Plant density and shoot pruning on yield and quality of a summer greenhouse sweet pepper crop in Northcentral Florida

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Abstract

In greenhouse crops, fruit yield and quality can be increased by managing shoot pruning and plant density. The effect of plant population density (2, 3 and 4 plant·m^{-2}, as function of in-row plant spacing: 66.5, 44.3 and 33.3 cm, respectively), and shoot pruning (1, 2 and 4 main stems) was studied for effects on fruit yield, fruit quality and plant growth of greenhouse grown sweet pepper (*Capsicum annuum* L. cv. Robusta) during Summer 1998 in Gainesville, Florida. Plants were grown in perlite bags and irrigated with a nutrient solution. Red fruits were harvested 84 and 118 days after transplanting (Apr. 14th). Additional fruit set was inhibited due to the high temperatures. Marketable yield (number and weight) per m^2 increased linearly with plant density and was greater on plants with four stems than in those with two or one stem. Extra large fruit yield per m^2 was not affected by plant density but was higher in four-stem plants. Total marketable yield and extra large fruit yields per plant were greatest in the four-stem plants at 2 plant·m^{-2}. The stem length and the number of nodes per stem increased linearly with the decrease in plant spacing. Stem length and number of nodes per stem were greater in single-stem than in four-stem plants. Number and dry weight of leaves, stem diameter, and total plant dry weight were higher in four and two than in single-stem plants. Total stem weight in four-stem plants increased linearly with the decrease of plant density. Results indicated that 4 plant•m^{-2} pruned to four stems increased marketable and extra large fruit yield in a short harvest period of a summer greenhouse sweet pepper crop in Northcentral Florida.

Introduction

In vegetable greenhouse production profits are greatly dependent on high yield and quality per unit area. Plant spatial arrangement is a crop management practice that has been used to increase yield per unit area in greenhouse sweet pepper (Verheij and Verwer, 1971; Guo *et al.*, 1991; Cebula, 1995; Lorenzo and Castilla, 1995). Wide within-row plant spacings increase per plant yield but decreases production per unit area in greenhouse (Cebula, 1995) or field (Stoffella and Bryan, 1988; Gaye *et al.*, 1991) peppers. Higher plant densities (4 vs. 3 plants•m^{-2}) reduced fruit weight from early yield (Cebula, 1995). Fruit weight, which is associated with fruit size, is of great importance because it determines prices for colored sweet pepper. In commercial greenhouse pepper crops fruit development is controlled by restricting the branching pattern to 2, 3 or 4 main stems. The reasons for pruning sweet pepper under greenhouse conditions are to train plant growth to facilitate light penetration throughout the leaf canopy for more efficient interception of light. Guo *et al.* (1991) reported higher sweet pepper yields in 2-stem plants at 4.5 plants·m^{-2} than in 4-stem plants at 2.25 plants·m^{-2}. Cebula (1995) reported that high total yield could be obtained from plants pruned to one stem grown at 8 plants·m^{-2} or 2-stem plants at 4 plants·m^{-2}.

Greenhouse sweet pepper is a relatively new crop in Florida with potential to expand production in the future. Local environmental conditions, seasonality, as well as the type of greenhouse structure used for growing may result in particular recommendations regarding crop management practices as plant density and pruning levels, that are different from studies reported from other countries. The present study was conducted to determine the effects of plant population density and number of stems per plant on sweet pepper red fruit yield and quality, and plant growth in a summer greenhouse crop at Northcentral Florida.

Materials and methods

The experiment was conducted during summer 1998 in a double layer polyethylene single type greenhouse of 9 x 30 x 4 m (width x length x height) (Atlas Greenhouse Systems, Inc.) North South oriented, located at the Horticultural Sciences Department Research Unit of the University of Florida, Gainesville. The greenhouse had a roof wing ventilation system, lateral curtains, and electric fans for ventilation. Sweet pepper (*Capsicum annuum* L. cv. "Robusta", De Reuiter Seed Co.) seedlings were grown on a 70-30 % peat moss-vermiculite (Terralite) substrate mix in 200-cell (2.5 cm x 2.5 cm x 6.7 cm) styrofoam transplant flats (Speedling, Sun City, Fla.). Polyethylene sleeves 0.32 m wide (flat), black-white (inside-outside), were filled with perlite (Aer-lite, Chemrock Inc.) to form a 2 m long bag, coincident with the length of an experimental plot. On April 14th, forty-two day seedlings were transplanted into the perlite bags. Three plant densities: 2, 3 and 4 plant·m^{-2}, as function of in-row plant spacing: 66.5, 44.3 and 33.3 cm, respectively and three shoot pruning levels (1, 2 and 4 main stems) were arranged in a factorial design with 3 blocks that divided the greenhouse area from North to South. Each plot consisted in three parallel double row bags. Bags from double rows were 0.50 m apart, and 1 m was left for a corridor between double rows.

In order to encourage initial vegetative growth, first (crown flower) and second order flowers were pulled from the plants in all treatments. Lateral shoots and flowers just above the cotyledonary node were also removed. Lateral branch shoots were pruned to form a plant structure of 1, 2 or 4 main branches. When pruning a main branch, only the flower on the branch node and its adjacent leaf were left. Lateral plastic twines and wood stakes were used to support the plants.

Plants were irrigated with a complete nutrient solution with nutrient concentrations levels developed for greenhouse grown hydroponic tomatoes - "formula method" (Hochmuth, 1991) -. Nutrient levels for different sweet pepper plant developing stages were adapted as follows: from transplant to second order flowers N-P-K concentration in the irrigation solution was 70-50-119 ppm, followed by 80-50-119 ppm until fruit set on third order flowers, and 153-50-148 ppm until the end of the experiment. Each plant was irrigated with pressure compensated emitters with a flow discharge of 130 ml·min^{-1}. Irrigation was scheduled by the use of a timing irrigation controller and kept to a per day volume that would give a 10-15% (v/v) of solution drainage from the bags. Daily applied volumes started from 1 l·plant^{-1}·day^{-1} (12 times a day) to 2.5 l·plant^{-1}·day^{-1} (48 times a day) after fruit set.

Air temperatures were recorded every half-hour by a data logger (CR10X, Campbell Scientific, Inc.) from May 12th to July 15th. Thermocouples were placed 2 m high, at two locations: 3 m from the ends, and along the middle double row of the greenhouse. On May 25th the greenhouse was covered with a 30% black shade cloth to reduce inside air temperatures.

Red fruits were harvested, 84 (July 6th) and 118 (August 1st) days after transplanting, from the central double row of the plots. Additional fruit set was inhibited due to the high temperatures. All fruits were counted, weighted and measured on diameter (maximum distance across shoulders), length (maximum distance without considering the peduncle), and pericarp thickness (as an average of measures in two locules at the middle of the fruit length). Fruits were graded by diameter into small (56-63.9 mm), medium (64-75.9 mm), large (76-83.9 mm), and extra large (>84 mm) size.

After the last harvest two plants from each plot were used for analyzing plant growth. Plant leaves number, main branch length, number of nodes per main branch, and stem diameter at the top level of the bag (1 cm over cotyledonary node) were measured. Plant leaf, stem and total canopy dry weight were determined.

Analysis of variance was performed on fruit yield and plant growth variables (SAS, 1989). When no interaction between pruning method by in-row plant spacing was found ($P \geq 0.05$)

mean from main effects were analyzed if they were significative ($P \leq 0.05$). Mean values for pruning levels were separated by Duncan's Multiple Range at $P \leq 0.05$ and plant density was analyzed for its polynomial (linear and quadratic) effects by regression analysis.

Results and discussion

Fruit yield by grade. In-row plant spacing and pruning method affected extra large fruit production (Table 1). Plant densities and pruning methods did not affect fruit yield of medium and large sizes (Data not shown). Within any of the fruit grades, fruit diameter, length, and pericarp thickness were significantly affected by plant density or pruning method (Data not shown). In the two summer harvests the yield per unit area of extra large fruits, by number and by weight, was significantly affected by pruning method, being highest in 4-stem plants and lowest in single-stem plants (Table 1). Plant spacing did not have an effect on the yield per square meter of this grade.

Plants responded differently in the pruning methods at the tested plant spacings with regard to extra large fruit yield (Table 1, Table 2). In 4-stem plants yield per plant of extra large fruits responded with a linear trend, increasing per plant yield as plant density decreased. The highest yield per plant of extra large fruits was obtained from plants with 4 stems and spaced at 66.5 cm between each other (Table 2). Two stem plants had higher extra large per plant fruit yield than single-stem plants at 44.3 and 66.5 cm between plants, but yield did not differ from 1-stem plants at the highest plant density (Table 2).

Total fruit yield. Total fruit yield (by number and by weight) per unit area increased linearly as plant spacing decreased (Table 1). Plants with a higher number of branches had a higher total number of fruits and a greater total fruit weight per unit area (Table 1). In 4-stem plants total weight per square meter was more than twice the yield of single-stem plants and 35 % greater than in two-stem plants.

Pruning methods responded differently to plant densities on total fruit yield per plant (Table 1, Figure 1). The total fruit number and weight per plant had linear responses to plant density in 2 and 4-stem plants. Yield per plant increment on the 2-stem plants was more affected by an increase of plant spacing than in 4-stem plants (Figure 1). A similar trend was observed for number of fruits per plant in the pruning method by plant density interaction (Data not shown). The highest total yields in weight and number per plant were obtained from 4-stem plants at the 66.5 cm with-in row plant spacing (Figure 1, Table 3).

Final plant growth. Number of leaves, leaf dry weight, total plant dry weight, and stem diameter were not affected by in-row plant spacing but differed significantly with pruning method (Table 4). In general, plants with 2 and 4 stems had a greater final plant growth than single-stem plants. Plants with larger number of branches had more leaves. Leaves and total plant dry weight, and stem diameter from 2 and 4-stem plants were similar but greater than in single-stem plants (Table 4). Branch length and number of nodes per branch increased linearly as in-row plant spacing decreased. Single-stem plants had a longer branch and a greater number of nodes than branches of 4-stem plants (Table 4). Internode distance was not affected by plant spacing or by pruning method.

Stem dry weight followed a linear trend for plant spacing only in 4-stem plants (Data not shown). As plant spacing decreased stem dry weight diminished. Four stem plants spaced at 66.5 cm had the highest stem dry weight. At 33.3 and 44.3 cm between plants, 4 and 2-stem plants had the same stem dry weight at but higher than single-stem plants (Data not shown).

Maximum and minimum air temperatures increased through the season (Figure 2). Covering the greenhouse with a black shade cloth (30% shade) reduced maximum air temperatures in 4 ^{o}C compared to outside air temperatures of previous weeks. Minimum

temperatures were 20 ^{o}C or higher after June 10th, and after June 15th maximum temperatures reached 37 to 40 ^{o}C with the greenhouse sides open and forced ventilation.

A pepper fruit is set on a stem node when environmental conditions are optimal. Temperature plays a predominant role in pepper fruit set (Rylski, 1986). Day temperatures in the range of 21-30 ^{o}C and night temperatures from 17-18 ^{o}C were reported to give a high fruit setting (Rylski and Spigelman, 1982). In the present study these conditions occurred early during the crop cycle (Figure 2). The harvested fruits were located on the second and third node of a branch (crown and first branch flowers were pulled out to promote plant growth before fruit set). Night temperatures over 21 ^{o}C and day temperatures as high as 38 ^{o}C caused flower abortion (Rylski, 1986). Minimum day temperatures after June were high enough to induce flower abscission. High temperatures during summer maintained vegetative growth and no fruit set on the higher nodes. The greater total yield per plant in 4-stem plants might have resulted from more fruit set which was limited by two harvests, compared to the 2 and 1-stem plants. The highest plant density produced the highest total yield per unit area, and pruning plants to 4 stems resulted in a higher total and extra large fruit yield than in 1 and 2-stemed plants.

Although the yields were low because of the short harvest period, planting with a within-row plant spacing of 33.3 cm (4 plants$\cdot$m^{-2}) and leaving 4 main stems per plant could be a possible management practice to increase yield and fruit quality on a late Summer greenhouse sweet pepper crop, in North Central Florida. Good ventilation of unheated protected pepper plants is very important in preventing flower abscission (Rylski, 1986). However, greenhouse sweet pepper yields could be increased in this region with early plantings, when environmental conditions are more optimum for fruit set and development. Plant density and number of stems per plant are factors that affect light interception by the canopy. As solar radiation varies through the year, the management of these variables to obtain high yield and fruit quality might be different for crops grown in different seasons (Papadopoulos and Ormrod, 1990; Lorenzo and Castilla, 1995).

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Table 1. Extra large (>84 cm diameter) and total marketable (medium + large + extra large) fruit yield from sweet pepper plants planted at several within-row spacing and pruned to one, two or four main stems.

	Extra large yield per area		Extra large yield per plant		Total yield per area		Total yield per plant	
	No. m^{-2}	g m^{-2}	No. $plant^{-1}$	g $plant^{-1}$	No. m^{-2}	g m^{-2}	No. $plant^{-1}$	g $plant^{-1}$
Within-row spacing (cm)								
33.3	4.6	658.8	1.1	164.5	12.8	1505.6	3.2	376.4
44.3	4.8	687.7	1.6	229.2	11.2	1374.8	3.7	458.2
66.5	3.6	535.5	1.8	267.8	9.0	1095.4	4.5	547.7
Significance	NS[v]	NS	L**	L**	L**	L**	L**	L**
No. of stems								
1	1.8 c [u]	243.3 c	0.6	79.5	7.0 c	767.1 c	2.3	256.2
2	4.1 b	596.1 b	1.4	205.9	11.5 b	1363.4 b	4.0	471.2
4	7.0 a	1042.0 a	2.5	376.1	14.4 a	1845.1 a	5.1	654.9
Significance	**	**	**	**	**	**	**	**
Interaction	NS	NS	**	**	NS	NS	*	**

[v] Linear (L) and significance at the 5% (*) and 1% (**) levels or nonsignificant (NS), respectively.
[u] Mean separation by Duncan's Multiple Range Test at $P \leq 0.05$.

Table 2. Extra large fruit yield per plant from sweet pepper plants planted at several within-row spacings and pruned to one, two or four main stems.

No. of stems	Within-row spacing (cm)	No. $plant^{-1}$	g $plant^{-1}$
	33.3	0.63	83.93
1	**44.3**	0.63	84.77
	66.5	0.50	69.90
Significance		NS[v]	NS
	33.3	1.10	162.77
2	**44.3**	1.63	227.73
	66.5	1.53	227.13
Significance		NS	NS
	33.3	1.70	246.90
4	**44.3**	2.53	375.20
	66.5	3.30	506.30
Significance		L**	L**

Within-row spacing (cm)	No. of stems	No. $plant^{-1}$	g $plant^{-1}$
	1	0.63 b [u]	83.93 b
33.3	**2**	1.10 ab	162.77 ab
	4	1.70 a	246.90 a
Significance		**	**
	1	0.63 c	84.77 c
44.3	**2**	1.63 b	227.73 b
	4	2.53 a	375.20 a
Significance		**	**
	1	0.50 c	69.90 c
66.5	**2**	1.53 b	227.13 b
	4	3.30 a	506.30 a
Significance		**	**

[v] Linear (L) and significance at the 1% (**) level or nonsignificant (NS), respectively.
[u] Mean separation by Duncan's Multiple Range Test at $P \leq 0.05$.

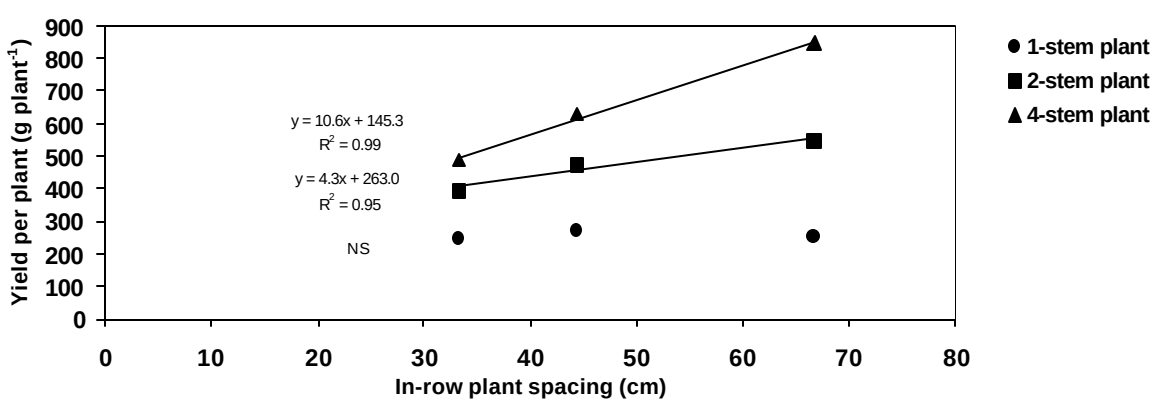

Figure 1. Linear effects of total fruit weight per plant for one, two and four stem plants at the three plant densities.

Table 3. Total yield per plant for sweet pepper plants at three plant densities at the three pruning methods: one, two or four main stems.

Within-row spacing (cm)	No. of stems	No. plant^{-1}	g plant^{-1}
	1	2.27 b[u]	246.67 b
33.3	**2**	3.37 a	394.70 a
	4	4.00 a	487.87 a
Significance		*[v]	**
	1	2.43 b	270.73 c
44.3	**2**	3.90 a	473.57 b
	4	4.87 a	630.33 a
Significance		**	**
	1	2.27 c	251.33 c
66.5	**2**	4.80 b	545.37 b
	4	6.47 a	846.43 a
Significance		**	**

[v] Significance at the 5 (*) or 1% (**) levels, respectively.
[u] Mean separation by Duncan's Multiple Range Test at $P \leq 0.05$.

Table 4. Growth characteristics of sweet pepper plants planted at several within-row spacings and pruned to one, two or four main stems after final harvest[z].

	No. leaves	Leaves wt (g)	Stem wt (g)	Tot. plant wt (g)	Stem diam.[y] (mm)	Branch length[x] (mm)	Node no. per branch[w]	Internode dist. (mm)
Within-row spacing (cm)								
33.3	94.3	40.0	46.5	86.5	18.0	805.9	15.6	51.8
44.3	88.1	39.0	48.3	87.3	18.7	803.3	15.5	51.8
66.5	92.3	43.3	49.7	93.0	18.0	722.6	14.3	51.7
Significance	NS[v]	NS	NS	NS	NS	L**	L*	NS
No. of stems								
1	60.6 c[u]	29.0 b	37.3 b	66.2 b	16.8 b	827.6 a	16.1 a	51.4
2	95.2 b	44.1 a	51.9 a	96.0 a	18.9 a	809.2 ab	15.7 a	51.7
4	119.2 a	49.2 a	55.3 a	104.5 a	19.8 a	695.0 b	13.6 b	51.1
Significance	**	**	**	**	**	**	**	NS
Interaction	NS	NS	*	NS	NS	NS	NS	NS

[z] Data are expressed on a per-plant basis.
[y] Base stem diameter was measured just below the cotyledonary node.
[x] Branch length from the crown flower node to the end of the shoot.
[w] Number of nodes per branch counted after the crown flower node.
[v] Linear (L) and significance at the 5 (*) or 1% (**) levels or nonsignificant (NS), respectively.
[u] Mean separation by Duncan's Multiple Range Test at $P \leq 0.05$.
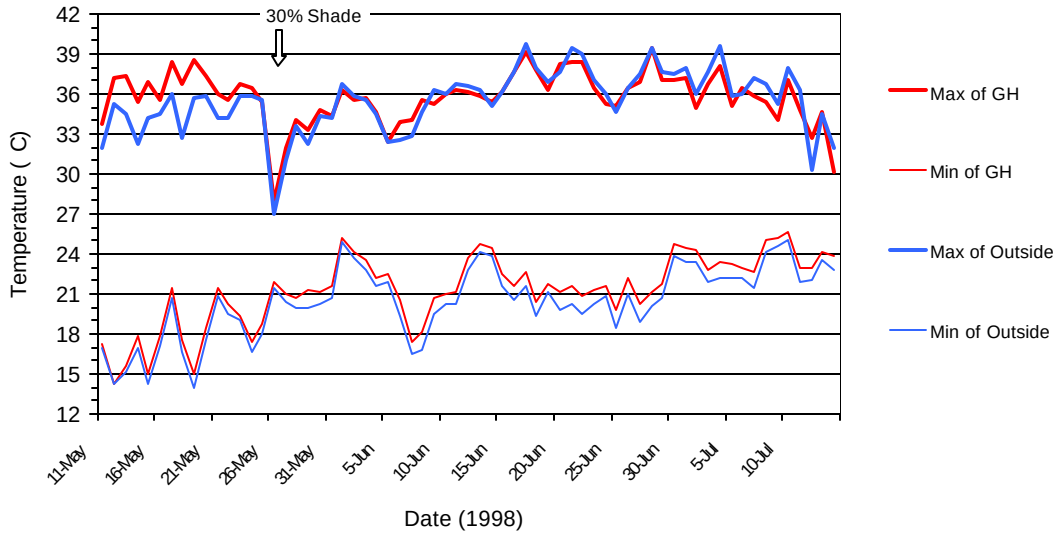
Figure 2. Maximum and minimum day air temperatures at 2 m high inside and outside the greenhouse. Data recorded from May 12 to July 19.