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In-row Plant Spacing Affects Growth and Yield of Pepperoncini Pepper

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***Abstract*. Pepperoncini pepper (*Capsicum annuum* var. *annuum* L. 'Golden Greek') was grown at in-row spacings of 7.5, 15, 22.5, 30, and 45 cm to determine the effect of plant population on growth and fruit yield in a 2-year field study. In 1992, pepper plants grown at the 15-cm in-row spacing had the lowest plant, stem, and leaf dry weights, while plants at the lowest density (45-cm spacing) had the highest plant, leaf, and stem dry weights and the largest leaf area (LA). Of plants grown at the 7.5-cm spacing, the total yield and fruit count per hectare were higher than at the other spacings; however, fruit yield per plant was lowest. In 1993, the lowest plant and leaf dry weights and LA and highest LA index (LAI) were from plants at the 7.5-cm in-row spacing. Plants at the 45-cm spacing had the highest plant and leaf dry weight and LA and the lowest LAI. Pepper plants grown at the narrowest spacing produced the lowest early and total fruit yield per plant but the most fruit per hectare. In general, plants grown at the narrowest spacings produced the smallest plant, leaf, and stem biomass but resulted in the highest fruit yields and counts per hectare and the lowest fruit yields per plant.**

Pepper *(Capsicum* species) has considerable biodiversity, including several species of commercial importance in the United States (Bosland, 1992). *Capsicum annuum* (L.) varies in plant growth habit, fruit pigmentation and size, pungency, and market characteristics. Within this species, there are numerous types, and each type and cultivar often have specific cultural and market requirements. Fresh and processed production of nonbell pepper types in the southern United States is expanding. There is limited research reported on the effect of environmental characteristics and cultural practices on yield and quality characteristics of these nonbell pepper types (e.g., Saamin, 1978).

Pepperoncini pepper is a processing type grown in the southern United States in limited quantities. Immature fruit of mildly pungent and nonpungent pepperoncini pepper are used as a pickled condiment. Demand is increasing due to the popularity of salad bars in the retail and food service industries. Most pepperoncini pepper in the U.S. market is imported from production areas in the Mediterranean. An estimated 9 million kilograms were imported into the United States in 1992 (Jim Lusk, personal communication). In general, production and harvesting costs are high and the returns relatively low in peppers grown for processing. Managing production inputs and minimizing production costs are increasingly important. Optimum plant population or in-row plant spacing studies have been conducted on bell (Batal and Smittle, 1981; Everett and Subramanya, 1983; Locascio and Stall, 1994; Russo, 1991; Stoffella and Bryan, 1988), cherry (Orzolek, 1981), pimento (Johnson et al., 1973), cayenne (Decoteau and Graham, 1994), and Tabasco peppers (Sundstrum et al., 1984). Little research has been conducted on pepperoncini pepper (Saamin, 1978). Our objective was to investigate the influence of in-row plant spacing on pepperoncini pepper growth and yield.

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Materials and Methods

Five in-row plant spacings were evaluated: 7.5, 15, 22.5, 30, and 45 cm on raised beds, 0.85 m wide and 15 cm high. Field studies were conducted at the Dept. of Horticulture Hill Farm in 1992 and the Burden Research Station in 1993 (Baton Rouge, La.). The soils at both locations were an Olivier silt loam (Typic Paleudults). On 27 May 1992 and 4 June 1993, pepperoncini pepper seeds ('Golden Greek', Petoseed Co, Saticoy, Calif.) were sown into 72-cell trays (cell length, 5.7 cm; 4.8 cm^3) filled with commercial soilless mix (Metromix 350; W.R. Grace & Co., Cambridge, Mass.) and placed in a greenhouse. Four-week-old transplants were hand-transplanted into 3.7-m-long plots on 1.1-m centers. Individual plots consisted of three rows, with all data obtained from the middle row. Plots received 650 kg preplant fertilizer (8N–10.4P–20K)/ha banded in the row and N (NH_4NO_3; 56 kg N/ha) sidedressed on the bed shoulder at first harvest. Recommended pepper plant establishment and pest management practices were followed (Boudreaux, 1992). Overhead irrigation was applied as needed throughout the season.

Immature fruit within the prescribed commercial size requirements (3.5 to 6 cm long) were removed by hand twice a week for a total of eight harvests. Marketable fruit were harvested manually, counted, and weighed for each plot. The first harvests were 4 Aug. 1992 and 17 Aug. 1993. Marketable fruit yields, summed for early (first three harvests) and total yield, were expressed on a per-plant and per-hectare basis. Fruit length, width, and weight were measured from five fruit per plot randomly selected at each harvest.

Plant characteristics were measured at last harvest. Stem length, leaf area (LA) [determined with an area meter (Delta-T Devices, Cambridge, England)], fresh and dry weights (70C for 48 h) of stem and leaf fractions, and leaf : stem ratio (dry-weight basis) were determined from one plant in each plot. The following growth characteristics were calculated according to Hunt (1990): specific LA (SLA) (LA ÷ leaf dry weight), LA ratio (LAR) (LA ÷ total plant weight), and LA index (LAI) (LA ÷ ground area per plant). In addition, stem diameter (measured with a caliper at the soil surface) was determined from three plants in each plot. In 1993, canopy height (from the soil to top of the canopy) was measured. The study was a randomized complete-block design, with four replications both years. Data were subjected to analysis of variance, and orthogonal contrasts were used to analyze significant trends.

Results and Discussion

Vegetative characteristics. In-row plant spacing influenced pepperoncini pepper plant growth in 1992 (Table 1). As in-row plant spacing increased from 7.5 to 45 cm, whole-plant, stem, and leaf dry weights and stem diameter increased linearly. Stem length, however, was unaffected by in-row plant spacing. LA also increased linearly with wider in-row plant spacing. There were no statistical differences in the leaf : stem ratio and SLA. In-row spacing influenced the LAR and LAI cubically. The highest plant, stem, and leaf dry weights and LA and the largest stem diameter were from plants produced at the widest spacing (45 cm). The lowest plant, stem, and leaf dry weights, the smallest stem diameter, and the highest LAR were from plants at the 15-cm spacing.

All plant characteristics, other than SLA, were influenced by in-row spacing in 1993 (Table 2). As in-row plant spacing increased from 7.5 to 45 cm, plant and stem dry weight increased linearly, while canopy height and stem length decreased linearly. Stem diameter and leaf dry weight were affected quadratically by spacing. LA and the leaf : stem ratio increased linearly with wider row spacing, but row spacing had no affect on SLA. LA ratio increased linearly with wider spacings, while the LAI was influenced quadratically. The highest plant and leaf dry weights, LA, leaf : stem ratio, and LAR and the lowest LAI were from plants produced at the widest (45 cm) plant spacing. The lowest whole-plant, stem, and leaf weights; LA; leaf : stem ratio; and

Table 1. Effect of in-row plant spacing on pepperoncini pepper plant characteristics, 1992.

In-row spacing (cm)	Plants/ ha (×1000)	Plant dry wt (g)	Stem Dry wt (g)	Stem Length (mm)	Stem Diam (mm)	Leaf dry wt (g)	Leaf area (cm^2)	Leaf/stem dry wt (%)	SLA[z] ($cm^2 \cdot g^{-1}$)	LAR[y] ($cm^2 \cdot g^{-1}$)	LAI[x] ($cm^2 \cdot cm^{-2}$)
7.5	121.1	31.9	17.6	531	11.1	14.4	1980	80	158	64	2.13
15	60.6	26.9	13.7	549	9.4	13.2	2110	103	175	81	1.14
22.5	40.4	35.8	20.7	556	11.5	15.1	2470	74	171	70	0.89
30	30.3	50.1	27.9	594	12.8	22.2	3240	78	157	66	0.87
45	20.2	66.4	35.5	584	13.3	30.9	5220	94	171	79	0.94
Significance		L***	L***	NS	L*	L***	L***	NS	NS	C*	L***, Q***, C***

[z]SLA (specific leaf area) = leaf area ÷ leaf dry weight.
[y]LAR (leaf area ratio) = leaf area ÷ total plant weight.
[x]LAI (leaf area index) = leaf area ÷ plant area.
NS, *, ***Nonsignificant or significant at $P \leq 0.05$ or 0.001, respectively; L = linear, Q = quadratic, and C = cubic.

Table 2. Effect of in-row plant spacing on pepperoncini pepper plant characteristics, 1993.

In-row spacing (cm)	Plants/ ha (×1000)	Plant dry wt (g)	Canopy ht (cm)	Stem Dry wt (g)	Stem Length (mm)	Stem Diam (mm)	Leaf dry wt (g)	Leaf area (cm^2)	Leaf/stem dry wt (%)	SLA[z] ($cm^2 \cdot g^{-1}$)	LAR[y] ($cm^2 \cdot g^{-1}$)	LAI[x] ($cm^2 \cdot cm^{-2}$)
7.5	121.1	34.3	66.6	20.6	713	12.0	13.8	3820	67	278	111	4.11
15	60.6	43.7	57.8	24.8	608	15.7	18.9	5310	77	283	122	2.86
22.5	40.4	61.4	57.3	33.9	677	16.7	27.5	7480	82	285	129	2.68
30	30.3	62.2	48.8	35.0	635	19.2	27.1	8110	79	300	131	2.18
45	20.2	62.3	45.4	33.9	602	18.1	28.4	8850	84	314	143	1.59
Significance		L**	L*	L*	L*	L***, Q*	L***Q*	L***	L*	NS	L*	L***, Q*

[z]SLA (specific leaf area) = leaf area ÷ leaf dry weight.
[y]LAR (leaf area ratio) = leaf area ÷ total plant weight.
[x]LAI (leaf area index) = leaf area ÷ plant area.
NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively; L = linear, Q = quadratic.

LAR and the smallest stem diameter and highest LAI were from plants at the 7.5-cm spacing.

Increased in-row spacing resulted in linearly increased plant dry weight and stem diameter in both years. Similar results have been reported for cayenne pepper (Decoteau and Graham, 1994) and bell pepper (Stoffella and Bryan, 1988). In our study, stem length decreased linearly in 1 of 2 years as in-row spacing increased. Similarly, Stoffella and Bryan (1988) and Everett and Subramanya (1983) reported that bell pepper stem length decreased with wider in-row spacing. In contrast, tabasco pepper stem length was not affected by in-row spacing (Sundstrom et al., 1984), and cayenne pepper plant height increased 1 year and decreased the 2nd year as a result of wider in-row spacing (Decoteau and Graham, 1994).

In-row spacing affected plant dry weight both years. Plant and leaf dry weight for plants spaced at 45 cm were about twice that of plants at the 7.5-cm spacing. The narrower in-row spacing resulted in a higher LAI, indicating the strong vegetative growth of the crop. The LAI of the 45-cm-spaced plants was about half that of plants at 7.5 cm. In addition, the narrowest spacing resulted in the lowest LAR (morphological index of the leafiness of the plant). In-row spacing, however, did not affect SLA, an index for the relative thinness of leaves.

With a hand-harvested crop like pepperoncini, erectness may be a desirable characteristic in terms of harvest ease. In general, plants at the wider spacings were more prostrate both years. The ratio of canopy height to stem length was highest for plants grown at the 7.5- and 15-cm spacing (>93%); it was only 75% at the widest spacing (1993). This result suggests that, in addition to longer stems of plants at narrow spacings, these plants also were more upright. Other researchers (Sundtrom et al., 1984) have postulated that individual pepper plants at close spacings use adjoining plants for support. In addition, the LA and LAR of plants at closer spacings were lower than for wider-spaced plants in our study, which may make it easier to locate fruit for hand removal.

Fruit yield characteristics. Pepperoncini pepper fruit yields were affected by in-row plant spacing (Table 3). As in-row spacing increased from 7.5 to 45 cm, early and total fruit yield per plant increased linearly, while total fruit yield and fruit count per hectare decreased linearly in 1992. Early fruit yield and number per hectare were influenced quadratically. The lowest and highest early and total yields were for plants grown at the 45- and 7.5-cm spacing, respectively. In 1993, in-row plant spacing influenced early pepperoncini yields. As in-row spacing increased, early and total pepperoncini pepper fruit yield and number per hectare decreased linearly. The highest early and total yield were for plants at the 7.5-cm spacing; the lowest yield was for plants grown at 45 cm. Early yield per plant did not differ due to spacing, while the total fruit yield per plant increased linearly with increased spacing. In-row plant spacing did not influence pepperoncini fruit length, width, and weight for early or total harvests in either year (data not presented).

In-row plant spacing significantly affected pepperoncini pepper yield components in both years. During 1992 and 1993, total yields of plants spaced at the narrowest spacing (7.5 cm) were 182% and 233% that of plants at the widest spacing (45 cm), respectively. Pepper fruit yields per plant were lower but the fruit count per hectare was highest at the narrow row spacing. There was no effect of spacing on fruit length, weight, or diameter, indicating that yield differences were due to fruit count per hectare. These results suggest that the yield-per-hectare increase with a narrower spacing is attributable to a higher plant population and lower fruit production per plant, rather than higher pepper yields per plant or fruit size. The results of this study are similar to those reported for once-over, hand-harvested cayenne pepper (Decoteau and Graham, 1994); multiple-harvested bell pepper (Everett and Subramanya, 1983; Stofella and Bryan, 1988); and single machine-harvested tabasco pepper (Sundstrom et al., 1984). In contrast, Locascio and Stall (1994) reported that in-row spacing affected bell pepper yield per plant (yield per plant was inversely related to plant population), while in-row spacing of 0.23 and 0.3 m did not influence total marketable yield. Total yield, however, was higher with row arrangements with higher rather than lower plant populations. Batal and Smittle (1981) concluded that total plant population was a more important factor affecting bell pepper yield than plant arrangement; yield from 27,000 plants/ha was lower than with populations of 40,000 to 60,000 plants/ha.

Miller et al. (1979) reported that bell pepper grown at a plant population of 48,000/ha resulted in a relatively low LAI (1.8 at 98 days after transplanting) and net assimilation rate. The LAI increased with time up to 98 days, after which it decreased. LAI in our study was highest for the narrowest in-row spacing in

Table 3. Effect of in-row plant spacing on pepperoncini pepper yield, 1992 and 1993.

In-row spacing (cm)	Plants/ha (×1000)	1992 Early yield[z] (g/plant)	(t•ha^{-1})	No./ha (×1000)	1992 Total yield[y] (g/plant)	(t•ha^{-1})	No./ha (×1000)	1993 Early yield[z] (g/plant)	(t•ha^{-1})	No./ha (×1000)	1993 Total yield[y] (g/plant)	(t•ha^{-1})	No./ha (×1000)
7.5	121.1	11.2	3.3 a	730 a	14.2	11.1	2940	6.9	2.2	470	9.7	8.4	2090
15	60.6	12.6	2.0 b	470 b	18.1	7.8	2180	11.8	2.0	430	19.3	8.6	2010
22.5	40.4	13.3	1.6 b	350 bc	25.9	7.7	2050	11.7	1.4	300	20.3	6.6	1610
30	30.3	18.7	1.4 b	320 bc	34.3	7.1	1950	13.5	1.2	260	21.1	5.1	1250
45	20.2	17.4	1.0 b	250 c	38.4	6.1	1670	10.7	0.7	150	22.0	3.6	940
Significance		L**	L**, Q*	L**, Q*	L**	L**	L**	NS	L**	L**	L**	L**	L**

[z]Early yield equals the first three harvests combined.

[y]Total yield equals the cumulative yield of eight harvests.

NS, *, **Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively; L = linear, Q = quadratic.

both years. Miller et al. (1979) and Stofella and Bryan (1988) suggested that bell pepper efficiency increases at higher plant populations. Our results indicate a similar trend; at higher pepperoncini pepper plant populations (i.e., narrower in-row spacing), plant efficiency was highest.

Our results indicate that in-row plant spacing affects plant growth and yield of pepperoncini pepper. Narrower in-row plant spacing (lower population density) resulted in plants that were smaller (less leaf and plant biomass), more upright, and produced less fruit yield per plant but higher fruit yield (tons per hectare) and number per hectare. The higher plant population at the narrower in-row spacings compensated for lower yield per plant considering that fruit weight and size were unaffected and resulted in increased yield per area. These results indicate that an in-row spacing closer than the 30- to 45-cm in-row spacing recommendation for pepperoncini in Louisiana (Boudreaux, 1992) may be optimal in terms of harvest ease and yield.

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