



Plant Row Spacing Effect on Growth and Yield of Green Pepper (*Capsicum annuum* L.) in Western Kenya

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Authors' contributions

This work was carried out in collaboration between all authors. Author ONE designed the study and wrote the first draft of the manuscript. Authors JPGO and NKK reviewed the study design and all drafts of the manuscript. Author NKK performed the statistical analysis. Author ONE managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Green pepper production based on the package of recommendations developed has not given the desired growth and yield performances in the world and specifically Kenya. Information is required with which to evolve the agronomic practices that will be adopted to maximize yield in green pepper production. Great attention should be paid when selecting the most appropriate spacing where there are very few reports and limited information regarding plant spacing in cultivation of the crop under the agro-climatic conditions of Kenya. Therefore, a field study was carried out at the Alupe Research Station, Busia County, to evaluate the growth and yield responses of green pepper under three row plant spacings namely: 50x40 cm, 40x40 cm and 30x40 cm during the long and short rainy seasons of 2015. The experiment was set up in a randomized complete block design with three replicates. The treatment effects were measured on plant growth for 12 weeks and ripe fruit yield parameters which were later cleaned statistically analyzed. The plant spacing had significant variation in almost all the growth and yield components except the fruit length. In

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both seasons, the number of branches per plant, stem girth and number of fruits per plant were found to be significantly increased with the increasing of plant spacing but the plant height, number of leaves per plant, fruit breadth and yield per plant were found to be significantly increased with the decreasing plant spacing. The highest yield per plant of 555.1 g and 551.8 g were realized during the short and long rainy seasons respectively in the 40 by 40 cm spacing treatment. Considering the yield of fruits per plant, the 40 by 40 cm plant spacing appeared to be the most recommendable for the cultivation of green pepper.

Keywords: Green pepper; row spacing; yield; yield components.

1. INTRODUCTION

Capsicum (*Capsicum annum* L. var. California Wonder) is also called bell pepper or sweet pepper and is one of the most popular and highly valuable annual herbaceous vegetable crop. It is cultivated outdoors as either a rainfed or irrigated crop. Pepper constitutes about 40% of the vegetables consumed worldwide [1]. Most of the peppers cultivated in temperate and tropical areas belong to the botanical species *Capsicum annum* L., thought to originate from Mexico and Central America. It is the world's second most important vegetables after tomato. In Kenya, it is minor vegetable but this crop has got high export potentiality considering its high nutritive value, it is therefore imperative to take attempts for its successful cultivation in the country. It contains vitamins A, C and E and it is used as flavour for soup and stew. 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 [2]. Although pepper is cultivated in some parts of Kenya, yields obtained by peasant farmers are often very low due to various production constraints. One of these is the low adoption of improved husbandry practices in the predominantly traditional smallholder production systems characterized by extensive cultivation technologies [3] (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. As a result of these, low yields are obtained, leading to the exorbitant prices per unit weight of the fruit [4]. Thus, little or no information is available on plant spacing and population that should contribute to the high yields expected in large-scale commercial pepper production systems. Successful cultivation of any crop depends in several factors. Plant spacing is an important aspect for production system of different crops. Optimum plant spacing ensures proper growth and development of plant resulting maximum yield of

crop and economic use of land. Yield of sweet pepper has been reported to be dependent on the number of plants accommodated per unit area of land [5].

Plant spacing is one of the agronomic practices that influence crop growth and development [6]. Aliyu et al. [7] reported that reducing the intra-row spacing of two pepper varieties from 50 cm to 40 cm significantly decreased plant height, number of fruits and diameter of fruits while total fruit yield per hectare was conversely increased. Studies on the spacing requirements, plant population and density are extensive on sweet pepper varieties [8,9,10,11,12,13,14,15,16]. Pepper population studies are few in Kenya which necessitated the adoption of production technologies and experiences available on bigger-fruited green pepper. The unsatisfactory performance is because green 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 unfavorable soil conditions and nutrient status.

Green pepper consumption in Kenya is increasing nowadays due to increasing demand by urban consumers. There is a good demand for export too. The export market needs fruits with longer shelf life, medium size, tetra lobed fruits with an attractive dark colour, mild pungency and good taste. But, the supply is inadequate due to low productivity of the crop. But there is increased demand for capsicum by the consumers and lot of farmers are also showing interest in the cultivation of this crop. Keeping in view of these aspects, the present study was a modest attempt to analyze the influence of row spacing on the growth and yield parameters of green pepper in Kenya.

2. MATERIALS AND METHODS

2.1 Study Site

The experiment was conducted at the Kenya Agricultural and Livestock Research

Organization (KALRO), Alupe Crops Station in Busia County during the long rain season (March to August) and short rain season (September to December). It lies within latitude 0°30'0" N, longitude 34°07'50" E with an elevation of 1157 m above sea level. The land used for the study was under sorghum and fallow for the previous seasons respectively before the current experiment. The rainfall pattern was bimodal with peaks in June and October. The total rainfall was less in the short rainy season (569.6 mm) than the long rainy season (705.4 mm). The mean relative humidity and average annual air temperature were respectively 76.9% and 24.1°C in the long rainy season, and 78.9% and 23.7°C in the short rainy season.

2.2 Cultural Practices

The nursery area was cleared and a nursery box of 3 m length, 2 m width and 20 cm height prepared and then a shed erected over the nursery box. The green pepper variety used for the study (California wonder) was obtained from an Agro-dealer in Malaba Town and sown in drills of 10 cm apart on February 2015 for the long rainy season planting and in August for the short rainy season planting. Rain was alternated with watering in the evening hours up to the time of transplanting. A fungicide was applied fortnightly as a preventive measure against pests, grasshoppers and crickets, seedlings.

Uniform seedlings of height 15 cm with 3 to 5 leaves at thirty days old were transplanted on experimental plots at each planting time with 2 cm depth maintaining a single seedling per hill. The plants were side-dressed with 50 kg /ha N and 50 kg/ha P₂O₅ in two splits; one-half at two weeks after transplanting and another one-half two weeks later. The plants were side-dressed again with Urea at the rate of 100 kg /ha at flowering. The crop was irrigated when needed depending on the moisture status of the soil and requirement of plants. Plots with transplanted seedlings were regularly observed to find out any damage or dead seedlings for its replacement and weeding was done by hand as per requirement and also plant protective measures were done against insects and diseases.

2.3 Experimental Design and Treatments

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. There were in total 9 unit plots, each plot of 3x2 m were made and raised by 10 cm

which was then separated by 0.50 m space. The blocks were also separated by a 1 m space. The treatments included 3 spacing such as 50x40 cm, 40x40 cm and 30x40 cm.

2.4 Data Collection and Analysis

Data were collected from five plants which were randomly selected from each plot for data collection on growth and yield characteristics during the growth of plants and at harvesting time of the crop. These were plant height (cm), number of branches per plant, number of leaves per plant, stem girth (cm), fruit length (cm), fruit breadth (cm), number of fruits per plant, individual fruit weight (g), and yield per plant (g). The recorded data for different characters were tabulated, cleaned and statistically analyzed using SAS version 9.0 to find out the significance of variation among the treatments. The analysis of variance was performed by F-test, while the significance of difference between the pairs of treatment means were evaluated by the Fischer's protected test at 5% level of probability.

3. RESULTS AND DISCUSSION

3.1 Plant Height and Stem Girth

Significant differences ($P=0.05$) were observed on the spacing levels during the long rainy season at four weeks after transplanting while no significant differences were observed at the other stages of sampling for both seasons as shown on Fig. 1 which is consistent with the findings by [17] who reported that plant distance had no significant effect on plant height. The maximum plant height was recorded from the narrowest spacing (30x40 cm) and differed significantly from that of the other spacings but at later stages there were inconclusive variations among treatments.

This increase in plant height in closer spacing can be explained from the fact that in case of higher population density, penetration of light was decreased which might have led to increase the endogenous auxins formation and enhanced the growth of the buds which due to competition tended to grow faster in order to outperform the next plant. The results of the present study for this character are in agreement with the findings of [18] stated that, plant height of sweet pepper was significantly increased with close spacing. The results of the present study for this character are also in agreement with the findings of [19] who stated that, plant height of sweet pepper was significantly increased with close spacing.

Viloria et al. [20] and Manchanda et al. [21] also expressed similar opinion on plant height of sweet pepper. Findings by [22] also reported that plant height decreased as in-row spacing increased. Similarly, in increased weed incidences where the row spacing in between plants increases due to high competition for essential nutrients, sunlight and moisture therefore again plant became taller in such competitive environments.

Significant variations between the plant spacing treatments were recorded on the stem girth of the green pepper plants (Fig. 2). The widest

spacing (50×40 cm) produced the maximum (4.74 cm) stem girth and it was gradually decreased with decreasing plant spacing where the lowest was recorded on the closest spacing (30×40 cm). 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, affected the stem circumference and is generally closely associated with plant growth rate. The result of the present study for this character is in agreement with the findings of [23].

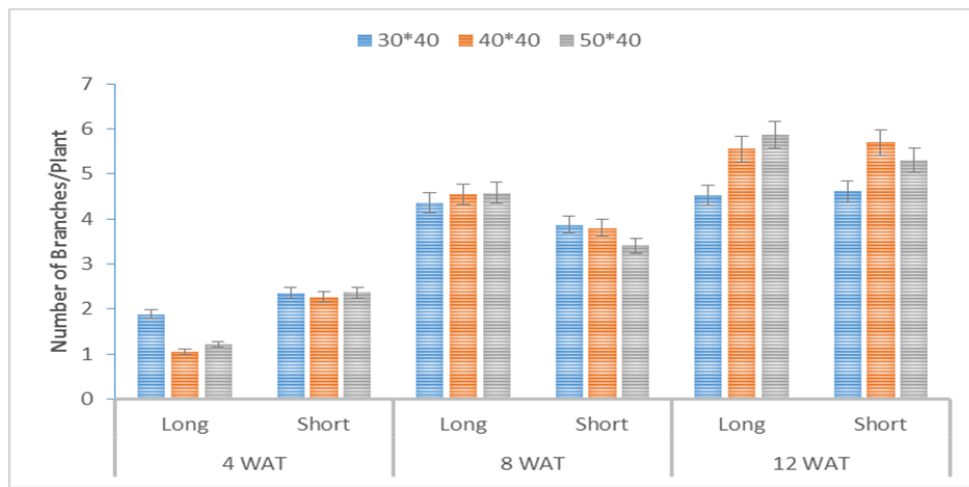


Fig. 1. The plant height of green pepper during the long and short seasons in Alupe-Kenya in 2015 at 2, 4, 6 and 8 WAT (Weeks after transplanting)

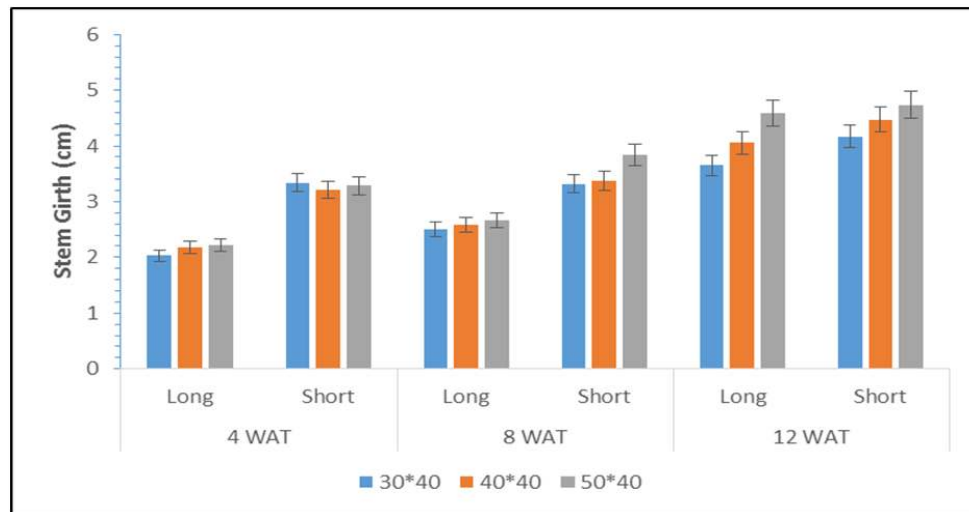


Fig. 2. The stem girth of green pepper during the long and short seasons in Alupe-Kenya in 2015 at 4, 6 and 8 WAT (Weeks after transplanting)

3.2 Number of Branches per Plant

Number of branches per plant differed significantly by different spacing levels where in the earlier weeks the narrow spacing (30×40 cm) showed the highest number of branches per plant but after 8 weeks from transplanting the wider spacings showed significantly higher average branches per plant. The maximum average number of branches (5.87) per plant was recorded from plants on the widest spacing (50×40 cm) while the lowest number of branches in a plant (4.42) was recorded from the closest spacing (30×40 cm) as shown on Fig. 3. The results of the present study for this character is in agreement with the findings of Ravanappa et al. [24] who reported that the lowest plant density treatment obtained from the widest spacing (75×60 cm) produced the highest number of branches per plant. This might be due to the plants of wider spacing could receive more light, nutrients and other resources than the plants of close spacing.

3.3 Number of Leaves per Plant

A significant variation in the number of leaves per plant was observed due to plant spacing (Fig. 4). The maximum number of leaves per plant (86.4) was recorded from 40×40 cm spacing. The minimum number of leaves per plant of green pepper was recorded from the

closest spacing (30×40 cm) which was however statistically similar to the widest spacing (50×40 cm). The measurements made on plant components show that more leaves 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. Since the distance between individual plants was 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. 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.

3.4 Number of Fruits per Plant, Fruit Length and Breadth

Among the yield contributing characters, number of fruits per plant is one of the important traits. The number of fruits per plant showed significant differences during the long rainy season due to

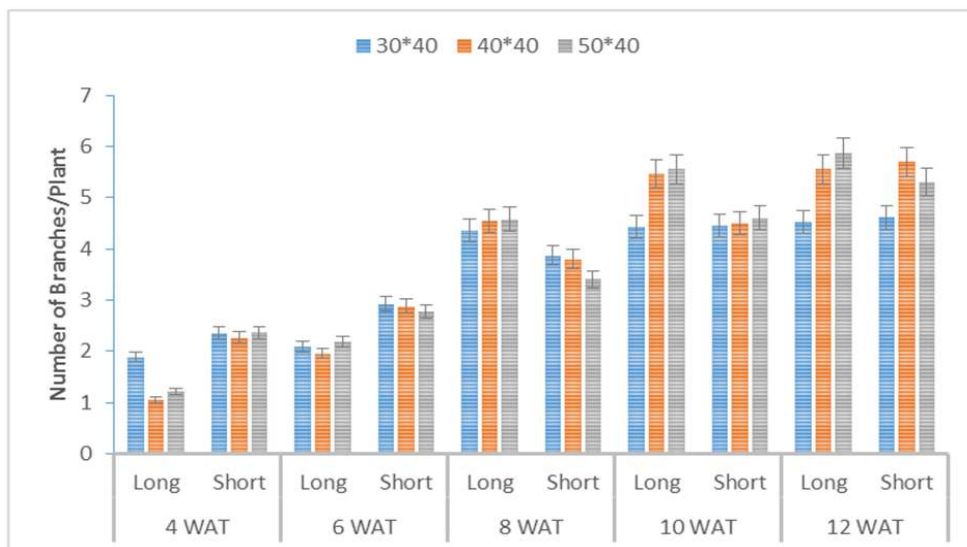


Fig. 3. The plant spacing influence on the number of branches per plant during the long and short rainy seasons of 2015 in Alupe-Kenya at 4, 6, 8, 10 and 12 WAT (WAT-Weeks after transplanting)

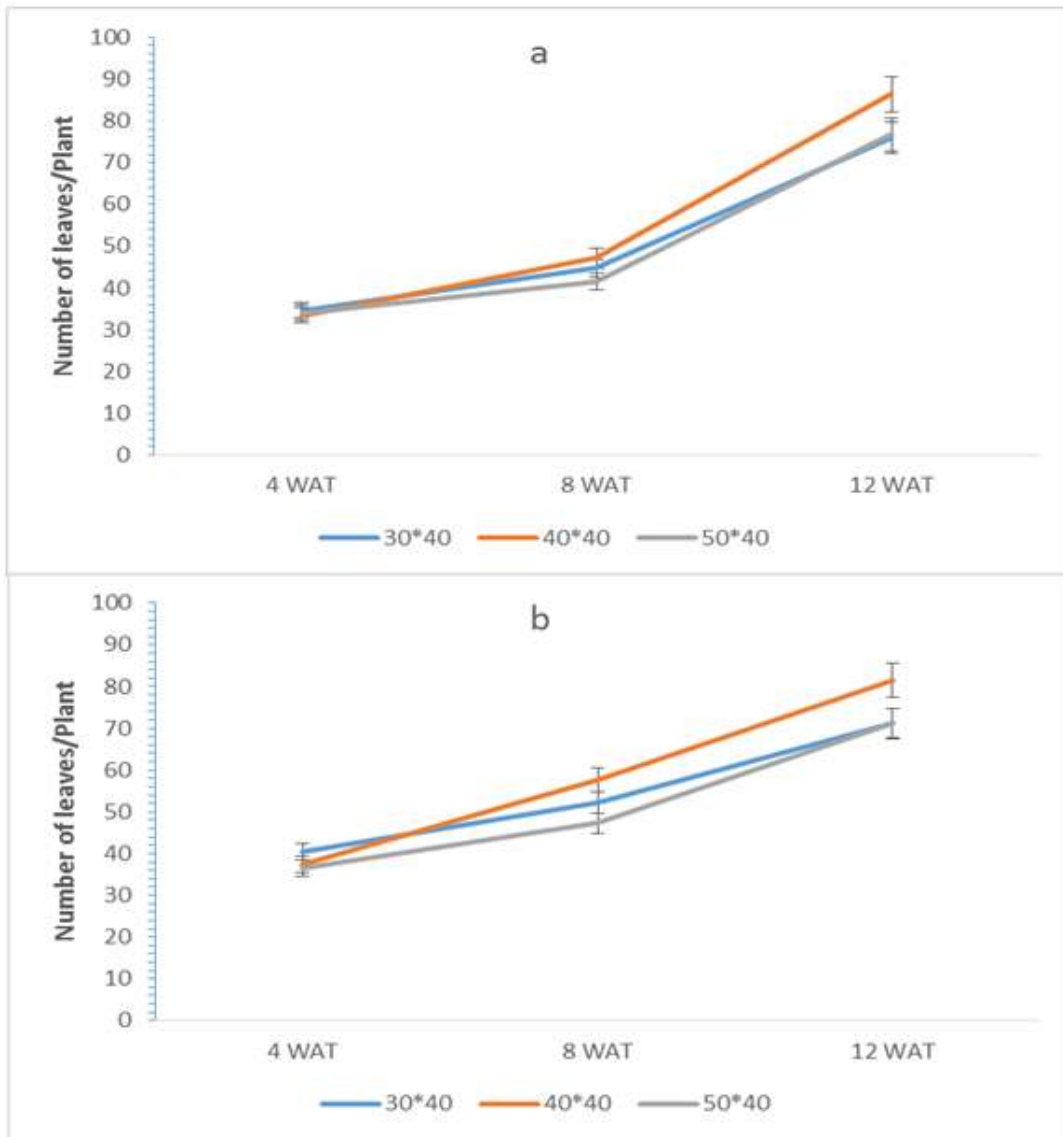


Fig. 4. The average number of leaves per plant during the long (a) and short rainy (b) seasons of 2015 in Alupe, Kenya under different plant spacing treatments at 4, 8 and 12 WAT (Weeks at transplanting)

plant spacing where the highest average number of fruits (4.59) per plant was recorded from the widest spacing (50×40 cm) which was significantly higher than those of the closer spacings (Table 1). Reduced number of fruits under wider spacing undergone less inter or intra plant competition which caused an increased number of fruits per plant. Plants tended to have higher photosynthetic potential (NAR) as in-row spacing increased due to excess light source for photosynthesis within the canopy. This could however only improved the individual

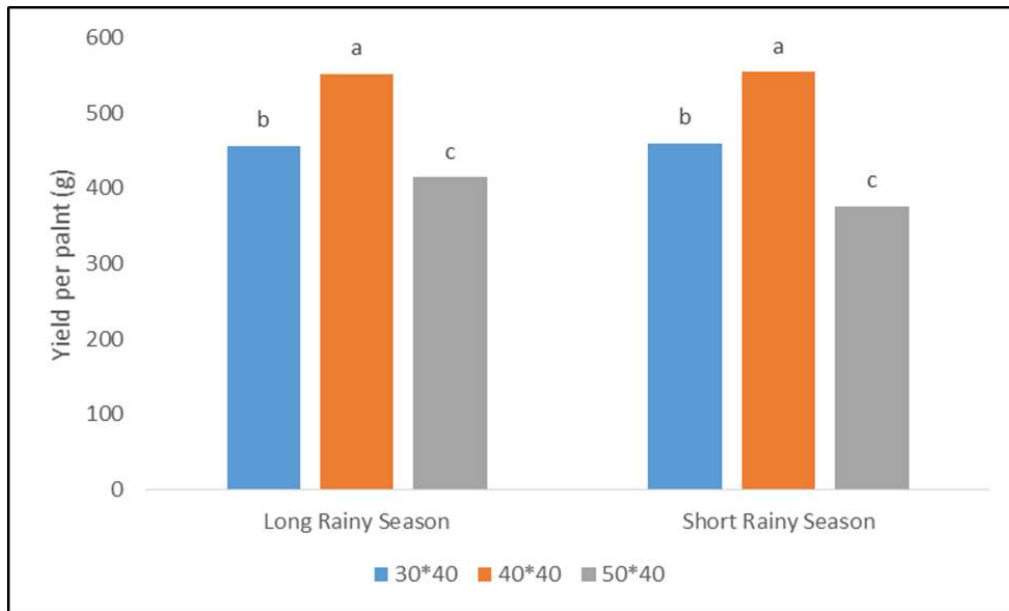
performance but could not compensate for the low leaf area per unit area of land as a result of the sparse population density. The results are in agreement with the report of [23] who stated that the number of fruits per plant decreased with closer plant spacing.

A non-significant variation in the length of fruits of green pepper was observed due to different plant spacing treatments (Table 1). The result on the fruit length agrees with those by [25] who stated that planting systems and distances

Table 1. The fruit length, fruit breadth and number of fruits per plant during the long and short rainy seasons at Alupe, Busia under different plant spacings in 2015

Spacing treatments	Fruit length (cm)		Fruit breadth (cm)		Fruits per plant	
	Long	Short	Long	Short	Long	Short
30*40	2.029	3.342	2.504 ^b	3.32 ^c	3.65 ^c	4.17
40*40	2.483	3.413	2.883 ^a	4.37 ^a	4.06 ^b	4.47
50*40	2.217	3.284	2.663 ^b	3.84 ^b	4.59 ^a	4.74
P-value	0.124	0.075	0.038	0.007	0.025	0.089

Different letters within each column refer to statistically significant differences according to Fischer's LSD mean separation test at P<0.05

**Fig. 5. The average yield per plant of green pepper during the long and short rainy seasons at Alupe-Kenya in 2015**

did not significantly alter plant height, main stem length, fruit length, fruit diameter or thickness of pericarp.

The spacing levels varied significantly in respect of the fruit breadth. The highest fruit breadth (4.37 cm) was obtained in plants of 40×40 cm which was statistically similar to that of 30×40 cm while the lowest fruit breadth was recorded in the closest spacing. The result on the fruit length is in disagreement with the report of [21] who reported that the fruit breadth of green pepper increased with decreasing plant density.

3.5 Yield per Plant

The yield per plant was significantly influenced by spacing levels as shown on Fig. 5 above. The maximum yield (551.8 g and 555.1 g for the long and short rainy seasons respectively) was

recorded from the 40×40 cm plant spacing and differed significantly from that of the other spacings. The lowest yield per plant was obtained from the widest spacing (50×40 cm) for both seasons. The wider spacing (40×40 cm) facilitated the plants to develop properly with less inter and intra plant competition for utilizing the available resources resulting higher yield per plant compared to the closest spacing (30×40 cm). The higher population density reduced yield per plant might be attributed to lesser fruit yield per plant. 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. The result of the present experiment is in agreement with the findings of Ravanappa et al. [24], who also obtained the highest yield with the lowest plant density treatment. The result is in agreement with the report of [25] who

reported that the individual fruit weight declined with increased plant density. Though fruits/plant were higher in the widest spacing (50×40 cm), the reduced average yield per plant was due to higher plants/m² in the 40×40 cm treatment which resulted in higher yield while the lowest yield per plant in the narrow spacing (30×40 cm) might be due to the reduced individual fruit weight. Russo [26], Nasto et al. [27] and Khasmakhi-Sabet et al. [28] had observed that the highest fruit yield of pepper was obtained when grown at the higher population densities.

4. CONCLUSION

Modern vegetable production practices accentuate the need to use optimum plant population through apt row spacings. Plants in wider row spacing had a more conducive micro-environment compared to higher plant densities at narrow row spacing but this could probably not compensate for the lesser plant number in a unit area which translated to a lower yield per hectare. The 40×40 cm spacing was found to be the best for production of sweet pepper under the Kenya Agricultural and Livestock Research Organization (KALRO), Alupe, Busia County conditions.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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