Turk J Agric For
27 (2003) 29-35

Effects of Plant Density and Number of Shoots on Yield and Fruit Characteristics of Peppers Grown in Glasshouses

H. Yıldız DAŞGAN*, Kazım ABAK
Department of Horticultural Science, Faculty of Agriculture, University of Çukurova, 01330 Adana - TURKEY

Received: 19.09.2002

Abstract: Plant density and pruning systems play a key role in the effective use of the area inside the greenhouse. Pepper (*Capsicum annuum* L.) cultivars, Amazon-long green and Balo bell-shape type, were grown in the winter cultivation period in a glasshouse. A constant space of 80 cm between rows with different within–row spacings (45 cm, 30 cm and 15 cm) and shoot numbers (between one and four shoots per plant) were applied to optimize plant density and number of shoots. Wider within–row spacing and higher shoot numbers per plant increased the number of leaves. However, the individual leaf blade area was higher for narrower within-row spacings with fewer shoots. While higher plant densities with a greater number of shoots reduced photosynthetically active radiation, they increased the leaf area index at fruiting level. In order to obtain high yields an assumption of 80 x 15 cm with two shoots per plant is suggested for peppers. When expensive seed is used then a 80 x 30 cm spacing with three shoots per plant might be more economical. Plant density and the number of shoots did not affect fruit quality characteristics, such as fruit weight, length, diameter, volume, dry matter, total soluble solids and the pH of the flesh in either cultivar.

Key Words: *Capsicum annuum* L., plant spacing, pruning, yield, fruit quality

Bitki Yoğunluğu ve Sürgün Sayısının Sera Biber Yetiştiriciliğinde Verim ve Meyve Özellikleri Üzerine Etkileri

Özet: Sera içerisindeki alanın etkin kullanılması konusunda, bitki yoğunluğu ve budama sistemi anahtar bir rol oynamaktadır. Biber (*Capsicum annuum* L.) çeşitlerinden Amazon-(uzun yeşil meyveli) ve Balo (dolmalık meyveli) çeşitleri kış döneminde serada yetiştirilmiştir. Bitki yoğunluğu ve sürgün sayısını optimize etmek için, sıra arası mesafe tüm uygulamalarda sabit olarak 80 cm kullanılırken, farklı sıra üzeri mesafeler (45 cm, 30 cm ve 15 cm) ile sürgün sayıları (1, 2, 3 ve 4 sürgün/bitki) kullanılmıştır. Bitkilerde sıra üzeri mesafe daraldıkça sürgün sayısı azaltılmıştır, azalan sürgün sayısında yaprak sayısı azalırken her yaprağın alanı artmıştır. Yüksek bitki yoğunluğu ve fazla sürgün sayısı, çiçek ve meyve seviyesinde PAR (Fotosentetiksel aktif ışınım) değerlerinin azalmasına neden olurken aynı bitkilerde LAI (Yaprak alan indeksi)'in artmış olduğu tespit edilmiştir. Bu çalışma sonunda, sera biberlerinden yüksek verim alabilmek için 80 x 15 cm bitki yoğunluğu ve 2 sürgünlü budama önerilmektedir. Ancak, tohum maliyeti yüksek olduğu durumlarda tohumun ekonomik kullanımını sağlamak için 80 x 30 cm ve 3 sürgünlü budama da önerilebilir. Bitki yoğunluğu ve sürgün sayısının, biber meyvelerinde ağırlık, boy, çap, hacim, meyve suyunda SÇKM ve pH gibi kalite özelliklerini önemli düzeyde etkilemediği tespit edilmiştir.

Anahtar Sözcükler: *Capsicum annuum* L., bitki sıklığı, budama, verim, meyve kalitesi

Introduction

The main pepper groups grown in the Mediterranean basin area consist of bell-shape, charleston, conic and long-green fruit types of cultivars. Growers do no pruning in open field pepper cultivation. However, in greenhouse production, pruning and plant density are very important for the optimization of plant spacing per unit area. In greenhouse cultivation of bell-shape and long-green peppers, the effects of plant density and pruning system are unknown and growers do not apply regular pruning systems depending on plant density.

There are many studies on plant density for different types of pepper: bell or sweet pepper (Ahmed, 1984; Stoffella and Bryan, 1988; Cebula, 1995; Jolliffe and Gaye, 1995), cayenne pepper (Decoteau and Graham, 1994), pepperoncini pepper (Motsenbocker, 1996) and paprika pepper (Cavero et al., 2001). Plant density and plant arrangement have a pronounced influence on plant development, growth and the marketable yield of many vegetable crops (Stoffella and Bryan, 1988). A number of studies have indicated a linear increase in fruit yield when plant density is increased (Decoteau and Graham, 1994;

* Correspondence to: dasgan@mail.cu.edu.tr

Jolliffe and Gaye, 1995; Motsenbocker, 1996; Stoffella and Bryan, 1988). Porter and Etzel (1982) and Ahmed (1984) reported that increasing plant density resulted in a greater yield of bell pepper fruit. Marketable bell pepper yield increased with greater plant density (Batal and Smittle, 1981; Everett and Subramanya, 1983; Locascio and Stall, 1982). Sundstrom et al. (1984) reported an increase in mechanically harvested tabasco pepper (*Capsicum frutescens* L.) yield when within-row spacing was decreased. An increase in yield with higher plant density was a result of increased numbers of fruit per hectare in direct-seeded paprika pepper (Cavero et al., 2001).

Although most authors have reported some information on the plant density of different types of peppers in open field production, studies on greenhouse pepper production are limited. The optimization of plant and shoot spacing in the greenhouse production of bell pepper was investigated by Cebula (1995); plants are usually trained to two shoots and the spacing of plants is 80 x 30 cm. The present study was carried out to clarify the optimum plant density and pruning system for bell-shape and long-green peppers grown in greenhouses.

Materials and Methods

The experiment was conducted at the greenhouse of the Horticultural Department of the Agricultural Faculty in Çukurova University, Adana, Turkey during the 2000-2001 winter cultivation period.

The "Amazon F_1"cv (long-green type) has 15-20 cm long fruit 1.5-2.0 cm in width and with intermediate pungency, and the "Balo F_1" cv (bell-shape type) has fruit 7-8 cm long and 6-7 cm wide with a sweet taste. Seeds of the cultivars, bought from Dutch companies, Balo from Rijk Zwaan and Amazon from Royal Sluis, were sown on August 7, 2000. Seedlings were planted in the greenhouse at the 5-6 leaves growth stage on September 20, 2000. The constant distance between rows was 80 cm. Within-row spacings used were 45 cm, 30 cm and 15 cm. Each plot was 4.5 m long and 0.8 m in width (3.6 m^2). The numbers of plants grown in the each plot were 10, 15 and 30 depending on the within-row spacings (45, 30 and 15 cm, respectively). Two different pruning methods (one and two shoots for 15 cm; two and three shoots for 30 cm and three and four shoots for 45 cm) were applied on each within-row spacing. Depending on the shoot numbers (between one and four shoots) the pruning methods applied at the plant development stages were first, second, third and fourth embranchment stages. During the cultivation period, every 10 or 15 days, all side shoots were removed on the main shoots and fruiting occurred on trained main shoots only. The optimization of plant spacing and shoot numbers in greenhouse bell pepper production (Cebula 1995) were chosen as the main models for modifying and adapting bell-shape and long-green peppers.

The following treatments were arranged in a split plot design with four replications,

The greenhouse was heated at night to maintain a minimum temperature of 16 ºC. Maximum temperatures (daytime) inside the greenhouse depended on the outside air temperatures and varied from 20 ºC to 34 ºC during the cultivation period. One bumble bee colony was placed in the greenhouse for pollination. A drip irrigation system was used for irrigation and fertilization. During the experiment 680 kg N, 260 kg P_2O_5 and 750 kg K_2O were applied per hectare.

The number of leaves per plant was recorded in the different plant development stages: 35, 74 and 148 days after transplanting (DAT). The blade area of the leaf located on the closest node to the first branching point was measured once, on 74 DAT. At the end of the experiment, the leaf area of the plants was recorded and the leaf area index (LAI) was calculated, i.e. leaf area divided by spacing area. Measurements of single-leaf blades and whole plant leaf areas were made with 10 plants from each replication (40 plants for each treatment) using a digital Hitachi Δt mark leaf area meter device.

The fruit harvest started on November 11, 2000 (52 DAT) and continued for 215 days with weekly harvests, ending on June 13, 2001 (267 DAT). The first 11 harvests (from November 11 to February 28) were treated as the early harvest period.

On April 4, 2001 (197 DAT), 20 fruits from each replication were sampled for to investigate fruit quality characteristics such as fruit weight, length, diameter, volume, dry matter, total soluble solids (TSS) and the pH of the flesh in both cultivars.

Photosynthetically Active Radiation (PAR) values were obtained, using a digital quantum meter (BQM model, Spectrum Technologies, Inc.), from three levels on

December 11, 2000 (82 DAT) and February 2, 2001 (135 DAT). The levels were above the plant level (a), fruit setting level (b) and fruiting level (c). The percentage values obtained from b and c were calculated with respect to a.

Results

The number of leaves was increased by wider within-row spacing and higher shoot numbers in both cultivars (Figure 1). However, the individual leaf blade area was generally higher in narrower within-row spacings (in higher plant density) with fewer shoots (Figure 2). A higher plant density with a higher number of shoots increased LAI (Table 1). The increase in plant density was the important factor in the more effective coverage of the soil surface by leaves. The cultivar Balo produced a higher number of leaves than the cultivar Amazon, although the opposite applies with regard to LAI (Table 1).

In both cultivars, PAR at the fruit setting and fruiting levels was similarly affected by within-row spacing and

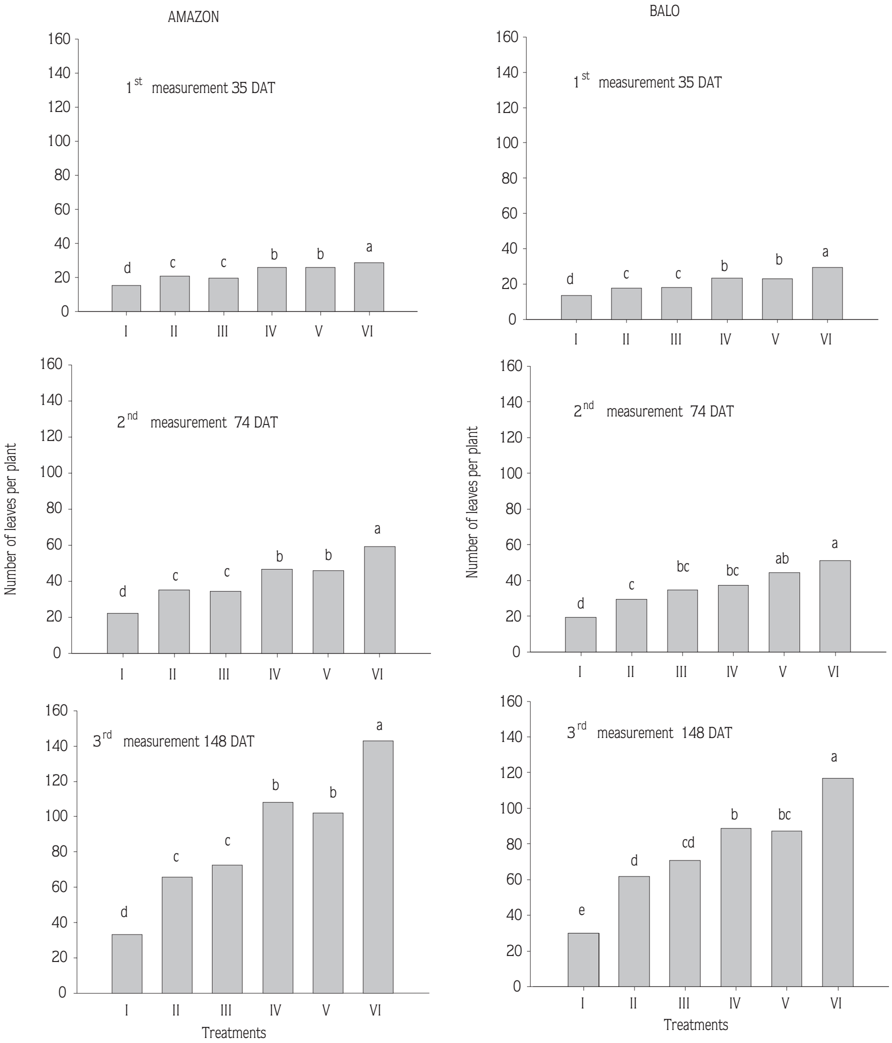

Figure 1. Effects of spacing/number of shoots and cultivars on number of leaves per plant at different measurement dates. The same letters on the bars of the same graph are not significantly different according to Duncan's Multiple Range test. DAT: Days after transplanting. Treatments: I. Spacing 80 x 15 cm (8.3 plants/m^2), pruning to one shoot, 8.3 shoots/m^2. II. Spacing 80 x 15 cm (8.3 plants/m^2), pruning to two shoots, 16.7 shoots/m^2. III: Spacing 80 x 30cm (4.2 plants/m^2), pruning to two shoots, 8.3 shoots/ m^2. IV. Spacing 80 x 30 cm (4.2 plants/m^2), pruning to three shoots, 12.5 shoots/m^2. V. Spacing 80 x 45 cm (2.3 plants/m^2), pruning to three shoots, 8.3 shoots/m^2. VI. Spacing 80 x 45 cm (2.3 plants/m^2), pruning to four shoots, 11.1 shoots/m^2

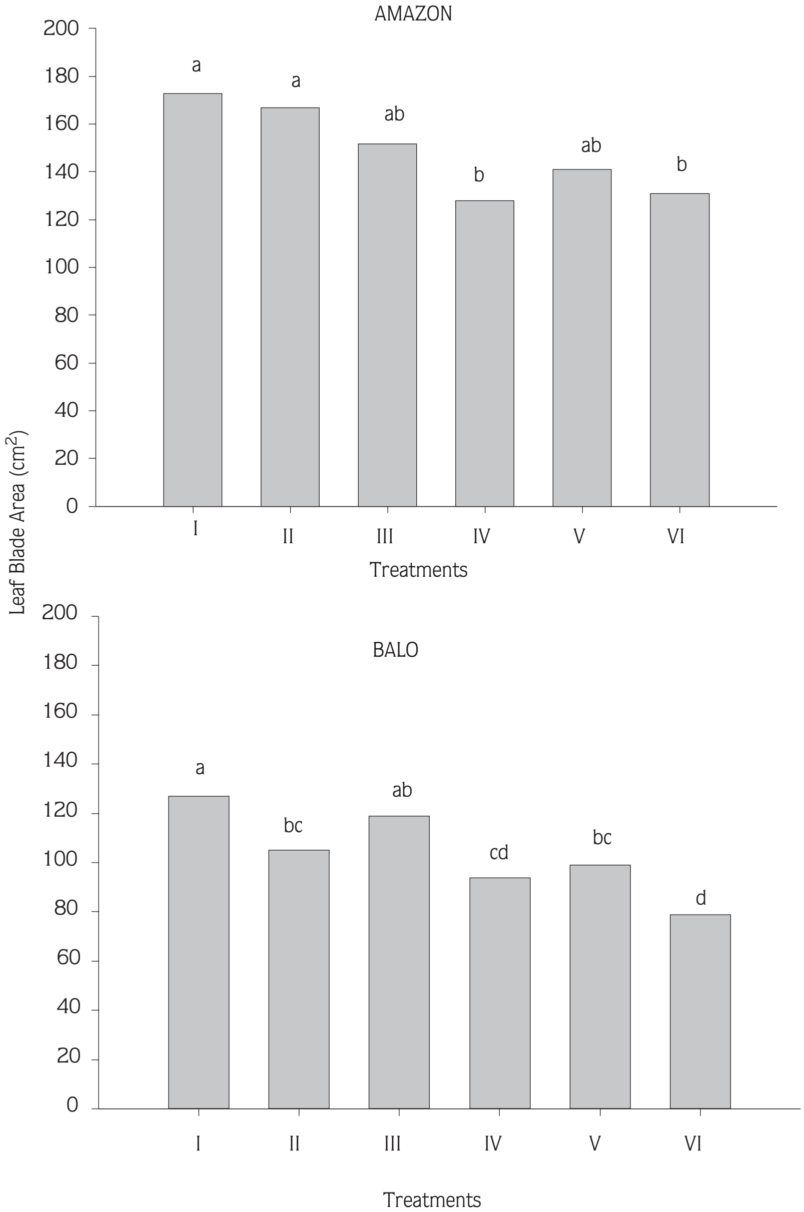

Figure 2. Effects of spacing/number of shoots and cultivars on leaf blade area measured on 74 DAT. The same letters on the bars of the same graph are not significantly different according to Duncan's Multiple Range test. See the legend of Fig. 1 for definition of the treatments

number of shoots. The plants on the narrowest within-row spacing (15 cm) with two shoots had the lowest PAR values at fruiting level, but the highest LAI (Table 1).

The results concerning yields are given in Table 2. Both cultivars produced similar early and total yields. As within-row spacing decreased and the number of shoots increased, both early and total yields per m^2 increased. The fruit number per plant was correlated positively with the within-row spacing (r = 0.93** Amazon, r = 0.92** Balo) and the number of shoots per plant (r = 0.98**for both cultivars). The highest total yield obtained was 11.15 kg/m^2 (mean of both cvs) from the highest plant density (80 x 15 cm) with two shoots per plant (Table 2). The second highest yield, which was from an 80 x 30 cm

Table 1. Effects of spacing/number of shoots and cultivars on the photosynthetically active radiation (PAR) in percentages of radiation measured over the plants and LAI.

Treatments	11. 12. 2000 (82 DAT*)		2. 02. 2001 (135 DAT)		
	FSL**	FL***	FSL	FL	LAI
			Cultivar		
Amazon	42	33	39	35	8.20 a
Balo	43	29	41	39	5.16 b
F value	NS++	NS	NS	NS	***
			Spacing/number of shoots		
I. 80 x 15cm/1 shoot	55	40	40	36	7.88 ab
II. 80 x 15cm/2 shoots	41	19	41	31	8.35 a
III: 80 x 30cm/2 shoots	38	31	41	40	6.53 cd
IV. 80 x 30cm/3 shoots	40	33	38	37	6.95 bc
V. 80 x 45cm/3 shoots	41	32	44	39	4.81 e
VI. 80 x 45cm/4 shoots	40	32	38	38	5.56 de
F value	NS	NS	NS	NS	***
			Interactions		
Cultivars x no. of shoots	NS	NS	NS	NS	NS

* DAT: Days After Transplanting, ++NS: Nonsignificant
** Fruit Setting Level
*** Fruiting Level

Mean separation within colums done by Duncan's Multiple Range test. Values with the same letter are not significantly different.

Table 2. Effects of spacing/number of shoots and cultivars on total and early yields of bell-shape and long-green types of peppers.

Treatments	Total yield (kg/m^2)	Total yield (kg/plant)	Early yield (kg/m^2)	Early yield (kg/plant)	Fruit no. per plant	Fruit no. per m^2
				Cultivars		
Amazon	8.15	1.88	3.39	0.78	74.2 a	320.24 a
Balo	8.00	1.82	3.20	0.73	29.6 b	129.79 b
F value	NS++	NS	NS	NS	***	
				Spacing/number of shoots		
I. 80 x 15cm/1 shoot	7.29 c	0.87 e	3.15 bc	0.38 e	23.9 e	199.0 cd
II. 80 x 15cm/2 shoots	11.15 a	1.34 d	4.39 a	0.53 d	36.9 d	308.6 a
III: 80 x 30cm/2 shoots	7.19 c	1.73 c	2.97 bc	0.71 c	48.0 c	200.0 cd
IV. 80 x 30cm/3 shoots	8.72 b	2.09 b	3.53 b	0.85 b	59.7 b	249.7 b
V. 80 x 45cm/3 shoots	6.42 c	2.31 b	2.59 c	0.93 b	64.1 b	174.1 d
VI. 80 x 45cm/4 shoots	7.70 bc	2.77 a	3.14 bc	1.13 a	78.7 a	218.7 c
F value	***	***	***	***	***	***
		Interactions				
Cultivars x no. of shoots	NS	NS	NS	NS	***	***

++NS: Nonsignificant * ** *** Significant at $P \leq 0.05$, 0.01 and 0.001, respectively.

Mean separation within colums done by Duncan's Multiple Range test. Values with the same letter are not significantly different.

Table 3. Effects of spacing/number of shoots and cultivars on some fruit quality characteristics of peppers.

Treatments	Weight (g)	Length (cm)	Diameter (mm)	Volume (cm^3)	Dry matter (%)	Soluble solids (%)	pH
				Cultivars			
Amazon	25.5 b	20.8 a	20.1 b	31.1 b	6.9 a	5.1	5.7
Balo	61.1 a	7.5 b	60.8 a	110.0 a	5.0 b	4.8	5.7
F value	***	***	***	***	***	NS	NS
				Spacing/number of shoots			
80 x 15cm/1shoot	42.4	14.0	41.2	71.7	6.4	5.0	5.8
80 x 15cm/2 shoots	42.4	13.7	38.0	71.5	6.3	4.9	5.7
80 x 30cm/2 shoots	55.0	14.3	41.3	66.5	6.5	5.0	5.7
80 x 30cm/3 shoots	44.4	14.8	41.2	73.4	6.4	4.9	5.7
80 x 45cm/3 shoots	44.4	13.7	41.3	69.8	6.4	5.0	5.7
80 x 45cm/4 shoots	42.1	14.3	39.8	70.7	6.5	4.8	5.7
F value	NS	NS	NS	NS	NS	NS	NS
				Interactions			
Cultivars x no. of shoots	NS	NS	NS	NS	NS	NS	NS

++NS: Nonsignificant* ** *** Significant at $P \leq 0.05, 0.01, 0.001$ respectively.
Mean separation within colums done by Duncan's Multiple Range test.

spacing and three shoots per plant, was 8.72 kg/m^2. The largest within-row spacing (80 x 45 cm) with three shoots produced the lowest yield (6.42 kg/m^2). The yield per m^2 decreased when wider within-row spacing and a lower number of shoots per plant were tested (Table 2).

The cultivar Amazon produced higher number of fruits (74.2 fruits/plant) than the cultivar Balo (29.6 fruits/plant) (Table 2). However, the difference between the fruit numbers per plant did not affect the yield (both cultivars had similar early and total yields) because Amazon had a lower fruit weight (25.5 g) than Balo (61.1 g) (Table 3).

Within-row spacing and the number of shoots did not affect the fruit quality characteristics. Depending on the treatment, as a mean of both cultivars, fruit weight varied from 42.1 g to 55.0 g, fruit length from 13.7 cm to 14.8 cm, fruit diameter from 38.0 mm to 41.3 mm, volume from 66.5 to 71.7 cm^3, dry matter from 6.3% to 6.5%, soluble solids from % 4.8 to 5.0% and flesh pH from 5.7 to 5.8. As expected, significant differences in some fruit characteristics between the two cultivars tested were observed due to the fruit types being bell-shape and long-green (Table 3).

Discussion

Decreasing the number of shoots reduced the number of leaves on the plants. However, the surface of a single leaf was extended (Figure 2). Vann et al. (1986) and Cebula (1995) observed similar compensatory growth properties in sweet peppers. Reducing the shoot number while increasing plant density caused more effective coverage of the soil by the leaf canopy (Table 1). While a higher plant density with a higher number of shoots (80 x 15 cm, two shoots) reduced PAR at fruiting level, it increased LAI (Table 1). Stoffella and Bryan (1988) and Cebula (1995) suggested that at a higher plant density, plant efficiency would be increased by higher LAI and a high net assimilation rate in bell peppers. Motsenbocker (1996) in pepperoncini peppers and Jolliffe and Gaye (1995) in bell peppers reported that leaf area per plant decreased while LAI increased as the plant density of the peppers increased. At higher plant densities of the bell pepper, greater radiation interception due to higher LAI in resulted higher biomass and fruit yield (Cebula, 1995; Lorenzo and Castilla 1995).

As plant density increased, early and total yield per m^2 in the both cultivars increased while early and total yield per plant decreased. This is probably because less spacing created higher interplant competition. Similar findings have been reported from open field experiments for bell peppers (Stoffella and Bryan, 1988; Batal and Smittle, 1981; Everelt and Subramanya, 1983; Jolliffe and Gaye, 1995) cayenne peppers (Decoteau and Graham, 1994) pepperoncini peppers (Motsenbocker, 1996) and paprika pepper (Kahn et al., 1997; Cavero et al., 2001). Cebula (1995) reported that the greatest yield of sweet peppers (8.37 kg/m^2) was obtained from single-shoot plants grown at highdensity, 80 x 15.6 cm, in a greenhouse experiment. In our greenhouse experiment, with bell-shape (Balo) and long-green (Amazon) peppers, the greatest yield per m^2 was obtained from the highest plant density, 80 x 15 cm, with two shoots pruned treatment (11.53 kg/m^2 from Balo and 10.76 kg/m^2 from Amazon).

Although Cebula (1995) reported that the limitation of shoot numbers affected fruit weight (the fewer shoots, the heavier fruits), in our experiment fruit size parameters such as weight, length and diameter were not significantly affected by within-row spacing or the number of shoots (Table 3). This could be due to the fact that fruit was harvested at approximately the same stage of development throughout the experiment (Stoffella and Bryan, 1988; Jolliffe and Gaye, 1995).

In conclusion, within-row spacing and the number of shoots affect the productivity of pepper plants. The productivity of the plant at high plant density can vary depending on the number of shoots per plant. In order to obtain a high yield from the unit area in the greenhouse, we suggest producing these cultivars with 80 x 15cm spacing and two shoots per plant (8.33 plant/m^2 and 16.66 shoots/m^2). If the seed cost is high and economical use of the seed is considered, a second suggestion 80 x 30 cm with three shoots (4.17 plants/m^2 and 12.51 shoots/m^2) might be acceptable. Plant density and number of shoots do not affect the fruit characteristics when the fruit is harvested at the same stage of development.

Acknowledgements

The authors wishes to thank Prof. S. Cebula for valuable discussions on a visit to Turkey. The authors also are grateful to MSc students Bulut Ekici and Sibel Koç for their considerable assistance in the greenhouse work, and to Dr. Saadet Büyükalaca for her help with the English text.

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