Effects of Inter and Intra Row Spacing on Growth and Yield Components of Hot Pepper (*Capsicum Annum L.*) Var Halaba

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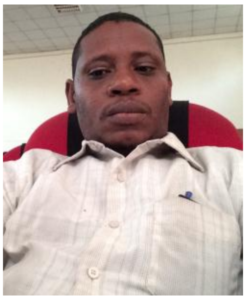

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ABSTRACT

A field experiment was carried out during 2014 and 2015 growing seasons at Galato research farm located in Halaba, southern Ethiopia to identify optimum plant density (row x plant spacing) that maximize growth and pod yield components of hot pepper. Four row spacing (40, 50, 60 and 70cm) and four plant spacing (20, 30, 40 and 50 cm) were arranged in 4 x 4 factorial combination in Randomized Complete Block Design (RCBD) with three replications. Results indicated that year x row spacing produced more significant ($P<0.05$) interaction compared to year x plant spacing, row x plant spacing or year x row x plant spacing. Row x plant spacing of 70 cm x 30 cm (47,619 plants/ha), 60 cm x 30 cm (55,555 plants/ha), 50 cm x 30 cm (66,666 plants/ha), 40 cm x 40 cm (62,500 plants/ha) and 40 cm x 50 cm (50,000 plants/ha) produced statistically similar HI results to that of 50 cm x 20 cm row x plant spacing (100,000 plants/ha). Lowest HI was measured due to 40 cm x 20 cm row x plant spacing (125,000 plants/ha). The maximum of 29.3 qt/ha of dry pod yield of hot pepper was measured due to 60 cm wide rows in 2014 (good year) where as the lowest pod yield of 15.4 qt/ha was obtained due to 40 cm wide rows in 2015 (bad year). Dry biomass yield of hot pepper was significantly higher ($P<0.05$) due to 50 cm wide rows in 2014 where as the lowest dry biomass yield was recorded due to 70 cm wide rows in 2015. Fruit yield/plant showed positive significant correlation with plant height ($r=0.572$) and pod numbers ($r=0.641$). Significant negative association was observed between HI (harvest index) and plant height ($r=-0.429$), and HI and branch number ($r=-0.512$). Results indicated that significantly higher ($P<0.01$) dry pod yield in 2014 was obtained due to 60 cm x 20 cm row x plant spacing (83,333plants/ha). However, 50 cm x 30 cm (66,666plants/ha) spacing produced statistically similar dry pod yield to that of 60 cm x 20 cm row x plant spacing. In 2015, dry pod yield was significantly higher ($P<0.01$) due to 70 cm x 30 cm row x plant spacing (47,617 plants/ha) compared to other row x plant spacing combinations. 60 cm x 30 cm row x plant spacing produced intermediary results in 2015. Thus, hot pepper requires wider row x plant spacing in drier times and narrower row x plant spacing in rainy times under field conditions of Halaba.

Keywords: *Row width, Plant spacing, Plant density, Halaba type, Dry pod yield, HI.*

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1. INTRODUCTION

Hot pepper (*Capsicum annum* L.) is one of the major cash crops in many areas of southern Ethiopia including Mareko, Meskan, Halaba and Hawasa Zuria. It is in the family *Solanaceae*, which includes plants such as tomato, eggplant, potato, tobacco and petunia. Hot pepper is a warm season dicotyledonous woody perennial small shrub with Diploid (2n=24) chromosome number that originated in Mexico, Central America and Andes of South America [1]. Hot peppers are under heavy demand in international and national markets, are eaten fresh or dried, or processed into a variety of products. They are popular food additives, valued for their color, pungency, and aroma. The national average yield of hot pepper is estimated to be 6t/ha but in the experimental plot its yield ranged between 25 to 30q/ha [1] . The low productivity was attributed to a number of biotic and abiotic constraints, which included sub optimal fertilizer use, lack of suitable varieties, and use of sub-optimal agronomic recommendations.

Besides development of strong genetic base and integrated pest management strategies, successful hot pepper production requires optimized cultural practices including mulching, population, plant arrangement, pruning, nutrition, defined soil moisture relations and developed other agronomic protocols. Studies on plant density on different types of pepper cultivars showed that plant density and plant arrangement could influence plant development, growth and marketable yield Shimeles, et al. [2]. Khasmakhi-Sabet, et al. [3] reported that increasing plant density resulted in greater yield/ha of bell pepper. Wider spacing on the other hand led to increase in fruit yield/plant with bigger fruits and more cracked fruits/plant [4]. Increasing plant density decreased pepper root dry weight and had positive relationship with fruit weight and root weight. Increase in yield with higher plant density was a result of increased number of fruits/ha in direct seeded paparika pepper [5]. Salvadore and his colleagues explored that yields per plant were 30% greater with a 0.31m rows than 0.23 m row spacing [6]. Even with the 33.3% larger number of plants per ha with the latter row spacing, yields per ha were similar with both row spacing. Yield per plant was inversely related to plant population in these studies. With 30% higher yield with row spacing of 0.31m than 0.23 m, the 33.3% increase in plant population with the 0.23m spacing compensated for the fewer plants and, as a result, yields were similar with the two-row spacing.

Yields per plant were also 30% higher with the row arrangement that had the fewest plants per ha (one plant row/1.22-m bed) than with the most plants (two plant rows/1.22-m bed and 3 plant rows /1.83-m bed). With the difference in plant population of 100%, total yields were significantly higher (25% to 35%) with the latter row arrangements than with the most commonly used one plant row /1.22m bed or two plant rows/1.83m bed. Row spacing also depended on irrigation management, mulch types, planting pattern and types of the variety. Saamin [7] found that there was no significant increase in pepper crop yield when in-row spacing was reduced from 50 to 25 cm. However, Ahmed [8] showed that yields were higher with closer spacing 30cm in-row and 70 between rows than with wider spacing (70 cm x 70 cm). Lan Chow Wing [9] studied the effect of row arrangement and plant density on the yield of hot pepper *"Piment Cipaye"*. Yields were the highest (up to 6.2 tons/ha) in plants grown 30-cm apart in single rows (55550 plants/ha) and the second highest (up to 5.8 tons/ha) in plants grown 30-cm apart in double rows (44400 plants/ha). However, yields increase with increasing plant population (reducing plant spacing) under irrigated conditions [10]. However, there are scholars that argue higher plant density do restricts light penetration and dry matter accumulation, thus reducing flowering bud development. Moreover, the strong interplant competition due to crowding and the shallow taproot system of these plants may have prevented the absorption of water and nutrients at deeper soil profiles there by reducing yields [11].

In Halaba area, farmers had their own chilli cultivar (variety) of hot pepper called *Halaba* type and grew it in rotation with tef, finger millet or strip cropped with maize. However, farmers grow hot peppers in dense populations locally called *tiktako* – which means filling all the spaces with plants. The average number of plants under farmers management was estimated around 125,000 to 150,000 plants/ha. Under such population, intensive management has only resulted about 12 to 16 qt/ha of dry fruit yield. The later was obtained from fields of innovative model farmers. The low yield was attributed to improper management practices. Although hot pepper is important crop in Halaba, improper or inadequate crop management practices can result in poor crop yields and subsequent high production costs. Hence, this study was proposed with prime objective of identifying optimum row x plant spacing combination that maximize growth and yield components of hot pepper.

2. MATERIALS AND METHODS

The study was carried out in Halaba special woreda (altitude - 1650m *asl*, latitude -7^{0}17'60"N and longitude 38^{0}06'60"E) in 2014 and 2015 cropping seasons. Four levels of inter row spacing (40, 50, 60 and 70 cm) and four levels of intra row spacing (20, 30, 40 and 50 cm) were arranged in Randomized Complete Block Design with 4 x 4 factorial combination of row x plant spacing with three replications. Seedlings of *Halaba* type variety were raised in nursery every in mid March. Transplanting of seedlings to the field was done in mid June and final harvesting was carried out in December. 200 kg/ha of DAP and 100kg/ha of urea were applied uniformly to all plots. All the P fertilizer was applied with the soil prior to planting. 50% of N fertilizer was applied during first weeding (15 to 21st day after planting) where as the remaining 50% of N fertilizer was applied 45 days after planting (during second cultivation) when the plants have established very well and the soil had sufficient moisture. An integrated disease and insect pest management methods that will include use of clean seeds, fungicidal seed treatment, appropriate agronomic practice, spray for aphids and foliar fungicides was undertaken uniformly for all plots. One kilogram of seeds was treated with 4g apronstar prior planting to prevent soil borne diseases. Seedlings were sprayed with dimethiote at the rate of 300 ml with 16 lit of water for a hectare of land to control aphid and other insects. Kocide was sprayed at the rate of 25g/15lit of water to control bacterial diseases and baylaton sprayed at the rate of 7g/15lit of water to control fungal diseases. To avoid way in of floods waterways were made and also tied ridges were created to prevent stagnation of water in the field. Data were gathered on plant height, number of branches, pods (fruit)/plant, pod length, pod diameter, biomass, pod yield (weight) /plant, pod yield/plot. Biomass and pod yield/plot was later converted to per hectare basis and harvest Index (HI) was calculated by dividing pod yield to biomass (pod yield plus dry vegetative yield). Finally, data were analyzed using SAS 9 computer software. When treatment effects were significant, means were separated using LSD (Least Significance difference) at 1 and 5% level of probability.

3. RESULTS AND DISCUSSION

3.1. Mean Squares of Growth and Yield Components

Among the main effects considered in this study, year produced stronger magnitude of effects compared to either row spacing or plant spacing. However, plant spacing produced least magnitude of effects where as row spacing was intermediate in its effects. Among the interaction effects, year x row spacing produced more significant ($P<0.05$) interaction compared to year x plant spacing, row x plant spacing or year x row plant spacing (Table 1). Daniel indicated that Halaba areas received 951.1mm and 531.3mm in 2014 and 2015, respectively despite consistently high average temperature in both years [18]. Thus, the observed strong influence of year on hot pepper production was attributed to variation in rainfall and temperature of the two years. This manifests the importance of moisture and temperature relationships in the growing season and calls for difference in management in varying moisture scenarios in the area. Hence, synthesis of main and interaction effects assumes the two years as independent environments.

Table-1. Summary of mean squares of hot pepper population experiment in Halaba

Source of error	DF	PH	PL	PN	BN	PYP	BYH	GYH	HI
Year	1	10784***	140***	3803***	25***	0.032***	18053**	1741***	0.001ns
Year x rep	4	151**	1.9ns	132**	0.07ns	0.012**	3048ns	72 *	0.077 *
Row spacing	3	18*	1.1ns	105*	1.6**	0.007ns	589ns	66ns	0.019ns
Year x row spacing	3	56ns	0.6ns	64ns	0.01ns	0.016***	4667*	201**	0.082 *
Plant spacing	3	33ns	1.9ns	8.4ns	0.6ns	0.001ns	6031**	451***	0.009ns
Year x plant spacing	3	33ns	2.3ns	11.1ns	0.01ns	0.03ns	2046ns	359***	0.062ns
Row x plant spacing	9	14ns	2.5ns	17ns	0.7*	0.03ns	1447ns	250***	0.069 *
Year x row x plant spacing	9	24ns	1.0ns	33ns	0.01ns	0.04ns	2299ns	155***	0.027ns
Error	60	36	2.4	30	0.33	0.02	1343	27.6	0.028
Total	95								

PH=plant height, PL=pod length, PN=pod number, BN=branch number, PYP=pod yield/plant, PD=pod diameter (cm), Biomass (qt/ha), BUH= biomass (qt/ha), HI=harvest index and PYH=pod yield/hectare, *, **,*** denote presence of significant difference at 5, 1 and 0.1 % level of probability where as ns states absence of significance difference at 5% level of probability

3.2. Main Effects of Year, Row Spacing and Plant Spacing

3.2.1. Year

Averaged over row and plant spacing, the effect of year was significant on all growth and yield components but harvest index. Results showed that plants were taller by 21.2cm, pods were longer by 2.4cm, pods were larger by 0.5cm, pod numbers were greater by 12.6 and plants had 1.1 more branches in 2014 than 2015. Similarly, plants produced 27.5 qt greater biomass in hectare of land, 40g more yield/plant and 8.6qt/ha greater yield in 2014 than 2015 (Table 2). Thus, hot pepper plants had shallow root system with large transpiring leaf surface and high stomatal conductance, and were subjected to drought in 2015. Hence, 2014 was favorable compared to 2015 for hot pepper production in Halaba area.

3.2.2. Row Spacing

Averaged over years and plant spacing, the effects of row spacing were not significant ($P<0.05$) on plant height, pod length, pod diameter, biomass, grain yield and harvest index. However, the effects of row spacing were significant ($P<0.05$) on branch number and pod number. Results indicated that significantly higher branch number was recorded due to 50 cm row spacing compared to 40 cm. However, the numbers of branches due to 50, 60 and 70 cm row spacing were indifferent statistically. Significantly higher pod number was counted due to 50 cm row spacing compared to 40 cm. However, the numbers of pods due to 50, 60 and 70 cm row spacing were indifferent statistically just like that of branch numbers. Thus, plants grown using 50 cm wide rows produced 4.3 more pods and 0.7 more branches compared to 40 cm wide rows.

3.2.3. Plant Spacing

Averaged over year and row spacing, the effect of plant spacing was non-significant ($P<0.05$) on plant height, pod length, pod diameter, pod number, branch number, pod yield/plant and harvest index. The non-significant response of growth and yield components obtained due to main effects of plant spacing ranging from 20 cm to 50 cm agreed with findings of Salau, et al. [12] who identified non significant intra row response in hot pepper (*Capsicum frutescens* L) in 2009 and 2010. However, plant spacing affected only dry biomass and pod yield significantly. Significantly higher dry pod yield per ha was obtained due to 30 cm plant spacing compared to 40 or 50 cm wider plant spacing. The dry pod yields due to 20 cm wide intra row spacing were intermediate (Table 2). Conversely, significantly higher dry biomass yield per ha was measured due to 20 cm wide intra row spacing compared to 50 cm wide plant spacing. However, dry biomass yield per ha due to 20 cm wide plant spacing was invariable with that of 30 cm and 40 cm plant spacing.

Table-2. Main effects of row and plant spacing on growth and yield of hot pepper

Row spacing	PH (cm)	PL (cm)	PD (cm)	PN	BN	PYP (g/plant)	PYH (q/ha)	BYH (q/ha)	HI
40	56.8	11.1	2.6	21.3	4.8	99	19.9	84.2	0.25
50	57.9	10.9	2.6	25.6	5.5	117	22.2	79.6	0.30
60	58.4	10.8	2.7	25.1	5.3	133	24.6	78.2	0.26
70	56.6	10.6	2.7	22.5	5.3	134	13.4	72.2	0.26
LSD%	ns	ns	ns	3.1*	0.33*	ns	ns	ns	ns
Plant spacing									
20	59.1	10.5	2.6	22.9	4.8	117	22.95	94.5	0.23
30	57.3	10.8	2.6	23.4	5.1	119	28.45	85.6	0.30
40	56.7	11.0	2.7	24.2	5.4	120	20.78	76.6	0.26
50	56.6	11.1	2.7	24.1	5.5	127	16.85	57.4	0.26
LSD%	ns	ns	ns	ns	ns	ns	2.9**	20.8*	ns
Year									
2014	68.0	12.1	2.9	29.9	5.7	140	26.5	92.3	0.28
2015	46.8	9.7	2.4	17.3	4.6	100	17.9	64.8	0.27
LSD%	2.4**	0.6**	0.08*	2.2**	0.24**	18**	2.1**	14.7*	ns
CV (%)	10.4	14.1	7.8	23.2	11.1	36.6	23.6	46.6	16.9

PH=plant height, PL=pod length, PN=pod number, BN=branch number, PYP=pod yield/plant, PD=pod diameter (cm), Biomass (qt/ha), BYH= biomass (qt/ha), HI=harvest index and PYH=pod yield/hectare, *, ** denote presence of significant difference at 5 and 1% level of probability where as ns states absence of significance difference at 5% level of probability

Thus, hot pepper plants produce more biomass per ha in narrower plant spacing and more pod yield per ha of hot pepper was obtained from intermediate plant spacing compared to wider plant spacing considered in the study. This result is in line with Mohammad, et al. [13] who identified vegetative growth characteristics (plant height, lateral stem number and leaf dry matter) and reproductive factors (fruit volume, fruit weight and plant yield) decreased with increasing plant density (decreasing rows and plant spacing), but total yield (kg/ha) increased with increasing plant density. In their findings, the highest and lowest total yields were obtained by plant density 100,000 plants/ha (50 cm wide rows) and 33,333 plants/ha (100 cm wide rows), respectively. The increment in pod and branch number, and subsequently pod yield/plant as row or plant spacing increased might be attributed to the possible competition for soil moisture and nutrients. Samih [14] also explained that as plant population density increases, competition for available water, mineral nutrients and light increases.

3.3. Interaction Effects

3.3.1. Two-Way Interaction Effects of Row X Plant Spacing

Averaged over years, the two way interaction effect of row x plant spacing was not significant ($P<0.05$) on plant height, pod length, pod diameter, pod number, pod yield/plant and biomass yield/ha. However, this two-way interaction was significant on harvest index (HI), dry pod yield (kg/ha) and branch number only. Results depicted that significantly highest harvest index was computed due to 50 cm x 20 cm row x plant spacing (100,000 plants/ha) compared to other row x plant spacing combinations. However, statistically similar results were obtained from row x plant spacing of 70 cm x 30 cm (47,619 plants / ha), 60 cm x 30 cm (55,555 plants / ha), 50 cm x 30 cm (66,666 plants / ha), 40 cm x 40 cm (62,500 plants / ha) and 40 cm x 50 cm (50,000 plants / ha). Averaged over years, dry pod yield (kg/ha) was significantly higher (P<0.05) due to 70 cm x 30 cm row x plant spacing. Dry pod yield due to 70 cm x 30 cm row x plant spacing was invariable with 40 cm x 30 cm, 70 cm x 20 cm, 40 cm x 20 cm, 60 cm x 40 cm (41,666 plants/ha) , 50 cm x 30 cm and 50 cm x 40 cm row x plant spacing (Table 3). The number of branches/plant were significantly higher (P<0.05) due to 50 cm x 40 cm and 50 cm x 50 cm compared to 40 cm x 20 cm row x plant spacing. Generally, row spacing above 50 cm combined with plant spacing of above 40 cm produced invariable number of branches compared to other row x plant spacing combinations. Thus, the numbers of branches were fewer in narrower spacing compared to wider spacing.

Table-3. Two-way interaction effects of plant x row spacing on HI, pod yield and branch number of hot pepper

Plant spacing (cm)	Row spacing (cm)			
	40	**50**	**60**	**70**
	Harvest index			
20	0.12	0.48	0.18	0.23
30	0.20	0.31	0.22	0.45
40	0.31	0.18	0.30	0.24
50	0.34	0.22	0.24	0.25
LSD%	0.19**			
	Dry pod yield (qt/ha)			
20	21.4	27.8	13.7	28.9
30	33.2	25.7	21.0	33.9
40	19.5	16.1	28.4	19.1
50	17.7	18.6	17.7	13.4
LSD%	5.9**			
	Branch number			
20	4.5	5.0	4.8	4.8
30	4.8	5.2	5.2	5.1
40	4.8	5.8	5.5	5.4
50	5.2	5.8	5.6	5.5
LSD%	0.55*			

LSD – least significance difference, *& ** denote presence of significant difference at 5 and 1% level of probability, respectively

3.3.2. Two-Way Interaction Effects of Year X Row Spacing

Averaged over plant spacing, two way interaction of year x row spacing did not affect significantly (P<0.05) parameters like plant height, pod length, pod number and branch number. However, year x row spacing interaction effect was significant on pod and biomass yield per ha (Table 4). Results manifested that highly significant (P<0.01) variations were recorded due to 60 cm wide row in 2014 than other year x row spacing combinations. In fact, pod yield from individual plants were invariable due to 60 cm and 70 cm wide rows in 2014 and due to 50 cm wide rows in 2015. The maximum of 29.3 qt/ha of dry pod yield of hot pepper was measured due to 60 cm wide rows in 2014 where as the lowest pod yield of 15.4 qt/ha was obtained due to 40 cm wide rows in 2015. Dry biomass yield (kg/ha) of hot pepper was significantly higher (P<0.05) due to 50 cm wide rows in 2014 where as the lowest dry biomass yield (kg/ha) was recorded due to 70 cm wide rows in 2015 (Table 4). With decrement in moisture, all growth and yield components of hot pepper had also decreased in this study. Thus, lower plant densities produced more vigorous plants and heavier seeds in both years. This could be due to less competition for nutrients and moisture between plants, which in turn influences the supply of assimilation of seeds. However, plants grown in lower plant densities could not compensate for reduced number of plants as evidenced by reduced overall growth and yield components.

Table-4. Effects of year x row spacing on yield and yield components of hot pepper at Halaba

Year	Row spacing (cm)	Pod yield (g/plant)	Pod length (cm)	Biomass (qt/ha)	Pod number /plant	Branch number/plant	Pod yield (qt/ha)
2014	40	123	11.8	73.0	27.5	5.33	24.5
	50	113	12.5	112.6	29.7	6.00	26.3
	60	168	12.1	96.7	32.1	5.67	29.3
	70	152	11.8	86.5	30.4	5.75	23.6
2015	40	75	9.9	55.7	15.0	4.38	15.4
	50	153	9.8	83.3	21.6	4.92	18.0
	60	100	9.6	62.4	18.2	4.67	20.0
	70	82	9.4	57.8	14.6	4.75	18.4
LSD%		36**	ns	29.5*	ns	ns	4.84*

LSD – least significance difference, *& ** denote presence of significant difference at 5 and 1% level of probability, respectively 1qt=100kg

3.3.3. Year X Row X Plant Spacing Effect on Dry Pod Yield of Hot Pepper

The three-way interaction effect of year x row spacing x plant spacing was significant growth and yield components of hot pepper. Results indicated that significantly higher ($P<0.01$) dry pod yield in 2014 was obtained due to 60 cm x 20 cm row x plant spacing (83,333 plants / ha). However, 50 cm x 30cm (66,666 plants / ha) spacing produced statistically similar dry pod yield per ha to that of 60 cm x 20 cm row x plant spacing. Moreover, 60 cm x 30 cm and 70 cm x 30 cm row x plant spacing resulted in intermediary dry pod yield. However, dry pod yield per ha due to 70 cm x 50 cm row x plant spacing produced least dry pod yield in 2014. In 2015, dry pod yield was significantly higher ($P<0.01$) due to 70 cm x 30 cm row x plant spacing (47,617 plants/ha) compared to other row x plant spacing combinations. 60 cm x 30 cm row x plant spacing produced intermediary results in 2015. However, dry pod yield due to 40 cm x 50 cm row x plant spacing was significantly the least in 2015. The year 2014 marks the time of sufficient rains where moisture was not limiting for growth of hot pepper. This finding varied greatly with the 60 cm x 40 cm (41,666 plants / ha) recommendation for mareko fana variety of hot pepper in Ethiopia [1]. This showed that narrow row x plant spacing produced higher yields in rainy year. Conversely, 70 cm x 30 cm, that is wider row x plant spacing produced greater yields in 2015, a year marked by moisture stress. Thus, hot pepper requires wider row x plant spacing in drier times and narrower row x plant spacing in rainy times under growing conditions of Halaba. The current finding denotes that farmers and development practitioners shall follow yearly meteorology forecasts prior deciding management options in hot pepper production. This result agreed with findings in Antiqua that showed 67% yield increase by increasing density from 10,000 to 26,000 plants/ha [15]. The result is also in line with findings of Skeete in Barbados, which stated that in Graeme hall, a place received about 1143mm annually, double or high density produced greater yield so that yield increased by a factor of 1.7 upon doubling density [16].

Table-5. Year x row x plant spacing effects on dry pod yield (qt/ha) of hot pepper

Plant spacing (cm)	Row spacing (cm)							
	2014				2015			
	40	50	60	70	40	50	60	70
20	27.3	31.6	42.9	21.0	14.8	16.9	17.5	15
30	24.6	38.8	33.6	32.8	18.2	20.4	24.1	34.1
40	24.4	18.0	21.7	25.5	17.5	19.3	21.9	12.7
50	21.6	16.9	18.8	15.0	11	15.4	16.5	11.7
LSD%	8.4**							

LSD – least significance difference, ** denote presence of significant difference at 1% level of probability. qt= 100kg

The total dry pod yield/ha increased as plant density was increased (Fig 1). The highest (2925 kg / ha) and the lowest (2447 kg / ha) was observed due to 66,667 and 28,571 plants / ha, respectively in 2014. Although the lowest pod yield (1537kg/ha) was obtained in lowest population of 28,571 plants / ha (40 cm x 20 cm), the highest pod yield was obtained due to 41,667 plants / ha (70 cm x 30 cm) in 2015. The relationship between pepper yield and plant density was shown in fig 1. The equation was

1) Y (2014) = $-453.35x^2 + 2375.1x$ for $r^2=-1.1$
2) Y (2015) = $-255.85 x^2+1449.1x$ for $r^2=-2.5$

where Y= dry pod yield (kg/ha)

X= level of plant density

This result is inconformity of research results of Aminifard, et al. [17] who obtained similar results in Birjand research farm in Iran. This formula could be used for making recommendations for pepper plant densities in similar or nearly similar agro-ecologies.

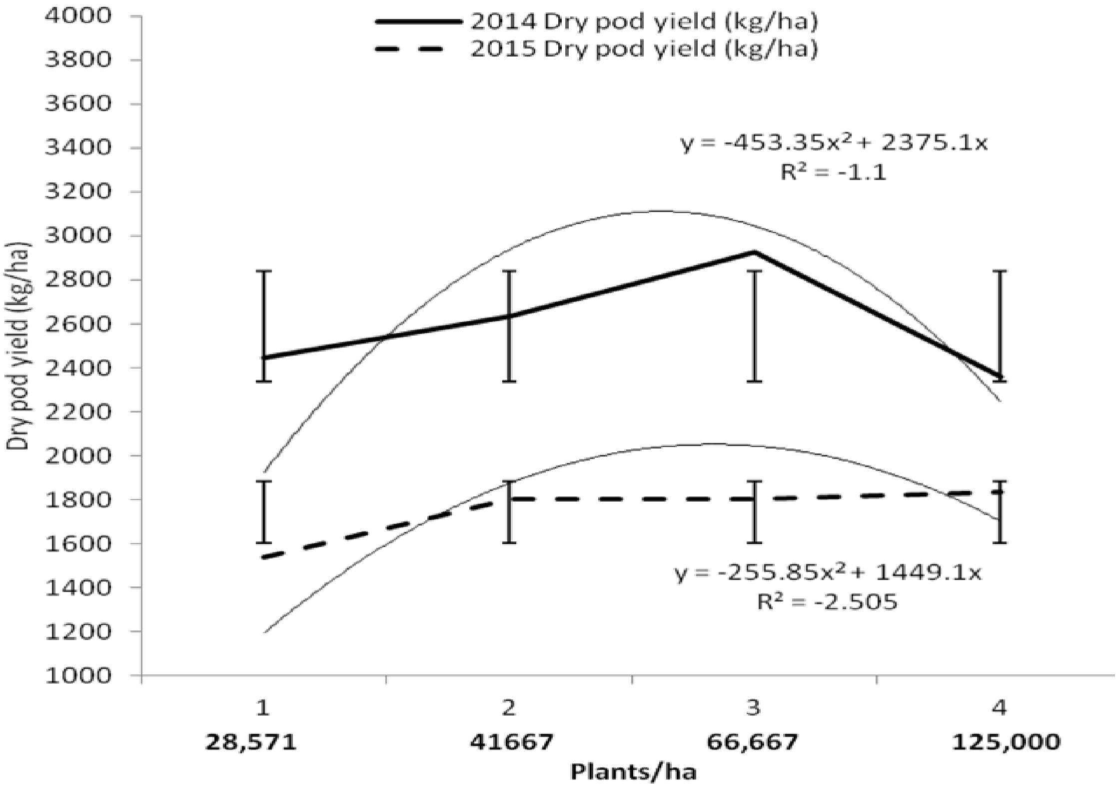

Fig-1. Relationship between dry pod yield and hot pepper population

Source: manpulation from this experimental data

3.4. Association of Traits

In 2014, there was significant positive association between PH and PYP (r=0.159, P<0.05) and PD and HI (r=0.128, P<0.05) in 2014 (Table 6). However, the association was negative between PH and PD (r= -0.121, P<0.05), PH and HI (r = -0.212, P<0.01), PL and PN (r = -0.297, P<0.01), PL and PD (r = -0.123, P<0.05), PL and PYP (r = -0.268, P<0.01), BN and PYP (r= -0.222, P<0.01), HI and PYP (r= -0.239, P<0.01). In rainy times and good year, plants that produced greater yields possessed taller heights and larger pods. Conversely, plants that produced lower yields possessed shorter heights and smaller sized pods.

In 2015, the strongest significant positive associations were recorded between PH and PN (r = 0.609, P < 0.001), PH and PYP (r = 0.572, P < 0.001), PN and PYP (r = 0.641, P < 0.01). However, weak positive association were measured between PH and PL (r = 0.187, P < 0.05), PL and PN (r = 0.157, P < 0.05), PL and PYP (r = 0.235, P < 0.01), PN and BN (r = 0.142, P < 0.05), BN and PYP (r = 0.186, P < 0.01) (Table 6). Thus in dry periods, plants that produced greater yields possessed taller heights, more branches and numerous numbers of larger pods. Thus, *Capsicum annum* var *halaba* plants that produced better yields possessed taller heights and larger pods in both rainy and dry years,

However, the association was negative between PH and HI (r= -0.429, P<0.001), PL and HI (r= -0.133, P<0.05), PN and HI (r= -0.512, P<0.01), PD and HI (r= -0.166, P<0.05), PYP and HI (r= -0.135, P<0.01) in dry years. Thus, harvest index of hot pepper decreased with increase in plant height, pod length, pod number, branch number and pod diameter. Thus, plants produced pod yield at the cost of growths of pod size (length and width), harvest index and branch numbers in drier year. The positive association among PL and PN, PL and PYP, PN and BN, PN and PYP, BN and PYP indicate that reduction in dry pod yield has resulted from reduced pod length, pod number and branches in 2015. Those in dry years, hot pepper plants were short; their pods were small and had fewer branches. The results of 2014 agree with findings of Daniel [18] who elaborated significant positive associations between fruit yield per plant with pericarp thickness (r = 0.91) and number of fruits per plant (r = 0.61) only, which indicates that these characters are the major components for pepper fruit yield. They also identified significant negative associations of fruit yield per plant with days to flowering (r = -0.73) and 50% fruiting period (r = -0.75). This in turn elaborated early flowering and fruiting cultivars produced higher yields due to high rates of early flower initiation and fruit development unlike late flowering of vigorous tall plants, which need a long growing period for fruiting that later produced the lower yield. Whereas the number of branches had significant positive associations with canopy width and number of fruits per plant, it had a negative association with fruit diameter and leaf area index. Their study also revealed number of fruits and number of branches negatively affected fruit diameter. However, plant height had a significant negative association with fruit number per plant, but a good positive association was obtained only with number of internodes, fruit length, and diameter [18].

Table-6. Correlation coefficient (r) of growth and yield components in 2014 and 2015 of hot pepper var Halaba (n=96)

2014							
	PH	**PL**	**PN**	**BN**	**PD**	**HI**	**PYP**
PH	1.000						
PL	-0.076ns	1.000					
PN	0.054ns	-0.297**	1.000				
BN	-0.055ns	0.102ns	0.060ns	1.000			
PD	-0.121*	-0.123*	0.011ns	0.116ns	1.000		
HI	-0.212**	-0.069ns	-0.028ns	0.114ns	0.128*	1.000	
PYP	0.159*	-0.268**	0.023ns	-0.222**	-0.032ns	-0.239**	1.000
2015							
PH	1.000						
PL	0.187*	1.000					
PN	0.609***	0.157*	1.000				
BN	0.015ns	0.096ns	0.142*	1.000			
PD	0.074ns	0.007ns	-0.041ns	0.103ns	1.000		
HI	-0.429***	-0.133*	-0.512***	-0.166*	-0.135*	1.000	
PYP	0.572***	0.235**	0.641***	0.186*	-0.056ns	-0.352**	1.000

PH=plant height, PL=pod length, PN=pod number, BN=branch number, PYP=pod yield/plant, PD=pod diameter (cm), Biomass (qt/ha), BUH= biomass (qt/ha), HI=harvest index and PYH=pod yield/hectare, *, **,*** denote presence of significant difference at 5, 1 and 0.1 % level of probability where as ns states absence of significance difference at 5% level of probability

4. CONCLUSION AND RECOMMENDATIONS

Four row and four plant spacings, totally 16 row x plant spacing combinations, possessing plant densities ranging from 28,572 plants / ha (70 cm x 50 cm) to 125,000 plants / ha (40 cm x 20 cm) were compared at Halaba in RCBD design to identify optimum row x plant spacing combination that maximize hot paper *var halaba* growth, yield and their components in 2014 and 2015 cropping seasons. Growth and yield components were evaluated from each row x plant spacing combination. Year affected growth and yield components more than either row spacing or plant spacing. Fruit yield/plant showed positive significant correlation with plant height (r=0.572) and pod numbers (r=0.641) where as significant negative association was restricted to HI and plant height (r=-0.429), and HI and branch number (r=-0.512) in 2015. In 2014, some of the associations were significant but are not strongly associated. The association of grain yield/plant was strong and positive to plant heights, and strong and negative to harvest index in both years consistently. However, the association of pod yield/plant to pod length and branch number became significant and negative in good years, and significant and positive in moisture deficit years. Moreover, farmers use of extremely dense plant populations beyond 60 cm x 20 cm row x plant spacing or beyond 83,333plants/ha was not justified in this study. The current finding elaborated that farmers may use either 60 cm x 20 cm row x plant spacing (83,333plants/ha) or 50 cm x 30cm (66,666plants/ha) in rainy years for production of *Halaba* type variety in Halaba area. Similarly, dry pod yield was significantly higher due to 70 cm x 30 cm (47,619 plants/ha) in dry years. Thus, farmers and development practitioners shall follow yearly meteorology forecasts prior deciding management options in hot pepper production. The finding should be demonstrated and popularized at farmers' field and their training centers prior large-scale use in the area.

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REFERENCES

[1] W. H. Greenleaf, *Pepper breeding. In: M.J. Basset (Ed.), Breeding vegetable ccrops*. Westport, Connecticut: AVI Publishing, Co, 1986.

[2] A. Shimeles, A. Bekele, W. Dagne, and W. T. Adeferis, "Genetic variability and association of characters in Ethiopian hot pepper (Capsicum Annum L.) landraces," *Journal of Agricultural Sciences*, vol. 61, pp. 19-36, 2016. *View at Google Scholar*

[3] A. Khasmakhi-Sabet, S. Sedaghathoor, J. Mohammady, and A. Olfati, "Effect of plant density on bell peper yield and quality," *International Journal of Vegetable Science*, vol. 15, pp. 264-271, 2009. *View at Google Scholar | View at Publisher*

[4] T. H. Nasto, Balliu, and N. Zeka, "The influence of plant density on growth charavteristics and fruit yield of peppers," *Journal of Acta Horticulturae*, vol. 830, pp. 609-912, 2009. *View at Google Scholar | View at Publisher*

[5] K. Law-Ogbomo and E. Egharevba, "Effects of plant density and NPK fertilizer application on yield and yield components of tomamto (Lecopesicum Escalentum Mill) in forest location," *World Journal of Agricultural Sciences*, vol. 5, pp. 152-158, 2009. *View at Google Scholar*

[6] J. Cavero, R. O. Gill, and M. Gutierrez, "Plant density affects yield, yield components and colour of direct seeded paprika pepper," *Journal of Horticultural Science*, vol. 36, pp. 76-79, 2001. *View at Google Scholar*

[7] S. Saamin, "Effects of spacing, fertilizing and trimming on performance of three cultivars of peppers," La. State Univ, MSc Thesis, 1978.

[8] M. K. Ahmed, "Optimum plant spacing and nitrogen fertilization of sweet pepper in the Sudan Gezira," *Acta Horticulture (ISHS)*, vol. 143, pp. 305-310, 1984. *View at Google Scholar | View at Publisher*

[9] K. F. Lan Chow Wing, "Effect of row arrangement and plant density on the yield of hot pepper (Piment Cipaye)," *Technical Bulletin, Ministry of Agriculture, Fisheries and Natural Resources, Mauritius*, vol. 4, pp. 21-23, 1984. *View at Google Scholar*

[10] E. R. Al-Gharibi and A. M. Abu-Awwad, "Effect of irrigation water quantities and planting spacing on hot pepper yield and efficient water use," *Dirasat, Agricultural Sciences*, vol. 32, pp. 27-36, 2005. *View at Google Scholar*

[11] B. Kebe, R. T. Dennis, and A. D. David, "Growth and yield characteristics of Lesquerella fendleri as a function of plant density," *Journal of Industrial Crops and Products*, vol. 9, pp. 63-71, 1998. *View at Google Scholar* | *View at Publisher*

[12] A. W. Salau, E. A. Makinde, and O. O. Olubode, "Bed height and intrarow spacing on pepper growth and fruit yield," *International Journal of Vegetable Science*, vol. 22, pp. 555-563, 2016. *View at Google Scholar* | *View at Publisher*

[13] H. A. Mohammad, A. Hossein, A. Atefe, and F. Hamide, "Effect of plant density and nitrogen fertilizer on growth, yield and fruit quality of sweet pepper (Capsicum Annum L.)," *African Journal of Agricultural Research*, vol. 7, pp. 859-866, 2012. *View at Google Scholar* | *View at Publisher*

[14] A. Samih, "Effect of plant density on flowering date, yield and quality attribute of bush beans (Phaseolus Vulgaris L.) under centre pivot irrigation system," *American Journal of Agricultural and Biological Sciences*, vol. 3, pp. 666-668, 2008.

[15] CARDI, *Annual report 1991/92 of Antigua unit. St John's.* Antigua: Caribbean Agricultural Research and Development Institute, 1992.

[16] S. Skeete, E. Henry, and J. Marecheau, *The influence of high density planting, mulching, foliar fertilizer and Mancozeb on the yield of hot pepper (Capsicum sp).* Christ Church, Barbados: Ministry of Agriculture and Rural Development, Graeme Hall, NY.

[17] M. H. Aminifard, H. Aroiee, Karimmpour, and H. Nemati, "Growth and yield characteristics of Paprika pepper (Capsicum Annum L.) in response to plant density," *Asian Journal of Plant Sciences*, vol. 9, pp. 276-280, 2010. *View at Google Scholar* | *View at Publisher*

[18] M. Daniel, "Response of medium and late maturing sweetpotato (Ipomoea Batatas L.) varieties to application of N and P fertilizers in Halaba Area of Southern Ethiopia," *Journal of Natural Sciences Research*, vol. 6, pp. 2224-3186, 2016.

BIBLIOGRAPHY

[1] Z. Assfaw and D. Eshetu, *Production and management of major vegetable crops in Ethiopia, Decemeber, 2015.* Addis Ababa, Ethiopia: EIAR, 2016.

[2] P. H. Everett and R. Subramanya, "Pepper production as influenced by plant spacing and nitrogen–potassium rates," *Proceedings of the Florida State Horticultural Society*, vol. 96, pp. 79–82, 1983. *View at Google Scholar*

[3] L. J. Salvadore and S. M. William, "Bell pepper yield as influenced by plant spacing and row arrangement, horticultural sciences department, institute of food and agricultural sciences, University of Florida, Gainesville, FL 32611," *Journal of the American Society for Horticultural Science*, vol. 119, pp. 899–902, 1994. *View at Google Scholar*