER), leaf-area index (LAI), and yield of okra [*Abelmoschus esculentus* (L.) Moench]. Okra cultivar Clemson Spineless was seeded at WRS of 8, 16, 24, 32, 40, and 48 cm in a randomized complete-block design replicated three times. CER and LAI were measured five times at about biweekly intervals between first flowering and final harvest. Fruits were harvested three times weekly for 7 weeks. There was no year-to-year variation in CER or LAI. Plants at 8 cm WRS attained maximum CER by 56 days after planting (DAP), while all other spacings took longer. CER at all WRS declined after 85 DAP. In 8 and 16 cm WRS, maximum LAI developed by 56 DAP, but 69 DAP were required at all other spacing. Depending on the spacing, LAI regressed linearly or cubically on DAP. Fruit number/plant (FNP), fruit fresh and dry weight/plant (FFW and FDW), and fresh and dry fruit yield/ha (FFY and DFY) were greater in 1991 than in 1990 as a result of more favorable weather during 1991. There was a linear increase in FNP, FFW, and FDW as WRS increased. Conversely, FFY and DFY were highest at 8 cm and decreased linearly in 1990 and quadratically in 1991 as WRS increased. Results of this study suggest that okra plants reach maximum CER and LAI earlier and produce higher fruit yield per unit area when spaced close together in the row.

Interception of radiation by crop plants depends on the size and structure of the canopy. Size of the canopy is determined by the leaf area index (LAI), while leaf angle and orientation govern canopy structure. Leaf characteristics for a given cultivar are fixed genetically. Altering leaf area indices through plant population management is commonly used for canopy modification (Kerby et al., 1990a, 1990b; Pardales and Belmonte, 1984; Park et al., 1989). Several studies have reported that optimizing light interception through manipulation of plant spacing increased yields (Gallagher and Biscoe, 1978; Jackson, 1980; Papadopoulos and Pararajasingham, 1997; Shibles and Weber, 1965).

Papadopoulos and Ormrod (1988b) found little difference in the net photosynthesis rates of upper leaves of greenhouse tomatoes (*Lycopersicon esculentum* Mill.) spaced 23, 30, 38, and 45 cm apart. On the contrary, Rodriguez and Lambeth (1975) reported that spacing was a prime determinant of photosynthetic rates of greenhouse tomatoes during spring. Buxton et al. (1977) pointed out that since location of

leaves inside a canopy influences availability of radiation for photosynthesis, effectiveness of increased leaf area from higher plant density could vary with the distribution of leaves in different portions of the canopy. According to Papadopoulos and Ormrod (1988a), light interception is more closely related to canopy LAI than is planting density.

Okra produces fruit beginning with the third to sixth node. Fruits are continually produced on new nodes of developing stems, which results in several weeks of harvesting. As vegetative growth and fruiting proceed simultaneously for an extended period, the plant is required to maintain a delicate balance in the partitioning of assimilate between vegetative and reproductive parts (Kohle and Chavan, 1967).

A review of literature by Siemonsma (1982) revealed that, in most cases, okra yield increased with population density up to 10 plants/m². More recent spacing studies (Gupta, 1990; Muoneke and Udeogalanya, 1991; Zuofa, et al., 1989) substantiated these earlier findings. However, Albregts and Howard (1974) found okra yield to increase up to 64 plants/m². In contrast, Hermann et al. (1990) in a greenhouse study in Germany reported no difference in okra yield among spacings of 4, 8, or 16 plants/m².

Further research is needed to better understand how within row plant competition affects the physiology, canopy development, and fruit yield of okra. In this study, the effects of different WRS on CER, LAI, and fruit yield of okra were determined.

This study was conducted during 1990 and 1991 at the Fort Valley State Univ., Agricultural Research Station, Fort Valley, Ga., located at lat. 32°34'N, long. 83°52'W. Soil type at the experimental site is Dothan sandy loam (fine loamy, siliceous, thermic, Plinthic Paleudult).

Soil was prepared to a fine tilth and okra 'Clemson Spineless' was planted in an east-west direction at appropriate seeding rates on 17 May in both years. Plots consisted of four rows, 0.92 m wide × 6.1 m long. The six WRS densities (8, 16, 24, 32, 40, and 48 cm), were arranged in a randomized complete-block design and replicated three times. Appropriate fertilization, weed, and insect control protocols were followed. Irrigation (50 mm per application) was applied as needed.

The CER (μmol·m⁻²·s⁻¹) was recorded at 56, 69, 85, and 114 DAP between first flowering and final harvest. Measurements were taken using a portable steady-state infrared gas-exchange system (Analytical Development, Huddleston, England). Fully expanded leaves on the distal portion of the main stem of two randomly selected plants were used to obtain nondestructive CER readings. Data were collected between 1000 and 1330 HR, when photosynthetic active radiation (PAR) ranged between 1276 and 1392 μmol·m⁻²·s⁻¹ and ambient temperature was between 29 and 34 °C.

A LAI-2000 Plant Canopy Analyzer (LI-COR, Lincoln, Nebr.) was used to estimate LAI five times at about biweekly intervals between first flowering (9 July) and final harvest (4 Sept.). Each data set consisted of one above-canopy irradiance reading and four below-canopy readings ≈15 cm above the soil along an evenly spaced diagonal transect between the two middle rows of each plot.

Each year, fruits were harvested from the two middle rows three times a week for 7 weeks from 25 July to 7 Sept. to determine fresh and dry fruit yield/ha (FFY and DFY). Five randomly tagged plants were also harvested for obtaining data on fruit number/plant (FNP), fruit fresh and dry weight/plant (FFW and FDW). The number of branches (BNP) on the tagged plants were counted at the time of last harvest.

All data were subjected to analysis of variance (SAS Inst., Cary, N.C., 1988). Regression analyses were performed by Proc GLM (SAS Inst., 1988). Regression equations were selected on the best and most significant ($P \leq 0.05$ for |T|) regression parameters with highest coefficient of determination (r^2).

Results and Discussion

Air temperature during the critical fruiting months of August and September was considerably higher in 1990 than in 1991 (Fig. 1). Total rainfall during the growing season for 1990 and 1991 was 306 and 548 mm, respectively (Fig. 2). Rainfall in August was 46% higher in 1991 than in 1990.

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¹To whom reprint requests should be addressed. E-mail address: whitehew@mail.fvsvu.edu

Fig. 1. Mean daily temperature from 1 May to 14 Sept. in 1990 and 1991.

Fig. 2. Mean biweekly precipitation from 1 May to 14 Sept. in 1990 and 1991.

Fig. 3. Seasonal changes in CO_2 exchange rate (CER) and leaf area index (LAI) at different within-row spacings (WRS) in okra (1990 and 1991 data combined). (A) 8 cm, $y = 35.9 - 0.23x$, $r^2 = 0.76^{**}$; 16 cm, $y = 2.3 + 0.63x - 0.005x^2$, $r^2 = 0.91^{**}$; 24 cm, $y = -11.3 + 0.98x - 0.007x^2$, $r^2 = 0.90^{**}$; 32 cm, $y = -12.3 + 0.99x - 0.007x^2$, $r^2 = 0.90^{**}$; 40 cm, $y = 35.3 + 1.54x - 0.010x^2$, $r^2 = 0.34^{NS}$; and 48 cm, $y = -14.5 + 1.06x - 0.008x^2$, $r^2 = 0.93^{**}$. (B) 8 cm, $y = 7.4 - 0.05x$, $r^2 = 0.86^{**}$; 16 cm, $y = 7.4 - 0.05x$, $r^2 = 0.71^{**}$; 24 cm, $y = -24.1 + 1.15x - 0.015x^2 + 0.00006x^3$, $r^2 = 0.75^{**}$; 32 cm, $y = -41.3 + 1.77x - 0.022x^2 + 0.00009x^3$, $r^2 = 0.75^{**}$; 40 cm, $y = 7.4 - 0.05x$, $r^2 = 0.75^{**}$; 48 cm, $y = -32.2 + 1.42x - 0.017x^2 + 0.00007x^3$, $r^2 = 0.80^{**}$. NS , * , ** Nonsignificant, and significant at $P \leq 0.05$ and 0.01 , respectively. L = linear, Q = quadratic, and C = cubic.

Fig. 4. Branch and fruit number/plant (BNP and FNP) at different within-row spacings (WRS) in okra. (A) Branch-1990, $y = 0.02 + 0.24x$, $r^2 = 0.91^{**}$; 1991, $y = 1.1 + 0.14x$, $r^2 = 0.88^{**}$. (B) fruit-1990, $y = 8.0 + 0.58x$, $r^2 = 0.98^{**}$; 1991, $y = 14.4 + 0.80x$, $r^2 = 0.98^{**}$. ** Significant at $P \leq 0.01$. L = linear.

There was no year-to-year variation in CER; therefore, data from both years were combined for analysis. The peak CER values were not affected by treatment (Fig. 3A). Minimum and maximum CER for treatments averaged 7.5 and 21.8 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, respectively. The maximum CER was reached at 56 DAP at 8 cm, and 69 DAP at all other WRS. The regression of CER on DAP was linear at 8 cm and quadratic at other WRS. At all WRS except 40 cm, r^2 values were highly significant and ranged from 0.76 to 0.93.

Miyaji (1984) and Crompton et al. (1984) also reported no effect of plant density on the photosynthetic rate of brightly lighted leaves of soybean [*Glycine max* (L.) Merrill] and field beans (*Vicia faba* L.). In greenhouse tomatoes, Papadopoulos and Ormrod (1988b) observed negligible effect of plant spacings between 23 and 45 cm on upper leaf CER, whereas Rodriguez and Lambeth (1975) reported highest CER at a plant spacing of 41 cm and lowest CER at a spacing of 25 cm.

The BNP at the time of final harvest ranged from 1.8 to 9.2/plant (Fig. 4A). The increase in branch number was linear with the increase in WRS.

The LAI was similar during both years; thus data from the 2 years were combined for analysis. The maximum LAI values for all

WRS were similar, and were reached from 56 to 69 DAP (Fig. 3B). Minimum and maximum LAI for all treatments during the reproductive growth phase averaged 2.3 and 4.9, respectively. The regression of LAI on DAP was linear at 8, 16, and 40 cm and quadratic at 24, 32, and 48 cm WRS with r^2 values ranging from 0.71 to 0.86.

A plant's ability to compensate for variations in density has been demonstrated in several crops (Nederhoff, 1984; Papadopoulos and Ormrod, 1988a). In the earlier stages of growth, plants at higher densities develop greater LAI, but by the time full canopy forms, such differences largely disappear. This occurs because plants at lower densities branch more and produce leaves on these branches, thus increasing canopy size.

Yield of okra and individual components thereof were higher in 1991 than in 1990. This was probably due to lower day temperature and higher rainfall during the August fruiting period in 1991.

The FNP increased linearly with WRS (Fig. 4B). It ranged from 13.3 to 34.5 in 1990 and 22.7 to 54.9 in 1991 as the WRS increased from 8 to 48 cm. Since okra bears a single flower/node, the number of nodes on a plant largely determines the number of fruits it can bear. Close spacing increases competition

among adjoining plants for available soil nutrients and water, as well as for aerial space for canopy formation. This prevents profuse branching and production of nodes on those branches for flowering and fruit set. Hermann et al. (1990) showed that fruit retention was 23% greater in okra when plant density was 4 rather than 16 plants/ m^2 .

The FFW and FDW also increased linearly with the WRS (Fig. 5 A and B). The FFW ranged from 151 to 342 g in 1990 and from 198 to 739 g in 1991. The ranges for FDW during 1990 and 1991 were 13.5–32.8 g and 20.2–66.6 g, respectively. Plants bore more fruits as spacing increased from 8 to 48 cm, and this could account in large part for the greater per plant fruit weight at wider spacings. Furthermore, Hermann et al. (1990) observed that okra plants produced heavier pods at wider spacings. Greater fruit weight and fruit number/plant at wider spacing have also been reported in other vegetable crops (Decoteau and Graham, 1994; Gaye et al., 1992; Kahn et al., 1997).

Contrary to the data fruit weight on a per plant basis, fresh and dry fruit yields on an area basis were greatest at 8 cm and decreased as the WRS increased to 48 cm (Fig. 6 A and B). The decrease was linear and quadratic in 1990 and 1991, respectively. The range of FFY in

Fig. 5. Fruit fresh and dry weight/plant (FFW and FDW) at different within-row spacings (WRS) in okra. (A) Fresh–1990, $y = 98.3 + 5.05x$, $r^2 = 0.99^{**}$; 1991, $y = 95.0 + 13.13x$, $r^2 = 0.99^{**}$; (B) dry–1990, $y = 8.3 + 0.49x$, $r^2 = 0.98^{**}$; 1991, $y = 10.3 + 1.15x$, $r^2 = 0.99^{**}$. ** Significant at $P \leq 0.01$. L = linear.

Fig. 6. Fresh and dry fruit yield/ha (FFY and DFY) at different within-row spacings (WRS) in okra. (A) Fresh–1990, $y = 18.4 - 0.26x$, $r^2 = 0.69^{*}$; 1991, $y = 32.4 - 0.81x + 0.010x^2$, $r^2 = 0.99^{**}$; (B) dry–1990, $y = 1.7 - 0.02x$, $r^2 = 0.67^{*}$; 1991, $y = 3.4 - 0.10x + 0.010x^2$, $r^2 = 0.96^{**}$. * , ** Significant at $P \leq 0.05$ and 0.01 , respectively. L = linear and Q = quadratic.

1990 was from 7.8 Mg-ha⁻¹ at 48 cm to 20.4 Mg-ha⁻¹ at 8 cm WRS. In 1991, both minimum and maximum FFY were higher, with a range of 16.8 to 26.7 Mg-ha⁻¹. Plants spaced at 8 cm within-row produced at full capacity starting from the first week of harvest, while it took 2 more weeks to reach maximum production at other WRS. The DFY ranged from 0.8 to 1.8 Mg-ha⁻¹ in 1990 and 1.5 to 2.7 Mg-ha⁻¹ in 1991.

Most earlier studies on okra plant population density have reported increases in crop productivity as density increased to 10 plants/m² (Gupta, 1990; Muoneke and Udeogalanya, 1991; Siemonsma, 1982; Zuofa et al., 1989). However, Albregts and Howard (1974) observed increases in yield up to 64 plants/m². In comparison, our study revealed a continual increase in fruit yield from the lowest (2.4 plants/m²) to the highest density (14 plants/m²). Increased yields at higher population densities have also been reported in other vegetable crops (Decoteau and Graham, 1994; Gaye et al., 1992). However, Hermann et al. (1990) observed no difference in okra yield at 4, 8, or 16 plants/m². In earlier preliminary work we showed that if density was >14 plants/m², plants had tall and slender stalks and lodged easily while fruiting.

In this study, there was a substantial population difference between consecutive WRS, with the narrowest WRS having six-times more plants than the widest. Furthermore, plants spaced at 8 cm within-row consisted mostly of main stem, and the number of branches increased linearly with WRS. Thus, fruits were borne primarily on main stems at 8-cm spacing and proportionately more were borne on secondary branches as the WRS increased. According to Siemonsma (1982), secondary branches in okra contribute less to yield than does the same as the main stem. This may explain, in part, the yield advantage of higher densities.

The results of this study clearly demonstrated the existence of a relationship between the seasonal physiological and morphological activities and fruiting behavior of okra plants. Plants at 8 cm WRS obtained peak CER and

maximum LAI ≈2 weeks before those at other spacings and were also 2 weeks ahead of other spacings in fruiting at full capacity. Vegetables marketed early in the season usually bring premium prices; thus closely spaced okra plants not only produce higher yields but also provide the added economic advantage of early harvests.

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