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Full Length Research Paper

Effect of plant population, stem and flower pruning on hydroponically grown sweet pepper in a shadenet structure

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A study was conducted in 2009/2010 and 2010/2011 to investigate the effect of plant population, flower and stem pruning of hydroponically grown peppers in a 40% (black and white) shadenet structure at the ARC-Roodeplaat VOPI. The research was done in an open bag hydroponic system with sawdust as growing medium. Pepper plants were subjected to three plant populations (2, 2.5 and 3 plant/m^2), three stem pruning treatments (2, 3 and 4 stems) and three flower pruning treatments (removal of first two or first four flowers or zero flower removal). Experimental layout was a randomized block design with two replicates. Sweet pepper fruits were harvested at a mature green stage. Data was collected on ten plants determining fruit number, fruit mass, unmarketable yield, marketable yield and total yield for all treatments. Stem pruning to four stems without removing any flowers at a plant population of 3 plants/m^2 resulted in the highest yield and quality. Pruning the first two or four fruits seemed to have no significant influence on yield. Results showed that sweet pepper yield and quality can be effectively manipulated by plant population and stem pruning, while flower pruning had insignificant ($p<0.05$) effect.

Key words: Flower abscission, fruit yield, open-bag hydroponic system, planting density.

INTRODUCTION

Capsicum annuum L. var. *grossum*, commonly known as sweet pepper, has gained popularity with consumers and hydroponic producers throughout South Africa. The sweet pepper is a high value crop and rich in vitamins, particularly provitamin A, vitamin B, vitamin C and minerals such as Ca, P, K and Fe (Malik et al., 2011). The total production of peppers during 2010 amounted to 18606.64 tons, with a value of R117 059 133.00 on the national markets (Department of Agriculture, Fishery and Forestry, Directory of Statistics and Economic Analysis, 2011). However, the demand of the local markets is usually not met, notwithstanding the potential of significant yield increase through improved cultivation practices.

Pepper has a shallow root system (Ikiz et al., 2009; Niederwieser, 2001) and according to Niederwieser (2001) and Jovicich et al. (2004) removal of the first two flowers enhances root development which subsequently improves vegetative growth before fruit set. It is further stated that a well-developed root system with improved vegetative growth will improve fruit bearing and fruit size. Poor root development may lead to insufficient nutrient and water uptake, which, subsequently, will affect yield and quality of sweet pepper.

A major reduction in tomato yield was reported when side shoots were allowed to develop, since the shoots utilize nutrients which would have been used for fruit development (Navarrete and Jeannequin, 2000). Pruning to two or three stems was reported to be effective in increasing yield and reducing fruit size of cherry tomatoes to a more acceptable marketable size (Maboko and Du Plooy, 2008).

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Ideal plant population can lead to optimal yields, whereas a too high or a too low plant population can result in relatively lower yield and quality. Yield per unit area appears to increase to certain maximum as plant density increases and then declines (Akintoye et al., 2009). Researchers have reported an increase in yield of sweet peppers with increase in plant population (Stoffella and Bryan, 1988; Lorenzo and Castilla, 1995; Cebula, 1995; Jovicich et al., 1999). However, there is little or no information on the relationship of plant population, flower pruning and stem pruning of sweet pepper when grown in a shadenet structure. The current research was conducted to determine the optimum combination of plant population, and flower and stem pruning to increase yield and quality of peppers per unit area in a shadenet structure.

MATERIALS AND METHODS

Experiments were conducted in a 40% black and white shadenet structure at the Agricultural Research Council-Vegetable and Ornamental Plant Institute (ARC-VOPI), Roodeplaat (25,59 S; 28,35 E and at an altitude of 1200 m above sea level) from October 2009 to April 2010, and September 2010 to March 2011. Seeds of sweet pepper cultivar 'Paso-real' (Sakata Seed Southern Africa Pty. Limited) were sown in 200 cavity seed trays in a nursery. The seed trays were filled with a commercial growth media, Hygromix® (Hygrotech Pty. Limited, Pretoria, South Africa) and covered with a thin layer of vermiculite after seeding. As soon as seedlings had two fully developed leaves, they were fertigated with 1g of fertiliser Multifeed®/1L of water using a watering-can once daily, followed by irrigation to reduce the build-up of salts. Mineral composition of Multifeed® were N (190 g/kg), P (82 g/kg), K (158 g/kg), S (3 g/kg), Mg (2.24 g/kg), Zn (350 mg/kg), B (1000 mg/kg), Fe (750 mg/kg), Mn (300 mg/kg) and Cu (75 mg/kg).

Seven week old seedlings were transplanted into 10 L plastic bags filled with sawdust at three plant populations, that is, 2, 2.5 and 3 plants/m^2. The plot size was 7m^2. Plants were pruned to two, three or four stems, and three flower pruning treatments with zero flower removal, first two flowers or first four flowers removed. The experiment was designed as a randomised block design (RBD). The treatment design was a 3 x 3 x 3 factorial replicated in 2 blocks. The factors were 3 plant populations, 3 stem pruning methods and 3 flower pruning methods.

Plants were irrigated every two hours, seven times a day. The irrigation volume was gradually increased as the plants enlarged to ensure that 10 to 15% of the applied water leached out. The purpose was to reduce salt build-up in the growth medium (total daily irrigation through the growing season ranged from 735 to 2 205 ml applied per plant).The composition and chemical concentration of fertilizers used were: Hygroponic® (Hygrotech Pty. Limited, Pretoria, South Africa) comprising of N (68 mg/kg), P (42 mg/kg), K (208 mg/kg), Mg (30 mg/kg), S (64 mg/kg), Fe (1.254 mg/kg), Cu (0.022 mg/kg), Zn (0.149 mg/kg), Mn (0.299 mg/kg), B (0.373 mg/kg) and Mo (0.037 mg/kg), calcium nitrate ($CaNO_3$) comprising of N (117 mg/kg) and Ca (166 mg/kg), and potassium nitrate (KNO_3) comprising of K (38.6 mg/kg) and N (13.8 mg/kg). The fertilizers applied as from transplanting until the plants were three weeks old, were 600 g Hygroponic and 600 g $CaNO_3$ in 1000 L water. Thereafter, 900 g Hygroponic and 900 g calcium nitrate was applied per 1000 L water. The electrical conductivity (EC) and pH of the nutrient solution was measured using pH and EC meters (HANNA Combo Instrument), and maintained within a range of 1.8 to 2.3 mS/cm and 5.8 to 6.1, respectively.

Four weeks after transplanting, the plants were trained using a 'V' trellising system (Jovicich et al., 2004). Each stem was trellised by twisting twine around the main stem and fixing it to a stay wire 2 m above the ground surface to support the plant. Side branches were removed weekly to maintain the number of stems as per treatments. Data collection was from mature green fruits harvested every second week. The sweet peppers were graded by mass: extra-large (XL)> 250 g, large (L) = 250-200 g, medium (M) = 200-150 g, small (S) = 150-100 g and extra-small (XS) <100 g. Healthy fruits that were blocky in shape were regarded as first grade, while other shapes were regarded as second grade. Extra-small sized fruits (<100 g), number and mass of fruits exhibiting blossom-end rot, sunscald and deformed fruits were recorded as unmarketable yield. Four large fruits (250-200 g) per treatment per replicate were selected to determine total soluble solids (˚Brix). For this purpose fruits were cut into pieces, blended and the puree filtered through cheese cloth. The °Brix was determined using a pocket refractometer PAL-1 (Atago®, Japan).

A factorial analysis of variance (ANOVA) was used to test for significant effects as well as all the interaction effects using GenStat (2003). The data was acceptably normal with homogeneous treatment variances. Means of significant effects were separated using Fisher's protected t-test least significant difference (LSD) at the 5% level of significance (Snedecor and Cochran, 1980).

RESULTS AND DISCUSSION

Effect of plant population

During both seasons (2009/2010 and 2010/2011), plant population did not show a significant influence on second grade fruits (Table 1). Plants grown at 3 plants/m^2 produced a higher number and mass of first grade fruits compared to 2 plants/m^2 during both seasons. Nasto et al. (2009) and Aminifard et al. (2010) reported the highest sweet pepper and paprika pepper yield, respectively, at high plant density. Deformed fruits were not affected by plant population. In both 2009/2010 and 2010/2011, unmarketable yield was not significantly affected by plant population. There was a significant increase in marketable yield with an increase in plant population in 2009/2010 (Table 1). Marketable yield was significantly higher at a plant population of 3 plants/m^2, as compared to 2 plants/m^{2}in 2010/2011, although it did not differ significantly at 2.5 plants/m^2. Total yield increased significantly with an increase in plant population during 2009/2010, as well as 2010/2011. Similarly, Aminifard et al. (2010), Jovicith et al. (2004), Lorenzo and Castilla (1995), and Cebula (1995) reported an increase in pepper yield at higher plant populations. This could be explained by increased number of plants per square meter, which might have contributed to production of extra fruits leading to high yield per square meter. Results of the study showed that total soluble solids (°Brix) were not significantly affected by plant population. Similar results were reported by Dasgan and Abak (2003).

Effect of stem pruning

Stem pruning did not have a significant effect on second grade fruits, both in 2009/2010 and 2010/2011 (Tables 2

Table 1. Effect of plant population on sweet pepper yield and quality.

Population/m^2	Second grade fruit		First grade fruit		Deformed fruit yield (%/m^2)	Unmarketable yield (%/m^2)	Marketable yield		Total yield (g/m^2)	°Brix
	Number /m^2	Mass (g/m^2)	Number /m^2	Mass (g/m^2)			Number/m^2	Mass (g/m^2)		
2009/10										
2	2.53	299	12.56^{c}	1817^{b}	12.7	40.8	15.09^{c}		2117^{c} 3548^{c}	2.37
2.5	2.18	265	16.17^{b}	2385^{a}	12.1	36.7	18.35^{b}		2650^{b} 4144^{b}	2.21
3	2.70	330	18.32^{a}	2713^{a}	9.5	34.9	21.02^{a}	3043^{a}	4705^{a}	2.10
$LSD_{0.05}$	ns	ns	1.95	333.2	ns	ns	2.11	349	559.3	ns
2010/11										
2	2.83	315	12.91^{b}	1783^{b}	14.2	26.2	14.36^{b}	2098^{b}	2791^{c}	-
2.5	2.62	285	14.12a^{b}	1982^{ab}	16.3	28.5	17.36^{ab}	2267^{ab}	3143^{b}	-
3	2.85	307	17.15^{a}	2388^{a}	12.5	28.0	20.00^{a}	2694^{a}	3718^{a}	-
LSD 0.05	ns	ns	3.058	443.9	ns	ns	3.408	481.6	189.3	

Figures in a column followed by the same letter are not significantly different (P>0.05), using Fishers' protected t-test.

Table 2. Effect of stem pruning on yield and °brix of sweet peppers in 2009/2010.

Stem pruning	Second grade fruit		Deformed fruit yield (%/m^2)	Unmarketable yield (%/m^2)	Total yield (g/m^2)	°Brix
	Number/m^2	Mass (g/m^2)				
2S	2.24	261	11.9	41.9a	3440^{b}	2.31
3S	2.82	349	10.2	34.7b	4252^{b}	2.20
4S	2.35	284	12.1	35.8b	4702^{a}	2.18
LSD 0.05	ns	ns	ns	5.15	559.3	ns

and 3). In 2010/2011, plants pruned to four stems produced significantly higher yield of first grade fruits than plants pruned to two or three stems. Deformed fruits were not significantly affected by stem pruning. Deformed fruits were generally observed when the fruits were developing between the stems, which resulted in fruits not receiving room for growth. The results showed that pruning to four stems increased marketable fruit yield significantly in 2010/2011. The percentage unmarketable yield was significantly higher when plants were pruned to two stems, compared to plants pruned to three or four stems in 2010/2011. Reduced unmarketable yield on plants pruned to three or four stems might be the result of good leaf coverage leading to the protection of fruits and flowers from direct sunlight, which reduced flower abscission, as well as deformed and sunscald fruits. Erickson and Markhart (2002) reported that deformed fruits were the result of flowers pollinated with high temperature treated pollen. The usual practice is to prune sweet pepper in greenhouse production to two stems (Cebula, 1995), but our results showed that plants pruned to four stems produced significantly higher total yield during experiments over two seasons, as compared to three or two stems. The number of stems did not affect total soluble solids of pepper, as also found by Dasgan and Abak (2003).

Effect of flower pruning

Flower pruning showed only a significant effect on total yield in 2009/2010 (Table 4). Zero flower removal resulted in the highest total yield, compared

Table 3. Effect of stem pruning on yield and quality of sweet pepper (2010/2011).

Stem pruning	Second grade fruits		First grade fruits		Deformed fruit yield (%/m²)	Marketable yield		Unmarketable yield (%/m²)	Total yield (g/m²)
	Number/m²	Mass (g/m²)	Number/m²	Mass (g/m²)		Number/m²	Mass (g/m²)		
2S	2.32	255	11.94[b]	1655[c]	15.0	14.26[b]	1911[b]	15.0	2636[c]
3S	2.84	306	14.52[b]	2008[b]	13.7	17.36[b]	2315[b]	13.7	3187[b]
4S	3.15	345	17.72[a]	2489[a]	14.3	20.88[a]	2835[a]	14.3	3829[a]
Lsd 0.05	ns	ns	3.058	443.9	ns	3.408	481.6	ns	189.3

Figures in a column followed by the same letter are not significantly different (P>0.05), using Fishers' protected t-test.

Table 4. Effect of flower pruning on yield and quality of sweet pepper (2009/2010).

Flower pruning	Second grade fruit		Deformed fruit yield (%/m²)	Unmarketable yield (%/m²)	Total yield (g/m²)	°Brix
	Number/m²	Mass (g/m²)				
0F	2.49	312	13.1	36.1	4695[a]	2.31
2F	2.53	300	10.5	38.4	3920[b]	2.15
4F	2.40	282	10.7	37.8	3781[b]	2.22
Lsd0.05	ns	ns	ns	ns	559.3	ns

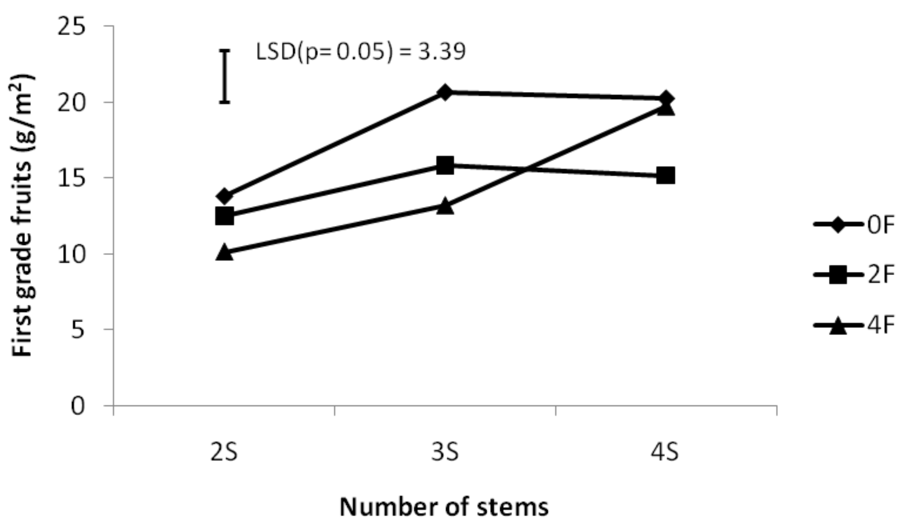

Figure 1. Interaction effect of stem and flower pruning on number of first grade fruits during year 2009/2010.

to plants pruned to 2 or 4 flowers in 2009/2010. Percentage deformed fruits yield was not significantly affected by flower pruning over two consecutive years Table 4 and 5. High summer temperatures might have contributed to the incidence of deformed fruits. Total soluble solids were not significantly affected by flower pruning during 2009/2010.

Interaction effect of stem and flower pruning

There was a significant interaction effect between stem and flower pruning on marketable yield and first grade sweet peppers (Figures 1, 2, 3 and 4). Plants pruned to three or four stems with zero flower pruning, as well as plants pruned to four stems with the first four flowers being pruned, produced the highest number of marketable fruits, marketable yield, and number and mass of first grade sweet pepper than other treatments (Figures 1, 2, 3 and 4). Plants pruned to four stems generally produced the highest yield. However, due to the high incidence of flower abscission, plants pruned to 3 or 4 stems, with or without flower pruning, performed similarly. Although flower abscission was not recorded in

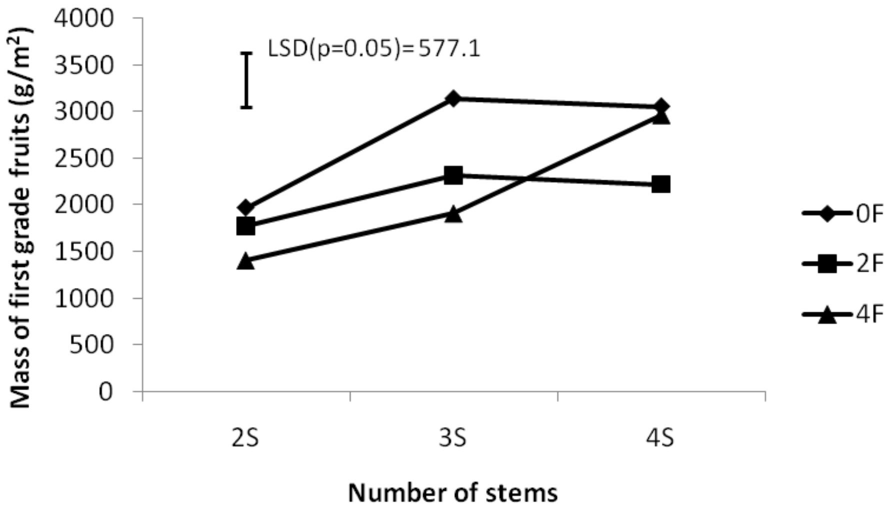

Figure 2. Interaction effect of stem and flower pruning on mass of first grade fruits in year 2009/2010.

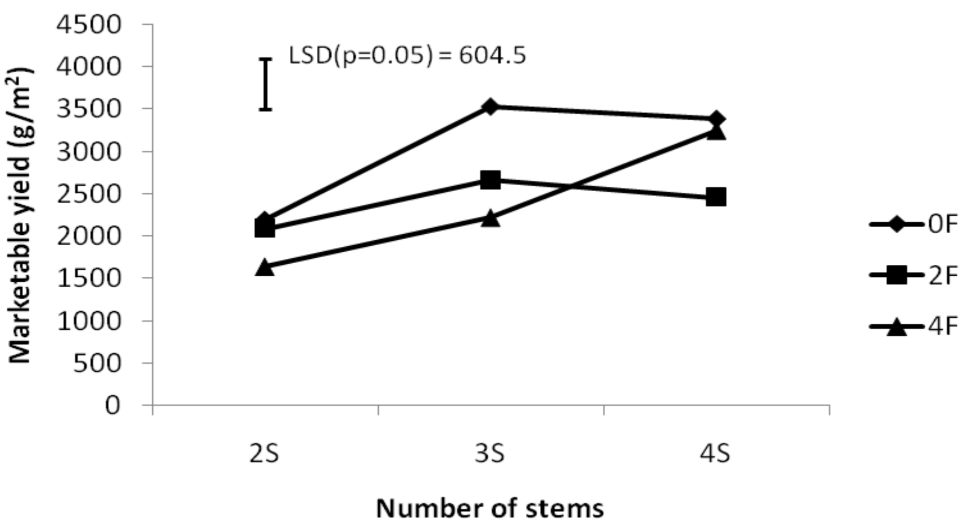

Figure 3. Interaction effect of stem and flower pruning on marketable yield in year 2009/2010.

this study, high temperatures might have predisposed flowers to abscission. Erickson and Markhart (2002) reported that pepper flowers are sensitive to temperatures of 33°C and above. They reported that peppers continued to produce flowers at temperatures of 33°C and above, and flowers abscised after opening resulting in significantly reduced fruit set. The incidence of flower abscission in all the treatments might have eliminated the beneficial effect of pruning flowers.

Conclusion

Cultivars that can withstand high temperatures in South Africa need to be introduced to improve fruit set, thereby reducing flower abortion/abscission. The results demonstrate that plants pruned to four stems and a plant population of 3 plants/m^2, as well as zero flower pruning, improved the yield of hydroponically grown peppers in a shadenet structure. Further studies need to investigate different cultivars and other production systems, such as temperature-controlled environment, soil cultivation, and a closed hydroponic system, to identify the beneficial effect of stem and flower pruning on yield and quality of peppers, while considering economic benefits.

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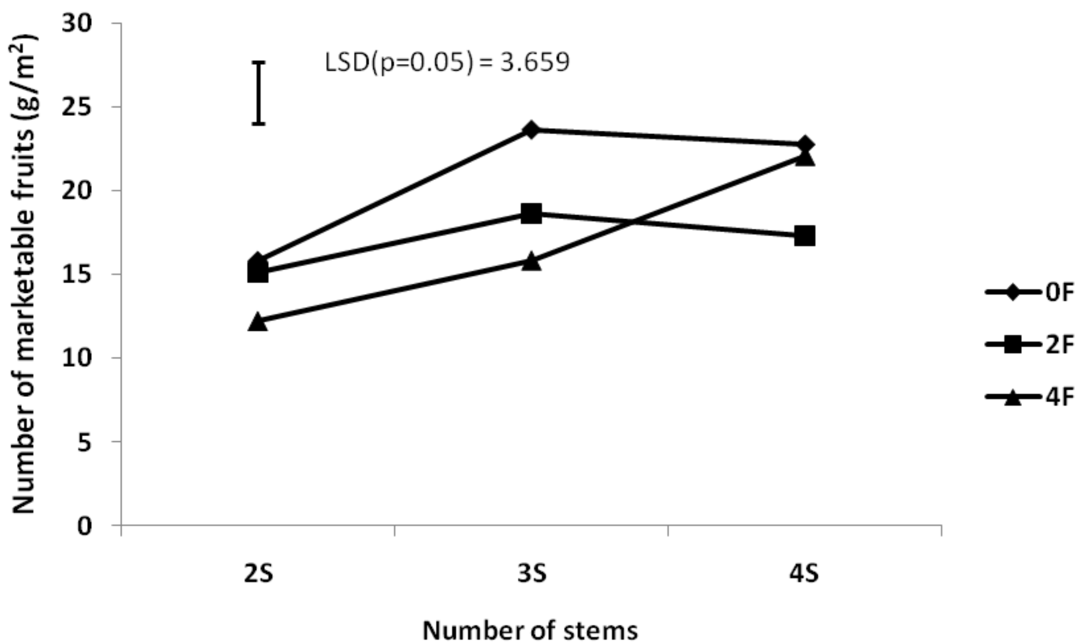

Figure 4. Interaction effect of stem and flower pruning on number of marketable fruits in year 2009/2010.

Table 5. Effect of flower pruning on yield and quality of sweet pepper (2010/2011).

Flower pruning	Second grade fruit		First grade fruit		Deformed fruit yield (%/m^2)	Marketable yield		Unmarketable yield (%/m^2)	Total yield (g/m^2)
	Number/m^2	Mass (g/m^2)	Number/m^2	Mass (g/m^2)		Number/m^2	Mass (g/m^2)		
0F	2.38	264	15.17	2135	15.1	17.55	2399	15.1	3309
2F	2.62	285	15.37	2109	13.3	18.00	2394	13.3	3216
4F	3.31	358	13.64	1909	14.6	16.94	2267	14.6	3829
Lsd 0.05	ns	ns	ns	ns	ns	ns	ns	ns	ns

Figures in a column followed by the same letter are not significantly different (P>0.05), using Fishers' protected t-test.

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