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GROWTH AND YIELD RESPONSES OF BELL PEPPER (*Capsicum annuum,* Rodo'Variety) TO IN-ROW PLANT SPACING

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ABSTRACT

Hot pepper production based on the package of recommendations developed for closely-related sweet pepper has not given the desired growth and yield performances. Information is required with which to evolve the agronomic practices that will be adopted to maximize yield in hot pepper, especially “Atarodo” (Rodo) production. A field study was carried out on the Teaching and Research Farm, Ekiti State University, Ado-Ekiti, to evaluate the responses of rodo to four in-row plant spacings: 60x40, 60x50, 60x60, and 60x75 cm during the wet seasons of 2009 and 2010. The treatment effects were measured on plant growth for 10 weeks and on ripe fruit yield. Plant height, number of branches, number of leaves and leaf area.plant^{-1}, leaf, stem and root dry matter yield, Leaf Area Ratio, Net Assimilation Rate and Relative Growth Rate increased with in-row spacing and the highest values were obtained at 60x75 cm spacing. The 60x40 cm spacing gave the highest number and weight of ripe fruits in both years and should be recommended for rodo production.

Keywords: hot pepper, population density, growth analysis, ripe fruits.

INTRODUCTION

Capsicum annuum, L. (Bell Pepper, Sweet Pepper, Cayenne or Round Chili) is one of the two cultivated hot pepper species in Nigeria, and occurs in two major fruit forms recognized locally as ‘Atarodo' (‘Rodo'): round-shaped fruits, hot; and ‘Tatase' (‘Tatasai'): bell-shaped fruits, mildly-hot (Olufolaji and Denton, 2000). Rodo exhibits the widest variation and is adapted to the humid forest and sub-humid derived savannah agro-ecological zones while the main Tatase production takes place in the dry savannah zone which has huge potentials for rainfed cultivation and under irrigation.

Nigeria produced 0.63 million metric tonnes (MT) pepper fruits in 1980 (FAO, 1980) which increased to 1.793 million MT in 2009 (FMARD, 2010). Nevertheless, pepper yield is still low, at average of 3.85 MT.ha^{-1}, and with much lower values obtained in the southern states due to many constraints. One of these is the low adoption of improved husbandry practices in the predominantly traditional smallholder production systems characterized by extensive cultivation technologies (Grubben and El-Tahir, 2004). This is because the agronomic research base to address yield-limiting problems has been lacking or is, at best, inadequate. Thus, little or no information is available on plant spacing, geometry and population that should contribute to the high yields expected in large-scale commercial pepper production systems.

Studies on the spacing requirements, plant population and density are extensive on sweet pepper varieties (Ahmed, 1984; AVRDC, 1989, Singh and Naik, 1990; Locascio and Stall, 1994; Sharma and Peshin, 1994; Motsenbocker, 1996; Bosland and Votava, 2000; Mavengahama *et al*., 2009; Islam *et al*., 2011). Pepper population studies are few in Nigeria which necessitated the adoption of production technologies and experiences available on bigger-fruited green and red sweet pepper for hot pepper. The unsatisfactory performance is because sweet pepper and hot pepper species differ in growth habits and fruiting characteristics even as they have different environmental requirements, most especially in the adaptation and sensitive reaction to unfavourable soil conditions and nutrient status.

Pepper is cultivated as a subsidiary crop in the traditional smallholder farms at various and wide spacings dictated by the types and number of component crops in the predominant mixed cropping systems (Okigbo and Greenland, 1976; Okigbo, 1983). The spacing suggested for sole pepper are: 60-90 cm apart or 30-60 cm in 75-90 cm rows (FFD, 2002); 61x70 cm (Olanrewaju and Showemimo, 2003); 50-80 cm rows and 20-40 cm in the row (Grubben and El-Tahir, 2004). This variation reflects the differences in pepper plant types and growth habits but from which 60-70 cm rows would appear adequate for pepper. ‘Rodo' is widely adapted to the sub-humid agro-ecological zone that characterizes Ekiti State in South-west Nigeria and so should be cultivated at the appropriate spacing with which to attain optimum plant population. Since pepper seedlings should be transplanted on rows 60 cm apart, it is desirable to evaluate the responses of *Capsicum annuum* (Rodo) to different intra-row spacings. A study was carried out at Ado-Ekiti to determine the effects of different in-row plant spacings on the growth and development and fruit yield of hot pepper (rodo) and with the results make a recommendation that will be a component of the improved practices for pepper cultivation.

MATERIALS AND METHODS

The effects of four in-row plant spacings: 60x40, 60x50, 60x60 and 60x75 cm were studied on pepper (*Capsicum annuum*, Rodo variety) in the Teaching and Research Farm, Ekiti State University, Ado-Ekiti (longitude 5^{o} 13'E, latitude 7^{o} 31'N) during the rainy seasons of 2009 and 2010. Ado-Ekiti, about 456 m above sea level, is in the sub-humid agro-ecological zone and characterized by annual rainfall of 1, 367 mm and average temperature of 27^{o} C. The experimental site in 2009 was a two-year fallow land infested with a weed spectrum dominated by Mexican sunflower (*Tithonia diversifolia*) and guinea grass (*Panicum maximum*). In 2010, the site was cleared from a 2009 late season crop of maize. The land was ploughed and harrowed and a fairly level portion measuring 25x30 m (750 m^2) was marked out and divided into 2.4x3.0 m plots separated by 1 m wide paths. Analysis of a composite sample from surface (0-15 cm) soil samples randomly taken within the experimental plots shows that the soil was a moderately acid (pH=5.9) sandy clay loam with 0.59% organic matter, 0.03% total N, 2.44 $mg.kg^{-1}$ available P and 2.92 $cmol.kg^{-1}$ effective CEC in 2009. The soil was a sandy loam in 2010 and contained 1.99% organic matter, 0.07% total N, 5.9 $mg.kg^{-1}$ available P and 3.73 $cmol.kg^{-1}$ effective CEC.

The treatments were replicated four times and laid out as Randomized Complete Block Design (RCBD). Seedlings of hot pepper (Rodo variety- NH Ca(R) 429) were raised in a nursery for six weeks and transplanted when they had attained average the height of 8-10 cm, 0.4-0.6 cm thickness and with 4-6 leaves at 40, 50, 60 and 75 cm apart in 60 cm rows. Each plot received 200 kg NPK 15-15-15 applied by band placement at 5-8 cm away from each seedling at two weeks after transplanting. The second dose of fertilizer (35 kg $N.ha^{-1}$ obtained from 75 kg $urea.ha^{-1}$) was applied by band placement at the time of first fruit-set. Data collection on plant height, number of leaves, number of branches, leaf area, root, stem and leaf fresh and dry weight commenced at 4 weeks after transplanting (WAT) and continued at two-week intervals until 12 WAT. The dry weights of roots and shoots (stem plus leaf) and leaf area were used to calculate relative growth rate (RGR), leaf area ratio (LAR) and net assimilation rate (NAR). Ripe fruits were harvested at five-day intervals from each plot, counted and weighed for a total of ten harvests. All data were subjected to statistical analysis using the Linear Model of the SAS (Statistical Analytical Systems Institute, 1995) and statistical inferences drawn based on variance ratio and treatment means separated using Duncan's Multiple Range Test (DMRT).

RESULTS

The effects of plant in-row spacing on pepper growth parameters in 2009 are shown in Table-1. Spacing had little effect on plant height at 4 WAT but the pepper plants increased in height from 6 and 8 WAT at all spacings. Plant height was similar for 60x40 and 60x50 cm but increased for 60x60 and 60x75 cm spacing between 10 and 12 WAT. The 60x40 cm produced the shortest plants (14.40-28.81 cm) which increased to the maximum values (16.53-35.34 cm) at 60x75 cm that were significantly different from lower spacings over the sampling period. The 60x50 and 60x60 cm spacings were similar at 8 and 10 WAT but plant height was significantly different among the spacings at 12 WAT. The number of branches increased with plant age but with less growth recorded between 10 and 12 WAT. At each sampling time, 60x75 cm produced the highest number of branches such that the maximum number at 12 WAT (5.50) was significantly different from 60x60 cm (5.41), 60x50 cm (5.04) and 60x40 cm (4.92). The 60x75 cm spacing increased the number of branches over 60x40 cm by 44 and 12% at 6 and 12 WAT, respectively. The least number of leaves was produced by plants spaced at 60 x 40 cm and which increased to the highest number at 60x75 cm over the sampling period. The 60x50 and 60x60 cm spacings were not significantly different over the 6-12 WAT. The number of leaves increased by 12.6 to 30% between 6 and 12 WAT as the spacing widened from 60x40 to 60x75 cm. Leaf area was significantly different with the widest spacing consistently producing the largest leaf area throughout the sampling period. Leaf area from 60x40 cm spacing (40.91 cm^2) was the least being significantly lower than 46.69 cm^2, 48.70 cm^2 and 52.84 cm^2 recorded for 60x50, 60x60 and 60x75 cm spacing, respectively at 12 WAT whereas 60x50 and 60x60 cm were similar at 10 WAT. The widening of plant spacing from 60x40 to 60x75 cm caused leaf area to increase by 15% at 4 WAT to 29% at 12 WAT.

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Table-1. Effect of spacing arrangement on growth parameters of pepper in 2009 season.

Weeks after transplanting					
Spacing (cm)	**4**	**6**	**8**	**10**	**12**
Plant height (cm)					
60x40	14.40c	17.50d	25.60d	28.26c	28.81d
60x50	15.83b	18.27c	27.40c	28.75b	29.47c
60x60	16.52a	19.40b	27.50b	28.96b	33.00b
60x75	16.53a	19.70a	28.24a	29.28a	35.34a
SE	0.017	0.059	0.014	0.107	0.108
Number of branches.plant^{-1}					
60x40	1.58c	2.99d	4.37c	4.65b	4.92d
60x50	2.00b	3.44c	4.43c	4.79b	5.04c
60x60	2.03ab	4.18b	4.70b	4.82b	5.41b
60x75	2.08a	4.33a	5.16a	5.46a	5.50a
SE	0.024	0.014	0.083	0.221	0.031
Number of leaves.plant^{-1}					
60x40	12.87b	15.00b	18.84c	21.66d	26.85d
60x50	13.36b	15.02b	19.79b	22.57c	32.87c
60x60	13.99a	15.22b	19.80b	23.35b	33.18b
60x75	14.13a	17.13a	21.22a	25.76a	34.82a
SE	0.200	0.135	0.152	0.252	0.290
Leaf area.plant^{-1} (cm^2)					
60x40	22.91b	27.20c	32.27d	37.78c	40.91d
60x50	24.27b	30.18b	37.32c	41.36b	46.69c
60x60	24.39b	32.86a	39.26b	42.11b	48.70b
60x75	27.07a	33.48a	40.90a	47.49a	52.84a
SE	0.577	0.421	0.452	0.532	0.635

Means with the same letter in each column are not significantly different (P=0.05).

The effects of in-row plant spacing on stem, root and leaf dry matter yield of pepper are shown in Table-2. Stem dry weight differed among the spacing treatments with the 60x40 cm and 60x75 cm consistently giving the least and highest values respectively over the sampling period whereas the increase in spacing from 60x50 to 60x60 cm had no significant effect at 4, 6 and 8 WAT. The value of 2.42 g averaged over the 4-12 WAT period from 60x40 cm spacing was the least compared to 2.52, 2.63 and 2.82 g obtained at 60x50, 60x60 and 60x75 cm spacing respectively. Leaf dry weight differed among the treatments with 60x75 cm giving the highest values and 60x40 cm the least. The highest values obtained with 60x75 cm spacing did not differ significantly from the 60x50 and 60x60 cm spacings at 8 and 10 WAT. The highest mean values were recorded in all treatments at 12 WAT with the 60x50 and 60x60 cm which gave similar values still inferior to the 60x75 cm spacing. Root dry weight differed significantly among the treatments with the 60x75 cm spacing producing the highest values and 60x40 cm the least. Thus, on a single plant basis, dry matter accumulation differed among the spacings as plants from 60x75 cm consistently gave higher dry matter yield than plants from narrower in-row spacings. More dry matter of similar magnitude was partitioned to the leaf and root than the stem at 4 WAT. This trend was reversed from 6 WAT as the stem dry weight matter yield was higher than the similar amounts partitioned to the leaf and root.

Table-2. Dry weight of pepper plant parts as influenced by different spacings in 2009 season.

Weeks after transplanting					
Spacing (cm)	**4**	**6**	**8**	**10**	**12**
Stem dry matter yield (gm)					
60x40	0.81c	1.71c	2.35c	3.07d	4.14d
60x50	0.88b	1.75bc	2.42b	3.32c	4.25c
60x60	0.91b	1.79b	2.43b	3.48b	4.54b
60x75	0.98a	1.88a	2.53a	3.80a	4.91a
SE	0.017	0.021	0.010	0.021	0.007
Root dry matter yield (gm)					
60x40	1.07c	0.94d	1.33c	1.89d	2.18c
60x50	1.20b	1.07c	1.36b	1.93c	2.20c
60x60	1.22b	1.12b	1.37b	1.98b	2.27b
60x75	1.33a	1.33a	1.40a	2.01a	2.35a
SE	0.017	0.011	0.008	0.010	0.014
Leaf dry matter yield (gm)					
60x40	1.05d	0.92d	1.31b	1.85b	2.15c
60x50	1.18c	1.05c	1.34b	1.71c	2.25b
60x60	1.20b	1.11b	1.35b	1.96a	2.25b
60x75	1.31a	1.32a	1.37a	1.98a	2.32a
SE	0.007	0.010	0.017	0.014	0.004

Means with the same letter in each column are not significantly different (P=0.05).

Table-3 shows that the effects of different in-row spacing on pepper plants in 2010. The pepper plants were also tallest at 60x75 cm and shortest at 60x40 cm spacing. The 60x50 cm and 60x60 cm spacings were not different at 10 WAT while the 60x75 cm was significantly different from the lower spacings at 12 WAT. The largest leaf area was produced at the 60x75 cm spacing with values that were significantly different from lower spacings at 6 to 12 WAT. The number of branches was highest at 60x75 cm spacing over the sampling period but the values were not significantly different from those at 60x60 cm between 4 and 8 WAT. Leaf area.plant^{-1} was highest at 60x75 cm which did not differ significantly from 60x60 cm at 10 WAT.

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Table-3. Pepper growth parameters as affected by plant spacing in 2010 season.

Weeks after transplanting					
	4	**6**	**8**	**10**	**12**
Spacing (cm)	**Plant height** (cm)				
60x40	17.87b	20.97b	31.10d	32.20c	34.86b
60x50	17.92b	21.14b	31.90c	33.62b	35.02b
60x60	18.86a	21.20b	33.60b	34.11b	35.06b
60x75	18.95a	22.70a	35.20a	36.57a	46.85a
SE	0.121	0.131	0.103	0.271	0.256
Number of branches.plant^{-1}					
60x40	1.88b	3.23c	4.96c	5.38c	5.46c
60x50	2.43ab	4.56b	5.31b	5.40c	5.66b
60x60	2.48a	5.26a	5.38ab	5.72b	5.82b
60x75	2.56a	5.36a	5.66a	6.03a	6.33a
SE	0.180	0.088	0.099	0.040	0.062
Number of leaves.plant^{-1}					
60x40	14.74c	17.47d	24.07b	27.40d	35.51d
60x50	16.07b	17.59c	24.20b	28.07c	40.91b
60x60	16.52a	17.77b	24.12b	29.73b	39.80c
60x75	16.61a	20.05a	28.43a	30.63a	43.16a
SE	0.056	0.033	0.155	0.133	0.240
Leaf area.plant^{-1}					
60x40	27.66b	32.13d	40.23d	43.41c	51.80d
60x50	31.88a	40.06c	43.61c	53.30b	56.33c
60x60	32.21a	41.14b	49.27b	58.10a	58.29b
60x75	32.95a	42.26a	55.23a	59.10a	66.41a
SE	0.540	0.260	0.499	0.510	0.421

Means followed by the same letter in each column are not significantly different (P=0.05).

Table-4 shows the dry matter partitioning of pepper plants as affected by different in-row spacings in 2010. The least leaf, root and stem dry weights were produced at 60x40 cm while the 60x75 cm gave the highest values over the sampling period. The 60x75 cm spacing was significantly different from lower spacings except 60x60 cm for root dry weight at 8-12 WAT and stem dry weight at 6 WAT.

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Table-4. Effect of in-row plant spacing on pepper dry matter yield in the 2010 season.

Weeks after transplanting					
	4	**6**	**8**	**10**	**12**
Spacing (cm)	**Stem dry weight** (g)				
60x40	0.81d	2.20c	2.70d	3.40d	3.71d
60x50	0.95c	2.32bc	3.18c	4.12c	4.38c
60x60	1.13b	2.45ab	3.30b	4.32b	4.64b
60x75	1.36a	2.52a	3.50a	4.65a	4.85a
SE	0.038	0.048	0.024	0.014	0.012
Root dry weight (g)					
60x40	1.04c	1.11d	1.54c	2.42a	2.56c
60x50	1.36b	1.27c	2.01b	2.61a	2.72b
60x60	1.61a	1.58b	2.06b	2.78a	2.91a
60x75	1.70a	1.77a	2.61a	2.81a	2.96a
SE	0.035	0.048	0.149	0.18	0.03
Leaf dry weight (g)					
60x40	2.14d	2.74c	3.29c	4.22d	4.36d
60x50	2.61c	2.84c	3.46b	4.42c	4.72c
60x60	2.72b	3.21b	3.59b	4.62b	5.03b
60x75	3.04a	3.70a	3.84a	4.79a	5.12a
SE	0.020	0.036	0.054	0.045	0.028

Means followed by the same letter in each column are not significantly different (P=0.05).

The indices of growth calculated for the different in-row spacings of pepper are shown in Table-5. The LAR, NAR and RGR increased with spacing such that the highest values were obtained at 60x75 cm.

Table-5. Effect of different in-row spacings on indices of growth and development in pepper.

Spacing	**Leaf area ratio**	**Net assimilation rate**	**Relative growth rate**
(cm)	$cm^2.g^{-1}$	$mg.cm^{-2}$	$mg.g^{-1}$
60x40	3.35	0.043	0.144
60x50	3.94	0.049	0.193
60x60	4.24	0.052	0.162
60x75	4.56	0.057	0.260

Table-6 shows the effects of spacing on fruit number of pepper. Fruit number decreased as the in-row spacing widened. In 2009, the highest fruit number was 384, 180.ha^{-1} for 60x40 cm and which differed significantly from the progressively lower numbers produced as in-row spacing widened to the least at 60x75 cm (282, 860 fruits.ha^{-1}). The highest fruit yield of 2.33 MT.ha^{-1} was obtained at 60x40 cm compared to 1.79 MT.ha^{-1} from the widest spacing. This highest yield did not differ significantly from 2.23 MT.ha^{-1} produced at the 60x50 cm spacing but both were superior to yields at 60x60 and 60x75 cm spacings. Fruit size, measured as average fruit weight, was 9% higher as spacing increased from 60x40 to 60x50 cm and subsequently declined but the fruits were still heavier at 60x75 cm than 60x40 cm. In 2010, fruit number was highest at 60x40 cm with 450, 980 fruits.ha^{-1} and which decreased as in-row spacing widened to the least at 60x75 cm. The number of fruits at 60x60 and 60x75 cm did not differ significantly. Fruit yield decreased as in-row spacing widened such that 60x40 cm gave the highest value (2.88 MT.ha^{-1}) which differed significantly from the 2.19 MT.ha^{-1} produced at 60x75 cm spacing. Fruit size measured 7.21 g at 60x60 cm and which was not significantly different from 6.83 g at 60x50 cm while 60x75 cm produced the smallest fruits.

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Table-6. Fruit yield characters of pepper as influenced by plant spacing.

Spacing (cm)	**Fruit number.ha^{-1} x10^{3}**	**Fruit yield, MT.ha^{-1}**	**Fruit size, g**
2009 Season			
60x40	384.18a	2.33a	5.97
60x50	335.06b	2.23a	6.53
60x60	323.80c	2.09b	6.30
60x75	282.86d	1.79c	6.20
SE	9.01	0.052	0.235
2010 Season			
60x40	450.98a	2.88a	6.38b
60x50	398.99b	2.70a	6.83ab
60x60	378.86c	2.73a	7.21a
60x75	371.17c	2.19b	5.90c
SE	5.97	0.06	0.14

Means followed by the same letter in each column are not significantly different (P=0.05).

DISCUSSIONS

Modern vegetable production practices emphasize the need to use optimum plant population attained with appropriate spacings and plant arrangements (Nasto *et al*., 2009). The spatial arrangement that reduces competition and ensures proper plant growth and development has been used to maximize yield per unit area of field-grown pepper (Gaye *et al*., 1992) and economic use of land. Competition for available water and mineral nutrients from the soil and light is greater at high plant population densities and these environmental factors, especially light intensity, stimulate the process of photosynthesis which, in turn, affects biomass production and is closely associated with plant growth rate. Hunt *et al*. (2002) observed that growth analysis as an explanatory, holistic and integrative approach to interpreting growth form and functions in relation to variable factors and uses primary data (weight, area, volume and content) of plant components to investigate the processes within and involving the whole plant. This study involved use of 40, 50, 60 and 75 cm in-row spacings on 60 cm rows with which to attain 41, 667, 33, 333, 27, 778 and 22, 222 pepper plants.ha^{-1}. The measurements made on plant components show that taller plants were observed as plant population reduced probably in relation to lower competition for physical production resources (soil moisture and nutrients) which would enhance nutrient availability and efficient utilization of assimilates. The number of leaves and leaf area.plant^{-1} were significantly different suggesting that plant density affected leaf formation and development in response to competition for available space for nutrient absorption which would influence plant vegetative growth and development. The least leaf area at 60x40 cm spacing from poor leaf development could be attributed to crowding effect on the plants due to competition. Since the distance between individual plants is reduced with the increase in population, intra-specific competition was higher and led to smaller sizes of individual plants in terms of number of leaves, branches and leaf area.plant^{-1} (Johnson and William, 1997). A larger leaf area.plant^{-1} due to increase in number and mass of leaves means a higher specific leaf area which was supported by greater investment in the stem (De Groot *et al*., 2002). This was reflected in the increase in plant height and number of leaf-bearing branches especially from 4 WAT. Islam *et al*. (2011) noted that the closest spacing of 50x30 cm gave the tallest sweet pepper plants with the least number of branches and leaves.plant^{-1} and stem girth. Decoteau and Graham (1994) had reported that plant height and width decreased linearly as in-row spacing increased from 15 to 60 cm. It will appear that the least spacing (60x40 cm) used in this study is not narrow enough to cause plants to increase in height from etiolation and crowding effect. Thus, the factors of individual better plant features are responsible for the differences in root, stem and leaf dry matter yields such that on a single plant basis, plants grown at 60x75 cm spacing accumulated the highest dry matter on account of more branches and increase in stem dry weight.

The development of generative organs (flowers and fruits) causes changes in the sink load of plants (Epstein and Bloom, 2002). Pepper flowers in 1-2 months after planting and the fruits appear about 2-4 weeks later. This experiment involved transplanting 5-6 weeks old seedlings to which fertilizers were applied two weeks later such that when measurement of growth parameters commenced at 4 WAT the plants should have entered the generative phase. AVRDC (1988) noted that the presence of fruits does not alter dry matter accumulation in pepper but its partitioning between the vegetative and generative parts. The dry matter partitioned to root and leaf was higher than to the stem at 4 WAT but this was reversed in favour of the stem as from 6 WAT. At this stage, the stem had developed more branches, become woody and so steadily accounted for increasing part of the total dry matter produced.

Plants tended to have higher photosynthetic potential (NAR) as in-row spacing increased due to excess light source for photosynthesis within the canopy. This only improved individual performance but could not compensate for the low leaf area per unit area of land as a result of the sparse population density. Russo (2003), Nasto *et al*. (2009) and Khasmakhi-Sabet *et al*. (2009) had observed that the highest fruit yield of pepper was obtained when grown at the higher population densities. The lower plant population densities produced more vigorous crops than at higher population densities but this could not compensate for the small number of plants per unit area. In this study, the total number of fruits and total yield.ha^{-1} increased with higher population densities because of contribution from the higher number of plants per unit area. The 60x40 cm spacing gave the highest yield which was similar to the yield from 60x50 cm in both years. This implies that a further reduction in the in-row spacing would probably not be beneficial and so the 60x40 cm spacing appears optimum and should be recommended for hot pepper (rodo) production. The population density from this spacing is 41,667 plants.ha^{-1} which is the same density obtained at 80x30 cm spacing recommended by AVRDC (2001). The population is lower than 50, 000-80,000 plants.ha^{-1} obtained from the within-row spacing of 20-40 cm in 50-80 cm rows normally used for pepper (Grubben and El-Tahir, 2004).

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