J. Sher-e-Bangla Agric. Univ., 11(1 & 2): 1-8, January & July 2020 ISSN 1997-6038

PERFORMANCE OF STEM AMARANTH DURING THE EARLY ESTABLISHMENT PERIOD OF MORINGA PLANTATION

A. Ahmed[1], M. G. J. Helal[2], N. Naher[3], M. Hasan[4] and H. Kausar[5]

ABSTRACT

A study was conducted to find out the effect of tree planting distances on growth, yield and yield attributing characters of stem amaranth (*Amaranthus oleraceus*) during the early establishment period of Moringa (*Moringa oleifera*) plantation. The study comprising of four treatments which were T_0 (open field condition), T_1 (15 cm away from tree base), T_2 (30 cm away from tree base), T_3 (45 cm away from tree base). At harvest, the maximum plant height (59 cm) and number of leaf (24.75 cm) of stem amaranth were recorded in control condition whereas the least plant height (49 cm) and leaf number (19.75) were recorded in T_3 treatment. The highest leaf length (9.60 cm) and leaf breadth (5.37 cm), stem girth (5.71 cm), stem length (60.66 cm), root length (15.88 cm), shoot and root fresh weight (74.10 g and 15.62 g), shoot and root dry weight and yield (14 t/ha) were observed in open field condition. The yield of stem amaranth in association with Moringa saplings was recorded lower compared to control condition. The yield reduction in treatments T_1 (12 t/ha), T_2 (10.2 t/ha) and T_3 (10.2 t/ha) were 16.6 %, and 26 %, respectively compared to open field condition. Among agroforestry treatments, the highest growth, yield and yield contributing characters were found in plants under T_1 treatment revealed that stem amaranth shared available plant nutrients from the pits of Moringa cuttings thus showing its potential to be used in Moringa based agroforestry farming system during the early stage of establishment in large-scale.

Keywords: agroforestry, interaction, *Moringa oleifera*, resource sharing, stem amaranth

INTRODUCTION

Bangladesh is one of the most densely populated countries in the world with its limited natural resources. The current population of Bangladesh is 165.8 million which is equivalent to 2.18% of the total world population. The country has a land area of only 14.39 million hectares, but due to the ever increasing population, per capita land area is decreasing at an average rate of 0.005 ha/ year. The land and forest are the most important natural resources which have diversified impact on all sectors of the society. To maintain the environmental equilibrium and rate of socio-economic development at least 25% area of a country should be covered with forest. In Bangladesh the total forest area covers about 17% of the land area but the actual tree covered area is around 9.4% which is decreasing at an alarming rate (Ahmed *et al.,* 2018). Bangladesh has no scope to further expand forest nor agricultural areas. So, combined production system integrating trees and crops together need to be developed. In these situations, Agroforestry, the integration of tree and crops or vegetables on the same area of land is a promising production system for maximizing yield and maintaining friendly environment (Fekadu and Mammo, 2016).

In Bangladesh, Moringa is a common tree growing mainly in homestead areas (Padulosi *et al.*, 2013). Moringa is a multipurpose vegetable tree with a variety of potential uses, of which the nutritional and medicinal properties are initially considered the most interesting. Moringa is said to provide 7 times more vitamin C than oranges, 10 times more vitamin A than carrots, 17 times more calcium than milk, 9 times more protein than yoghurt, 15 times more potassium than bananas and 25 times more iron than spinach (Rockwood *et al.*, 2013). Vegetables grown in Bangladesh are not sufficient. The demand of vegetables is increasing but unfortunately the area under vegetable production is decreasing due to increasing the area of rice and wheat cultivation. Amaranth is a common vegetable in Bangladesh. In early summer, the availability of vegetable is limited. In that period amaranth can partially overcome this limited condition. Amaranth leaves are high in protein, b-carotene, iron, calcium, vitamin C, and

[1] MS Student, [2]Assistant Professor, [3&5]Professor, Dept. of Agroforestry and Environmental Science, [4] Dept. of Genetics and Plant Breeding, Sher-e-Bangla Agricultural University, Dhaka, Bangaldesh.

folic acid (Achigan-Dako *et al.*, 2014). Vegetable amaranth (*Amaranthus cruentus*) is a good source of minerals, vitamins, phenolics and carotenoids; it also contains betalains, a nitrogen containing group of natural pigments, as well as proteins and fibers (Venskutonis and Kraujalis, 2013). Amaranths are often described as drought tolerant plants (Liu and Stutzel, 2002; Hura *et al.*, 2007).

During the early establishment of Moringa vegetables can easily grow in their surrounding areas. At the early establishment period of tree, the competition for growth resources (water, nutrients and light) between tree and associated crop is perhaps absent or minimum (Noman *et al.*, 2018). Plantation of Moringa tree in association with vegetables and spices as agroforestry practice would be beneficial for socio economic development as well as for sound environmental condition. Hence, it would be wise to conduct experiments during the early period of the Moringa tree plantation in association with different vegetables at different spacing in terms of growth and yield performance for identifying the best tree-crop combination. Therefore, the present study was undertaken with the objective of determining the growth and yield performance of stem amaranth in association of Moringa saplings at different distances from Moringa tree base during the early establishment period.

MATERIALS AND METHOD

The experiment was conducted to evaluate the responses of early summer vegetable amaranth in association with drumstick (*M. oleifera*) as well as to find out the best tree crop interactions in Agroforestry system.

Experimental site

The experiment was carried out at the Agroforestry Field Laboratory under the Department of Agroforestry and Environmental Science, Sher-e-Bangla Agricultural University, Dhaka during the period from January 2018 to April 2018.

Plant materials

In this experiment, a total of 12 equal sizes cuttings of *M. oliaferae* were collected from Manikganj District. The seeds of Amaranth var. Dhrutoraj was collected from United Seed Company, Siddique Bazar and Dhaka. A 40 cm deep square size pit was dug at 5 feet distance in the experimental field. All the cuttings were 3.8 feet in length which was placed separately at the center of each pit. After planting, the above ground length of each sapling was 2.6 feet which was similar for all used as tree planting materials. Irrigation was done as necessary by using watering cane.

Experimental design and treatment combination

The vegetable amaranth in association of 60 days old Moringa saplings were sown following the Randomized Complete Block Design (RCBD). Each of the four treatments was replicated five times. Four treatments which were used in this study are as follows:-

T_0= Open field referred to as control T_1= 15 cm distance from the tree base
T_2= 30 cm distance from the tree base T_3= 45 cm distance from the tree base

Land preparation and crop husbandry

The experimental field preparation was started on 1 January 2018 and all operations were done by spades. Then the land was left fellow for one month. During this time all crop residues and weeds were removed from the land, broken stones and bricks were sorted out and finally 20 cm raised bed was leveled properly for Moringa plantation. Amaranth seeds were sown in the experimental plot on 27 February 2018 by line sowing method at a depth of 10 cm furrow line maintaining a spacing of 9 cm from row to row. No other chemical fertilizers were used in this study but cow dung (20 t/ha) which was applied in the experimental field during final land preparation. No pesticide and insecticide were applied as the crops were not infected by any pest and diseases. Irrigation, weeding and other intercultural operations were done when and where necessary.

Measurements and definitions

Amaranth was harvested at 50 days after sowing (DAS) when the crop reached at edible size. Plant samples of amaranth were collected randomly from each rows of the respective plots. A total of 20 plants of amaranth were selected from each plot for data collection. Plant height was measured in centimeter by using a scale at 10, 20, 30 and 40 at harvest after seeding (DAS) from the ground level to the tip of the plant leaf. Number of leaf per plant, five plants from each plot were selected randomly and tagged properly. The leaf number was counted precisely for each plant. Leaf length and breadth of the leaves were measured with a centimeter scale. Stem girth (cm), each stem of the plant with a roller scale, then the sum of stem diameter was divided by 5 to record average stem diameter of plant. Shoot length (cm), shoot length was measured for by a centimeter scale at harvest. Root length (cm), the length of the root was measured by a centimeter scale for randomly selected five plants from each plot. Then the sum of the root length was divided by five to record root length of plant. Fresh weight (g) randomly 5 plants were selected from the each plot. Then shoot and root weight were weighted separately by balance. The sum of the fresh weight of five plants was divided by five then it was recorded as fresh weight of single plant (g). Dry weight (g) after taking fresh weight, the sample plants were oven dried. Then shoot and root weight were weighted separately by electronic balance. The sum of the dry weight of five plants was divided by five then it was recorded as dry weight of single plant (g). Fresh yield (t/ha), the yield of stem amaranth per hectare was calculated by converting the total yield (kg) of stem amaranth per plot.

Analysis of data

All the data were subjected to analysis of variance (ANOVA) and tested for significance using Least Significant Difference (LSD) using R-3.5.1 software (R Core Team).

RESULTS

Plant height

Plant height of stem amaranth was found significantly different due to different spacing from tree base at different sampling dates (Table 1). The plant height was increased gradually with the advancement of crop growth up to harvest. At 10 DAS, the plants belong to open field condition (T_0 treatment) exhibited the highest plant height that was statistically similar with the plant height recorded in T_1 and T_2 treatments. At 30 DAS, significantly highest plant height (27.75 cm) was observed in control condition which was significantly higher than other treatments. The lowest plant height (25.37 cm) was recorded in plants grown at 45 cm distance from the tree base (T_3 treatment). At harvest (50 DAS), plant height ranges from 58.75 cm to 49 cm where plants belong to control treatment appeared as tallest followed by T_1 and T_2 treatments and plants belong to T_3 treatment was the shortest in height.

Table 1. Effect of tree-crop interactions on plant height (cm) of stem amaranth at different measurement dates

Treatments	Plant Height (cm)				
	10 DAS	**20 DAS**	**30 DAS**	**40 DAS**	**Harvest**
T_0	3.75 a	13.75 a	27.75 a	50.87 a	58.75 a
T_1	3.62 a	12.75 b	26.75 b	49.50 b	56.37 b
T_2	3.37 a	11.75 c	26.75 b	47.12 c	53.25 c
T_3	2.75 b	11.25 c	25.37 c	45.78 d	49.00 d
LSD	0.421	0.53	0.682	1.16	1.06
CV (%)	7.8	2.6	1.6	1.5	1.2
Sig. level	**	**	**	**	**

T_0 = Control; T_1= 15 cm distance from the tree base; T_2= 30 cm distance from the tree base; T_3= 45 cm distance from the tree base; Means within columns followed by the same letter are not significantly different, 5% or 1% level of probability, least significant difference (LSD) test

Leaf number

Number of leaves per plant exhibited different results under different treatments (Table 2).The highest number of leaves per plant at harvest was found where amaranth was grown under control conditions. At the early stage of growth (10 DAS), plants belong to open field condition (T_0 treatment) resulted the highest number (4.25) of leaves compared to other treatments. During the middle stages of growth (30 DAS), amaranth grew at both 30 and 45 cm away from tree produced least number of leaves per plant. At harvest, under T_0 treatment, the number of leaves per plant was 24.75 which was highest and the lowest no. of leaves were found in plants under T_3 treatment that was 19.75 where amaranth was grown at 45 cm away from tree base.

Table 2. Effect of tree-crop interactions on number of leaves of stem amaranth at different measurement dates

Treatments	Leaf number				
	10 DAS	**20 DAS**	**30 DAS**	**40 DAS**	**Harvest**
T_0	4.25 a	9.75 a	12.25 a	16.00 a	24.75 a
T_1	3.25 b	8.75 b	10.62 a	14.75 b	21.62 b
T_2	2.87 b	7.37 b	10.5 b	14.00 b	21.37 b
T_3	3.25 b	8.50 c	11.5 b	14.75 b	19.75 c
LSD	0.62	0.88	0.82	01.17	0.94
CV (%)	11.53	6.45	4.59	4.94	2.69
Sig. level	**	**	**	*	**

T_0 = Control; T_1= 15 cm distance from the tree base; T_2= 30 cm distance from the tree base; T_3= 45 cm distance from the tree base; Means within columns followed by the same letter are not significantly different, 5% or 1% level of probability, least significant difference (LSD) test

Leaf length and breadth

At harvest, leaf length and leaf breadth differ significantly among the treatments (Table 3). The highest leaf length was recorded in T_0 treatment (9.6 cm) which was closely followed by the plants belong to T_1 treatment (8.87 cm) that is statistically similar with T_2 treatment (8.42 cm). The lowest leaf length was recorded in plants under T_3 treatment which was 24.06% lower than control condition. Again in case of leaf breadth, the highest leaf breadth (5.37 cm) was found in control conditions (T_0) where amaranth was grown in open field which was statistically similar with the leaf breadth (4.75 cm) recorded in T_1 treatment (15 cm away from tree base) and the lowest results (4.28 cm) were recorded in plants 45 cm distance from tree base (T_3 treatment).

Table 3. Effect of tree-crop interactions on leaf length and leaf breadth of stem amaranth

Treatments	Leaf length (cm)	Leaf breadth (cm)
T_0	9.60 a	5.37 a
T_1	8.77 b	4.75 ab
T_2	8.42 b	4.33 b
T_3	7.29 c	4.28 b
LSD	0.55	0.65
CV (%)	4.1	8.75
Sig. level	**	*

T_0 = Control; T_1= 15 cm distance from the tree base; T_2= 30 cm distance from the tree base; T_3= 45 cm distance from the tree base; Means within columns followed by the same letter are not significantly different, 5% or 1% level of probability, least significant difference (LSD) test

Stem girth, stem length and root length

Significant variation was observed among the different treatments in respect of stem girth at harvest of stem amaranth (Table 4). Maximum stem girth was recorded (5.7 cm) in open field condition followed by T_1 treatment (4.68 cm). Stem girth (4.43 cm) observed in plants 30 cm away from tree base was statistically similar with the result found in T_1 treatment. The minimum stem girth (4.12 cm) was found under 45 cm distance from tree (T_3 treatment). It was noteworthy that stem girth of the plants belonging to the treatments T_2 and T_3 were statistically similar. The length of stem differs significantly among different treatments (Table 4). The length of stem was observed maximum (60.66 cm) where plants were in control conditions (T_0) followed by T_1 and T_2 treatment. The lowest stem length (51.85 cm) was results in plants that were grown at 45 cm (T_3) distance from tree base. Root length significant variation was observed in respect of root length for different treatment combinations (Table 4). Highest root length (15.88 cm) was found in plants that were grown in open field condition followed by plants grown in 15 cm and 30 cm distance from tree base. The minimum root length (11.72 cm) was resulted for T_3 treatment.

Table 4. Effect of tree-crop interactions on stem girth, stem length and root length of stem amaranth

Treatments	Stem girth (cm)	Stem length (cm)	Root length (cm)
T_0	5.71 a	60.66 a	15.88 a
T_1	4.68 b	57.9 b	14.68 b
T_2	4.43 bc	55.42 c	12.89 c
T_3	4.12 c	51.85 d	11.72 d
LSD	0.46	1.2	0.7
CV (%)	6.15	1.33	3.21
Sig. level	**	**	**

T_0 = Control; T_1= 15 cm distance from the tree base; T_2= 30 cm distance from the tree base; T_3= 45 cm distance from the tree base; Means within columns followed by the same letter are not significantly different 1% level of probability, least significant difference (LSD) test

Fresh weight

Shoot fresh weight of stem amaranth was observed significantly different among treatments (Table 5). The significantly height fresh weight (74.10 g) was found at T_0 treatment (control condition). The second highest fresh weight (72.05 g) was recorded in T_1 treatment which was statistically similar with T_0 treatment. The minimum fresh weight (68.70 g) was recorded in plants at 45 cm distance from tree base (T_3 treatment). Significant variation was observed among treatments in respect of root fresh

Table 5. Effect of tree-crop interactions on fresh weight (FW) of stem amaranth

Treatments	Shoot FW (g)	Root FW (g)
T_0	74.10 a	15.62 a
T_1	72.05 ab	14.05 b
T_2	71.07 bc	13.70 b
T_3	68.70 c	11.97 c
LSD	2.45	0.59
CV (%)	2.14	2.7
Sig. level	**	**

T_0 = Control; T_1= 15 cm distance from the tree base; T_2= 30 cm distance from the tree base; T_3= 45 cm distance from the tree base; Means within columns followed by the same letter are not significantly different 1% level of probability, least significant difference (LSD) test

weight also. The highest weight (15.62 g) of root per plant was recorded in open field condition (T_0) followed by T_1 and T_2 treatment. The root fresh weight for T_1 (14.05 g) and T_2 (13.70 g) were statistically similar. The lowest root weight was recorded in T_3 (11.97 g) treatment which was significantly different from other treatment combinations.

Dry weight

Dry weight of amaranth shoot exhibited different results in terms of different treatments (Table 6). Shoot dry weight was observed highest (4.33 g) on open field condition T_0 treatment where T_1 treatment comprises second highest dry weight. The plants under T_3 treatment was found minimum in shoot dry weight (3.54 g) results in distance of 45 cm from tree base. The root dry weight of stem amaranth varied significantly in different treatments. Maximum root dry weight was recorded in T_0 treatment (1.05 g) followed by T_1 and T_2 treatment. The results found for T_1 (0.96 g) and T_2 (0.93 g) had no significant difference. The lowest root dry weight (0.87 g) was observed in T_3 treatment.

Table 6. Effect of tree-crop interactions on dry weight (DW) of stem amaranth

Treatments	Shoot DW (g)	Root DW (g)
T_0	4.33 a	1.05 a
T_1	3.81b	0.96 b
T_2	3.68 b	0.93 b
T_3	3.54 b	0.87 c
LSD	0.3	0.052
CV $_{(\%)}$	4.97	3.41
Sig. level	**	**

T_0 = Control; T_1=15 cm distance from the tree base; T_2= 30 cm distance from the tree base; T_3= 45 cm distance from the tree base Means within columns followed by the same letter are not significantly different 1% level of probability, least significant difference (LSD) test

Yield

Significant variation was found among different treatment combination in respect of fresh yield (Table 7). Among different treatments, yield was recorded highest (13.85 t/ha) in open field condition where stem amaranth was grown intensively without association with Moringa tree. The yield found for different planting distances had no significant difference though second highest yield (11.5 t/ha) was found for T_1 treatment followed by T_2 and T_3 treatment.

Table 7. Effect of tree-crop interactions on yield (t/ha) of stem amaranth

Treatments	**Yield (t/ha)**	**Yield reduction (%)**
T_0	13.8 a	–
T_1	11.5 b	16.6
T_2	10.2 b	26.0
T_3	10.2 b	26.0
LSD	2.1	–
CV (%)	11.53	–
Sig. Level	*	–

T_0 = Control; T_1= 15 cm distance from the tree base; T_2= 30 cm distance from the tree base; T_3= 45 cm distance from the tree base; Means within columns followed by the same letter are not significantly different 1% level of probability, least significant difference (LSD) test

DISCUSSION

Plants belong to control treatment (T_0) were the fastest growing and performed consistently better in morphological characteristics compared the plants belongs to agroforestry treatments. The higher yield in control treatment may be explained by the fact that plants utilized substantial amount of production inputs particularly light, irrigation water and organic amendments without any challenge from tree components. At harvest, plant height varied significantly among the treatments however early plant heights were not significantly different. It confirmed the below ground tree-crop competitions for resource sharing among the treatments were minimum at the beginning which gradually increased with the advancement of crop growth (Noman *et al.*, 2018). Plant height is influenced by genetic as well as environmental conditions. The increase in plant height also could be due to better availability of soil nutrients in the growing areas of control condition which have enhancing effect on the vegetative growth of plants by increasing cell division and elongation and the varietal variability to absorb the nutrients from the soil (El-Tohamy *et al.*, 2006). Our result is similar with the results of Sharma (1999).

The number of leaves under T_3 treatment was 20.2% lower than control condition at harvest. Besides, the leaf length, leaf breadth, stems girth in control condition (T_0 treatment) were maximum followed by T_1, T_2 and T_3 treatment. This research results were in contrast with the past research results (Dola *et al.*, 2016). The decreasing trends of plant growth parameters with the increasing distance from Moringa tree base. This was happened perhaps due to the fact that Moringa cuttings were planted 60 days prior to stem amaranth. By this periods, plants nutrients in the pits of Moringa saplings becomes in available form which were taken readily by the stem amaranth belongs to T_1 treatment without any interferences by the Moringa cuttings as these were in the early growing periods. Consequently plant nutrients becomes less available to the plants belong to T_2 and T_3 plants respectively.

In agroforestry systems, yield reduction had been reported compared to sole cropping (Zamora *et al.*, 2007; Sanou *et al.*, 2012). Yield reduction in agroforestry system occurs usually due to competition between trees and crops for light, water, and nutrients (Allen *et al.*, 2004; Jose *et al.*, 2004; Zamora *et al.*, 2007). Reductions in crop growth and corresponding yield losses are known to happen when tree and crops are grown in close proximity. Tree species rooting pattern consists of deep and far reaching lateral roots so as to cover a bigger soil volume to capture more resources compared to crops. As a results, soil moisture, soil nutrients and solar radiation decreased in agroforestry treatments. Therefore, the competition for soil moisture and nutrients are important in tree-crop systems (Sudmeyer and Hall, 2015; Sudmeyer *et al.*, 2002). However, Moringa are known to have limited water requirement which primarily an adaptation strategy is enabling them to grow under harsh environmental conditions (Akhter *et al.*, 2005).

CONCLUSION

All the plant growth characteristics and yield of stem amaranth were higher in control conditions. Among the agroforestry treatments the highest yield was found in T_1 treatment compared to T_2 and T_3 treatments. Plants under T_1 treatment obtained resource inputs from the pit of Moringa saplings. The yield reduction was only 16 % in the plants belong to T_1 compared to control condition suggesting that farmers may cultivate stem amaranth in association with Moringa in the early stage of plantation.

Acknowledgement

The authors acknowledge the support of the Project Implementation Unit-BARC, NATP 2 (Project No. 432), Bangladesh Agricultural Research Council for its financial support without which this research would not have been possible.

REFERENCES

Achigan, D.E., Sogbohossou, O. and Maundu, P. 2014. Current knowledge on *Amaranthus* spp.: Research avenues for improved nutritional value and yield in leafy amaranths in sub Saharan Africa. *Euphytica.,* 197(3): 303–317.

Ahmed, A., Ataullah, M., Rashid, P., Paul, A.R., Dutta, S. and Ali, M.S. 2018. Species diversity, change in forest cover and area of the Sundarbans, Bangladesh. *Bangladesh J. Bot.*, 47(3): 351-360.

Akhter, J., Mahmood, K., Tasneem, M.A., Malik, K.A., Naqvi, M.H., Hussain, F. and Serraj, R. 2005. Water-use efficiency and carbon isotope discrimination of *Acacia ampliceps* and *Eucalyptus camaldulensis* at different soil moisture regimes under semi-arid conditions. *Biolog. Plantarum.*, 49: 269–272.

Allen, S., Jose, S., Nair, P., Brecke, B. and Ramsey, C. 2004. Competition for ^{15}N-labeled fertilizer in a pecan (Carya illinoensis K. Koch)-cotton (*Gossypium hirsutum* L.) alley cropping system in the southern United States. *Pl. and Soil.,* 263(1/2): 151–164.

Dola, F.A., Rahman, H.M.S., Wadud, M.A. and Rahman, G.M.M. 2016. Performance of red amaranth and ipil-ipil based alley cropping system. *J. Agrofor. Environ.*, 10 (1): 35-38.

El-Tohamy, W.A., Ghoname, A.A. and Abou-Hussein, S.D. 2006. Improvement of Pepper Growth and Productivity in Sandy Soil by Different Fertilization Treatments under Protected Cultivation. *J. Appld. Sci. Res.*, 2(1): 8–12.

Fekadu, Z.M. and Mammo, M. 2016. Agroforestry Technologies in Livelihood Improvement in the Eastern Cape Province, South Africa. 10.13140/RG.2.1.1422.9360.

Foidl, N., Makkar, H.P.S. and Becker, K. 2001. The potential of *Moringa oleifera* for agricultural and industrial uses. *Fuglie, L.J. (Ed),* 2001. The miracle tree: the multiple attributes of Moringa. CTA Publication. Wageningen, the Netherlands, 45–76 pp.

Hossain, S.M.A. and Bari, M.N. 1996. Agroforestry farming system. In: Haque, M.A. (edn) Agroforestry in Bangladesh. Swiss Development Co-operation (SDC), Dhaka and Bangladesh Agricultural University (BAU), Mymensingh. 21–28 pp.

Hura, T., Grzesiak, S., Hura, K., Thiemt, E., Tokarz, K., Wędzony, M. 2007. Physiological and biochemical tools useful in drought tolerance detection in genotypes of winter triticale: Accumulation of ferulic acid correlates with drought tolerance. *Ann. of Bot.,* 100: 767–775.

Jose, S., Gillespie, A. and Pallardy, S. 2004. Interspecific interactions in temperate agroforestry. *Agrofor. Sys.*, 61: 237-255.

Liu, F. and Stützel, H. 2002. Leaf water relations of vegetable amaranth (*Amaranthus* spp.) in response to soil drying. *European J. Agron.*, 16 (2): 137–150.

Noman, M.A.A., Sahel, M.O.R., Ahmed, F. and Wadud, M.A. 2018. Performance of drumstick-chilli based agroforestry practice in charland ecosystem. *J. Agrofor. Env.,* 12 (1 & 2): 73-76.

Padulosi, S., Thompson, J. and Rudebjer, P. 2013. Fighting poverty, hunger and malnutrition with neglected and underutilized species (NUS): needs, challenges and the way forward. Biodiversity Intl. Rome.

Core, T.R. 2013. A language and environment for statistical computing. Foundation for Statistical Computing, Vienna, Austria.

Rockwood, J.L., Anderson, B.G. and Casamatta, D.A. 2013. Potential uses of *Moringa oleifera* and an examination of antibiotic efficacy conferred by *Moringa oleifera* seed and leaf extracts using crude extraction techniques available to underserved indigenous populations. *Int. J. Phytothearpy Res.,* **6**: 61–71.

Sanou, J., Bayala, J., Teklehaimanot, Z. and Paulin, B. 2011. Effect of shading by baobab (Adansonia digitata) and nere (Parkia biglobosa) on yields of millet (Pennisetum glaucum) and taro (Colocasia esculenta) in parkland systems in Burkina Faso, West Africa. *Agrofor. Sys.,* 85: 431-441.

Sharma, K.K. 1999. Wheat cultivation in association with *acacia nilotica* L. wild ex. Del field bund plantation a case study. *Agrofort. Sys*., 17**:** 43–51.

Sudmeyer, R. and Hall, D. 2015. Competition for water between annual crops and short rotation mallee in dry climate agroforestry: The case for crop segregation rather than integration. *Bioma and Bioener.,* 73: 195–208.

Sudmeyer, R., Hall, D., Eastham, J. and Adams, M. 2002. The tree-crop interface: The effects of root pruning in south-western Australia. *Australian J. Exp. Agric.,* 42: 763–772.

Venskutonis, P.R. and Kraujalis, P. 2013. Nutritional components of amaranth seeds and vegetables: a review on composition, properties and uses, *Comprehn. Rev. Food Sci. Food Saft*., 12: 381–412.

Zamora, D., Jose, S. and Nair, P.K. 2007. Morphological plasticity of cotton roots in response to interspecific competition with pecan in an alley cropping system in the southern United States. *Agrofor. Sys.,* 69: 107–116.