American Journal of Experimental Agriculture
6(1): 7-14, 2015, Article no.AJEA.2015.059
ISSN: 2231-0606

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Effects of Plant Spacing on the Growth, Yield and Yield Components of Okra *(Abelmoschus esculentus L.)* in Botswana

Mogapi E. Madisa[1*], Thembinkosi Mathowa[1], Christopher Mpofu[1] and Thato A. Oganne[1]

[1]Department of Crop Science and Production, Botswana College of Agriculture, Private Bag 0027, Gaborone, Botswana.

Authors' contributions

This work was carried out in collaboration between the authors. Authors MEM and TM designed the study and authors TAO and CM carried out field and laboratory work. Authors MEM and TM managed the literature searches and author TM managed statistical analysis. Authors TM and MEM managed the manuscript. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJEA/2015/14199
Editor(s):
(1) Lanzhuang Chen, Laboratory of Plant Biotechnology, Minami Kyushu University, Japan.
Reviewers:
(1) Ouoba Kondia Honoré, UFR-Sciences and Technology, Polytechnic University of Bobo, Burkina Faso.
(2) Anonymous, Pakistan.
Complete Peer review History: http://www.sciencedomain.org/review-history.php?iid=740&id=2&aid=7152

Original Research Article

Received 23rd September 2014
Accepted 19th November 2014
Published 9th December 2014

ABSTRACT

Okra is a newly cultivated crop in Botswana. Plant population has been identified as one of the factors that contribute to poor plant development and lower yields. The effects of various intra-row spacing on yield and yield components of okra variety; Clemson Spineless was evaluated at Botswana College of Agriculture in Sebele. The treatments consisted of five intra-row spacings of 30, 45, 60, 75 and 90 cm for treatments 1-5 respectively, each of the treatment was replicated three times in a Randomized Complete Block Design (RCBD). Yield and yield components were determined on five pre-determined plants from each plot and the raw data was subjected to analysis of variance (ANOVA). Generally, a significant treatment effect was revealed for plant height with narrower plant spacing of 30 cm significantly increasing the plant height. Wider plant spacing of 90 cm significantly increased the plant weight, number of branches and leaves. A non-significant treatment effect was observed for stem diameter, fruit length and diameter, number of flowers and fruits. Based on the results wider intra-row spacing of 90 cm is recommended for okra production.

**Corresponding author: E-mail: madisamogapie@yahoo.co, memadisa@bca.bw;*

Keywords: Plant spacing; clemson spineless; vegetative development; A. esculentus; Botswana.

1. INTRODUCTION

Okra (*A. esculentus*) is a member of the mallow family Malveceae and genus Abelmoschus [1-5]. It is a vigorous, half-woody, herbaceous, semi-fibrous, warm season annual and dicotyledonous plant [6]. Okra thrives well in most soil types from sandy loam, loam and or clay soils with a pH range of 5.8-8.0 [7], it is native to an area extending from Ethiopia to the Sudan and was introduced to Egypt in the seventh century [1,2]. It was then carried through North Africa and areas bordering the Mediterranean and eastward [1,2]. Okra is also known elsewhere as okro, gumbo, ochro, bhindee, lady`s finger and guimbabo [3]. There are numerous types which differ in fruiting time and shape, colour of leaves and stem length [8,3,4]. The mostly cultivated varieties are *Abelmoschus caillei* (*A. Chev*) and *Abelmoschus esculentus* (L.) Moench. *A. caillei* is an unconventional okra type which grows naturally in many parts of West Africa whereas *A. esculentus* is a conventional type which is a native of Asia [4]. The successful exotic cultivar to Botswana is *A. esculentus* commonly referred to as Clemson Spineless which is a uniformly spineless, medium dark green, angular pods 12-15 cm long. It grows up to 1.2-1.5 m in height and takes about 55-58 days to fruit [8]. The immature fruits are ready for fresh harvest between three and seven days after flowering [9].

Total world production of okra was estimated at 4.99 million metric tons, cultivated from an area of 0.78 million hectares with an average yield of 6.39 t ha^{-1} [5]. West and Central Africa region accounts for more than 75% of okra produced in Africa, however the average productivity is very low at 2.5 tha^{-1} [10]. Production of okra is all year round but more abundant during the rainy season. However, specific local cultivars are grown in specific areas depending upon their photoperiodic requirements. During dry season okra is grown under irrigation or in valley bottoms or riverbanks using residual moisture [11]. According to Majanbu et al. [12] fresh pod is highly valuable and can be found in almost every African market. Moreover, fresh pods are usually marketed in open streets markets or supermarkets without any kind of temperature or humidity control [13]. Although okra is a new crop in Botswana, it is of economic importance in the country because of the influx of foreign nationals from countries where it is widely consumed.

One of the major aspects of crop ecology, production and management which limit crop production is improper crop spacing in the field [1,14-17] and to some extent fluctuating environmental factors [4]. A spacing of 60-90cm×20-90cm is used depending mostly on the growth habit of the cultivar [14,17]. In addition, wider row spacing is said to be more productive since management practices like weeding and other practices can be easily carried out [1]. Fatokun and Chheda [18] investigated the response of two high yielding okra cultivars to different population densities in Ibadan (Nigeria). It is reported that number and weight of fruits $plant^{-1}$ as well as the vegetative branches $plant^{-1}$ decreased significantly with increase in population density from 61×30.5 cm to 61×91.5 cm. However, with late planting in the season two plants $stand^{-1}$ were found to increase yield for the two cultivars over the single plant stand. Norman [19] reported in studies of four plant population density in Makurdi (Nigeria) that a spacing of 40×40 cm produced not only highest number of productive branches and fruits $plant^{-1}$, but also the highest fruit weight $plant^{-1}$ and together with spacing of 40×30 cm they produced the highest fruit yield ha^{-1}. Fruit size for spacing 40×30 cm, 40×35 cm and 40 cm × 40 cm which was essentially similar was larger than that of 40×25 cm spacing which produced the lowest number of productive branches and fruits $plant^{-1}$ and the lowest fruit weight $plant^{-1}$ and fruit yield ha^{-1}. Similar results were obtained by [20,6]. Many local farmers practice broadcasting system in Botswana. This wastes seeds planted ha^{-1} and promotes over-crowding, thus increasing competition among plants and making weeding and other farm operations difficult. There has not been substantial research done on okra by the Department of Agriculture Research (DAR) in Botswana, as such information on the effects of plant spacing on the growth and yield of okra is not sufficient. The aim of this study was to evaluate the effect of intra-row spacing on commonly grown okra variety in Botswana.

2. MATERIALS AND METHODS

2.1 Location and Climate

The field experiment was conducted using variety Clemson Spineless at Botswana College of Agriculture (BCA) garden in Sebele from January to April 2010. The garden is located 24º33`S and longitude 25º54`E at elevation of

994 m above sea level, 10 km from Gaborone City center, along Gaborone-Francistown highway. The climate of the study area is semi-arid with an average annual rainfall (30 year mean) of 538 mm [21,22]. Most of rainfall is received in the summer months, starting in late October, continuing to March/April (Fig. 1). Soils are predominantly sandy loams (76% sand, 10% silt and 14% clay) with low water holding capacity, low cation exchange capacity (1.2 meq/100 g) and pH of 6.3.

2.2 Experimental Design and Establishment

The experiment was laid out in a Randomized Complete Block Design (RCBD) with five intra-row spacing of 30 cm, 45 cm, 60 cm, 75 cm and 90 cm being treatments 1-5, thus R_{30}, R_{45}, R_{60}, R_{75} and R_{90}, respectively. The inter-row spacing was kept constant at 50 cm. Each treatment was replicated three times. This gave a total of fifteen (15) plots of 2.5 m by 5.0 m, each plot with six rows including guard rows.

2.3 Cultural Practices

The experiment was established on piece of land previously ploughed using a tractor. The land was leveled using hand tools. Compound fertilizer NPK 2:3:2 (22) was applied once at a rate of 80 kg ha^{-1} before planting. Two Clemson Spineless seeds were sown per hole and thinning out to one seedling per stand at three to four leaf-stage was done. Watering was done once or twice per week depending on the weather conditions to keep the soil moist. Weeds were removed whenever they appeared in the experimental site; the most common and problematic weeds species identified during the experiment were; *Argemone mexicana, Chenopodium carinatum, Datura ferox* and *Tribullus teristeris*.

2.4 Data Collection

Developmental measurements were carried out on five pre-determined plants from each plot. Plants were tagged and the following data was recorded every fortnight from 6 weeks after emergence (WAE); plant height measured using a meter ruler from base to the terminal bud, stem diameter measured using a digital calibrated vernier caliper at about 10 cm above the soil surface, number of leaves and plant braches both determined quantitatively by counting. Number of flowers and fruits produced were both determined quantitatively by counting and were recorded every seven days from 8 and 9 WAE, respectively. A sample of five fruits from each plot was selected at random and their fresh weight measured using an electric balance (PGW 4502e), length measured using a 30 cm ruler, fruit diameter measured using a digital calibrated vernier caliper and seed number determined quantitatively by counting were recorded at termination of the study.

2.5 Data Analysis

The data collected was subjected to analysis of variance (ANOVA) using the STATISTIX-8 program. Treatment means were separated using Tukey's Studentized Range (HSD) Test at $P = .05$.

3. RESULTS AND DISCUSSION

3.1 Branch-lets and Leaves

Treatments had no effect on okra branching in weeks 6 and 8 and number of leaves in week twelve. However, wider spacing treatments (R_{90}, R_{75}, R_{60} and R_{45}) significantly increased branching in weeks 10 and 12 and leaf production in weeks 6, 8 and 10 as compared to (R_{30}) narrower spacing (Table 1). The non-significant treatment effect observed in weeks 6 and 8 was expected since the plants were still small hence no intra plant competition. While the significant treatment effect observed in weeks 10 and 12 is attributed to less intra plant competition for light and nutrients. Wider spacing helped the okra plant to utilize its energy properly in the production of leaves and branching because there was less competition for light, nutrients nor was overlapping from adjacent okra plants within the row [23]. It was also observed that the taller okra plants had fewer branches and hence fewer number of leaves (Tables 1 and 2). Leaf numbers also decreased over time (Table 1), possibly due to unfavourable weather conditions and senescence. Similar result was obtained by [20,6] where taller okra plants and fewer leaves were observed at closer spacing. Ibeawuchi et al. [1] observed that okra height decreased over time as row spacing increased. The study also showed that okra spaced at 30 cm within the row was significantly taller than other okra plants spaced otherwise from 2-8 weeks after planting. Ijoyah et al. [20] also reported that tallest okra plants were produced from the intra-row spacing of 25 cm which was significantly ($P<.05$) greater than that produced from the wider intra-row spacing. The number of branches plant^{-1} and leaf area also decreased as intra-row spacing reduced. This may be attributed to competition for light because plants at closer spacing get less amount of sunlight and other growth resources hence their tendency to grow upright instead of lateral and producing branches. Wider spacing helped the plants to utilize its energy properly in branching because there was not much competition for light nor was overlapping from adjacent okra plants within the row.

3.2 Number of Flowers and Fruits

Spacing treatments had no significant (P>.05) effect on the number of flowers and fruits (Table 1). The flower production across the treatments was affected by rainfall that rained every day of the week with an average rainfall amount of 113.9 mm recorded in April (Fig. 1). It was expected that treatment R_{90}, R_{75} and R_{60} respectively would have high flower production but most of the flowers were destroyed and dropped by the rains. Fruit production was also indirectly affected by the loss of flowers. Table 2 shows that treatments R_{90}, R_{75} and R_{60} had notably higher fruit production. This could be attributed to the increase in productive node of okra that increased with row spacing; R_{90} had 77%, while R_{75} and R_{60} had 69% and 66% respectively which affected yield as reported by [1]. However, the differences in means of the fruits produced were not significantly different for all row spacing. Ijoyah et al. [20] reported that the number of okra pods per plant decreased as intra-row spacing reduced.

3.3 Seeds

Treatment R_{60} significantly (P<.01) produced the highest number of seeds per fruit (84.3) though similar to R_{45} (Table 1). Although there was no significant differences in both fruit length and diameter, intra plant spacing of 45 cm and 60 cm had superior values (Table 2). This might have influenced significant differences in number of seeds observed (Table 1). This could be attributed to the fact that at lower plant spacing there was intense competition among the plants while at wider spacing vegetative production was stimulated at the expense of seed production. The findings suggest that 45 cm to 60 cm gives the highest number of seeds. A similar trend was observed by Norman [19], Ijoyah et al. [20] and Maurya [6] for fruit weight and diameter which positively correlates with number of seeds. Moniruzzaman et al. [24] found out that at the spacing of 60×30 cm the plants grew relatively taller and increase seed yield per hectare but reduced number of mature fruits per plant, length and diameter of mature fruit and number of seeds per fruit. The highest number of seeds fruit^{-1} (62.2) was recorded in the widest spacing of (60×60 cm) identically followed by 60×50 cm spacing. Similarly, the highest seed yield plant^{-1} was obtained from the widest spacing (60×60 cm) followed by 60×50 cm. However, the widest spacing of (60×60 cm) gave the lowest seed yield ha^{-1} (1.96 tons).

3.4 Plant Height (cm)

Generally, effect of spacing seemed to be negatively correlated on okra plant height with plants spaced at 30 cm revealing superior absolute numbers compared to the rest. However, the effect was non-significant in week 6, a highly significant and significant (P<.05) effects were observed in weeks 8 and 10, respectively (Table 2). Moreover, a non-significant effect was observed for week twelve (Table 2). This may be attributed to the close spacing of 30 cm which resulted in tall plants, possibly because of intra competition for light. However, both number of branches and leaves increased with increase in plant spacing (Table 1), possibly because of less intra plant completion for other resources such as nutrients. Similar results were reported by [25,17] in green pepper where closer spacing produced the tallest plants and shortest plants were obtained from the widest spacing. Plants spaced at 45, 60, 75 and 90 cm respectively are of approximately the same height possibly because there was less competition for light. Maya et al. [25] and Islam et al. [17] also reported maximum average number of branches per plant was recorded from plants of the widest spacing and the lowest number of branches from closest spacing. This might be due to the fact that the plants of wider spacing receive more light, nutrients and other resources than of close spacing.

3.5 Stem Diameter (cm)

Spacing treatments had no significant (P>.05) effect on okra stem diameter for the entire period of the study (Table 2). However, wide row spacing with lesser plant population revealed superior stem diameter. On contrary, study by Islam et al. [17] on green pepper found out that stem girth was statistically significant due to different plant spacing. The widest spacing produced the maximum stem girth and it gradually decreased with decreasing spacing. The plants planted at widest spacing produced profuse branching without lodging [20]. From the present study, wider row spacing tended to produce stronger plants that did not require any support unlike at closer spacing where the plants were thinner and weaker.

3.6 Fresh Fruit Weight (g)

Treatments effect seemed to be positively correlated on okra fresh fruit weight with 90 cm spacing significantly (*P*<.01) increasing fruit fresh weight for week 8 and a significant (*P*<.05) effect was observed for weeks 9, 10 and 11, respectively (Table 2). Plant spacing influenced the individual fruit weight. The maximum fruit weight was obtained in the widest spacing (90 cm). The widely spaced plants produced heavier fruits as they had stronger plants than at closer spacing. The result are in agreement with Ijoyah et al. [20], Islam et al. [17] and Maurya [6] who reported maximum yield at wide spacing because wider spacing facilitated the plants to develop properly with less inter and intra plant competition for utilizing the available resources resulting in higher yield plant^{-1}.

3.7 Fruit Size (Length and Diameter)

Mean fruit length and diameter were not significantly different at *P*>.05 across the five treatments evaluated (Table 2). However, treatment R_{45} and R_{60} had the largest fruit compared to the rest. In a study by Norman [19], narrower plant spacing of 40×30 cm and 40×40 cm produced the largest fruit as compared to wider plant spacing, this finding partly agrees with the current study for the wider spacing which had smaller fruits. Ijoyah et al. [20] and Maurya [6] obtained significantly higher fruit weight and fruit diameter of okra at spacing of 60×40 cm higher than at wider spacing. The non-significant treatment effect between wider and narrower spacings could be attributed to the effect of rainfall that affected the number of flowers resulting in less competition among fruits at lower plant spacing. The present results seems to suggest that over spacing of plant does not necessarily result in corresponding increase in fruit size because excessive spacing had no impact on fruit size. Instead it leads to underutilization of the land hence lower productivity. Therefore, it can be inferred that intra plant spacing of 45 cm to 60 cm gives the optimum fruit size.

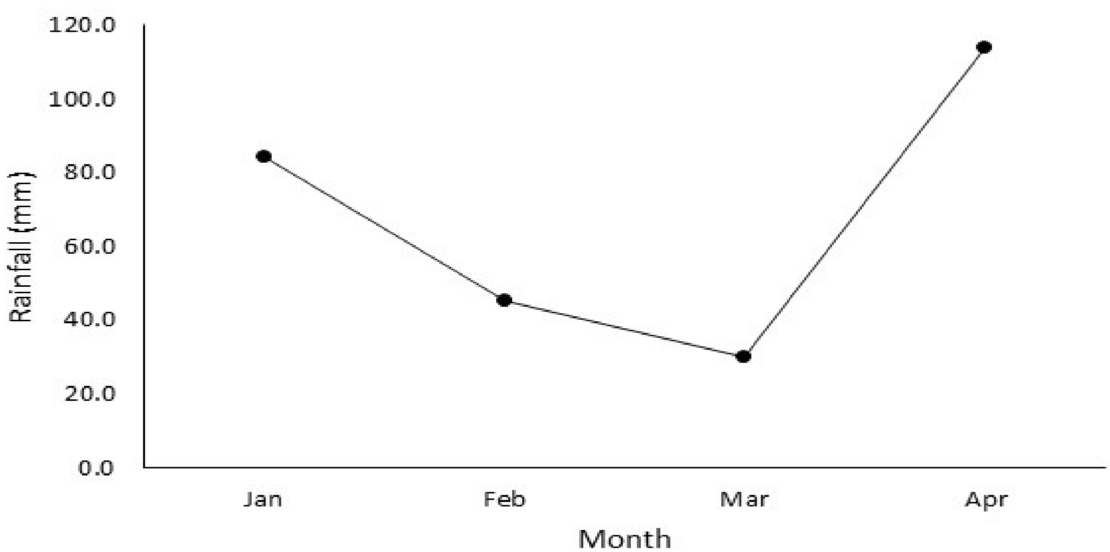

Fig. 1. Mean monthly rainfall recorded during the study

Table 1. Mean branch, leaf, flower, fruit and seed number of okra as influenced by plant spacing

Treatments	Branch				Leaves				Flowers				Fruits			Seeds
	Week 6	Week 8	Week 10	Week 12	Week 6	Week 8	Week 10	Week 12	Week 8	Week 9	Week 10	Week 11	Week 9	Week 10	Week 11	
R_{30}	1.0	1.0	1.0b	1.0b	12.3b	21.7b	22.7b	15.7	1.3	3.0	3.0	2.3	1.0	1.7	1.7	65.3bc
R_{45}	1.0	1.0	1.0b	1.3b	21.7ab	31.3ab	27.7ab	18.7	1.0	2.7	2.7	2.3	1.0	2.0	2.0	79.3ab
R_{60}	1.0	1.3	1.3ab	2.7a	21.7ab	31.0ab	29.7ab	18.7	1.0	2.7	3.0	3.0	0.3	1.7	2.7	84.3a
R_{75}	1.3	1.3	1.7ab	2.7a	22.7ab	35.0a	32.7a	18.7	1.0	3.0	3.0	3.0	0.6	2.7	2.7	59.7c
R_{90}	1.3	1.3	2.0a	3.0a	28.3a	34.7a	32.7a	19.7	1.0	2.7	2.7	2.7	1.0	2.7	2.7	63.7c
Significance	ns	ns	*	**	*	*	*	ns	ns	ns	ns	ns	ns	ns	ns	**
HSD	ns	ns	0.96	1.03	10.85	12.12	8.77	ns	ns	ns	ns	ns	ns	ns	ns	14.39
CV (%)	27.90	26.35	24.40	17.12	18.06	14.01	10.71	20.99	24.21	15.97	13.51	16.06	42.70	24.21	22.13	7.25

*** Highly significant at P<.01, * significant at P<.05, ^{ns} non-significant at P>.05. Means separated using tukey's studentized range (HSD) test at P≤.05, means within columns followed by the same letters are not significantly different. Where R_{30}-R_{90} are intra-row spacing of 30, 45, 60, 75 and 90 cm*

Table 2. Mean plant height, stem diameter, fresh fruit weight, fruit length and fruit diameter of okra as influenced by plant spacing

Treatments	Plant height (cm)				Stem diameter (cm)				Weight (g)				Fruit length (cm)	Fruit diameter (cm)
	Week 6	Week 8	Week 10	Week 12	Week 6	Week 8	Week 10	Week 12	Week 8	Week 9	Week 10	Week 11		
R_{30}	256.7	569.7a	759.7a	861.5	1.4	2.0	2.3	2.6	60.8b	55.6b	58.7b	54.5b	13.4	2.7
R_{45}	236.9	527.8b	683.6ab	800.8	1.5	2.7	2.5	2.7	64.1b	62.3ab	59.3b	62.6ab	15.0	3.0
R_{60}	232.7	516.3b	683.7ab	790.7	1.6	2.5	2.6	2.8	65.7b	66.3ab	62.1ab	61.9ab	15.3	2.9
R_{75}	243.5	516.7b	660.7ab	774.3	1.6	2.5	2.5	2.7	69.7ab	72.5ab	76.2a	72.8ab	13.7	2.8
R_{90}	230.5	511.5b	611.2b	722.4	1.7	2.5	2.9	3.1	78.2a	80.6a	71.1ab	80.2a	13.9	2.8
Significance	ns	**	*	ns	ns	Ns	ns	ns	**	*	*	*	ns	ns
HSD	ns	38.73	129.12	ns	ns	Ns	ns	ns	10.06	23.50	15.00	24.60	ns	ns
CV (%)	13.88	2.60	6.75	12.07	18.61	13.44	27.08	17.86	5.28	12.37	8.13	13.16	16.76	9.33

*** Highly significant at P<.01, * significant at P<.05, ^{ns} non-significant at P>.05. Means separated using tukey's studentized range (HSD) test at P≤.05, means within columns followed by the same letters are not significantly different. Where R_{30}-R_{90} are intra-row spacing of 30, 45, 60, 75 and 90 cm*

4. CONCLUSION

This study showed that intra-row spacing of 90 cm significantly increased the plant weight, number of branches and leaves. The narrower spacing of 30 cm produced taller and weaker plants, while intermediate intra-row spacings revealed superior values for non-significant parameters. On the basis of these results, wider intra-row spacing of 90 cm is recommended for production of okra. However, further studies need to be conducted to verify the findings.

ACKNOWLEDGEMENTS

We are grateful to the Ministry of Education, Skills and Development for providing a scholarship to Thato A. Oganne. We thank Botswana College of Agriculture for providing resources including, amongst other things, field and laboratory.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history.php?iid=740&id=2&aid=7152