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Agroforestry practices under boundary planted mahogany trees in charland based farming system

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Abstract: The experiment was conducted in South char Kalibari situated at the bank of Brahmaputra river adjacent to the Bangladesh Agricultural University, Mymensingh, during the period from August 2018 to July 2019 to observed the performance of rice, okra and kangkong in combination with seven years old boundary planted mahogany trees as agroforestry practice. Mahogany trees were planted in south, north and west direction of the experimental field during the year 2011 maintaining plant to plant 10ft. distance. Along with mahogany tree rice was cultivated during aman season under irrigated condition. Okra and kangkong were cultivated during summer season. In each orientation i.e. south, north and west, three distances viz. 0-12 ft., 12-24 ft., 24-36 ft. etc. were selected for crops cultivation which were considered as the different treatments of this study. Rice, okra and kangkong also cultivated without mahogany tree combination in the respective season which was the control treatment of this study. For each crop total ten treatments {1 + (3x3) =10} in control, south, north and west side were defined as T_0, T_1, T_3, T_4, T_5, T_6, T_7, T_8 and T_9 respectively. Different growth and yield characteristics of rice, okra and kangkong were observed under the above-mentioned treatments. It was found that growth and yield of rice significantly influenced by orientation and distances but orientation effect was non-significant in case of okra and kangkong. Yield of all tested crops gradually decreased towards the base of mahogany. Due to shade effect or orientation effect on rice yield also varied in different orientation which results more yield reduction in case of rice. Average yield reduction of all treatments in rice, okra and kangkong were 52.29, 27.26 and 26.60%, respectively. Average growth of mahogany trees almost similar with and without crops combinations. Land Equivalent Ratio (LER) of mahogany-rice, mahogany-okra and mahogany-kangkong are 1.37, 1.62 and 1.63, respectively. C:N ratio was slightly increased which indicate better soil health after the experimental study. Considering the LER analysis and increased C:N ratio, it is clear that mahogany-rice-okra and mahogany-rice-kangkong will be profitable agroforestry technology for charland based farming system.
Key words: Agroforestry practice, Mahogany tree, charland, boundary plantation, farming system.

Introduction

With the rapid growth of the world's population, the population of Bangladesh is growing rapidly which is now 165 million and the population densities is now 1265 per Km^2 (3,277 people per $mile^2$). It is the eighth-most populated country in the world with almost 2.2% of the world's population. 39.4% of the total population lives in urban areas (65 million) (Worldometer, 2020). The area of the country is 1, 47,570 sq. k.m (56,977 sq. miles) of which 86 lakh hectares is cultivable land (BBS, 2018). According to the United Nations, more than 7 billion people populated the Earth in 2011 and this number is expected to go up to 9.3 billion by the mid-century. To meet the demand for food by 2050, production will have to increased by over 60% (FAO, 2018). Population is growing rapidly but the amount of land is not increasing but decreasing day by day for the construction of new houses, factories, roads and highways, brickfields, hospitals, educational establishments, religions institutions and other infrastructure etc. The ever-growing population per capita land area is decreasing at an alarming rate of 0.005 ha/cap/year since 1989 (Hossain and Bari, 1996). The agriculture sector plays an important role in economic development as well as food security of this highly populated country. Agriculture sector contributes about 13.82% to the country`s Gross Domestic Product (GDP) and employs around 40.60% of total labour force (BBS, 2019).

Forestry plays an important role in maintaining environmental equilibrium and socio-economic implementation of the people. A country needs 25% forest land of its total area for ecological stability and sustainability. Unfortunately, Bangladesh is endowed with only 17% of unevenly distributed forests (BBS, 2013). Estimated present wood demand of the country is about 13.2 million cubic meters. Against this current demand, the supply of wood is about 8.57 million cubic meters (BFRI, 2019). A large gap is being observed between the demand and supply of timber. Demand for wood products is likely to grow due to increasing population and their affordability. On the other hand about 10% of the homestead trees are being removed annually without any replacement (Abedin and Quddus, 1991). Therefore, since there is no opportunity of increasing natural forest area to meet the domestic demand for wood and fuel, the only way to increase the forest is by planting trees.

With the growing population, the need for more productive and sustainable use of land has become more urgent. In the current worrisome situation, modern and new strategies need to be used to increase agricultural production as well as forest resources. Some strategies have been suggested to overcome the next challenge, agroforestry is one of them. Agroforestry, the integration of tree and crops/vegetables on the same area of land is a promising production system for maximizing yield (Nair, 1990) and maintaining friendly environment. Growing of crops/vegetables in association with trees is becoming popular day by day for their higher productivity, versatile/multipurpose use and environmental consciousness among the peoples (Sheikh and Khaleque, 1982). The combination of agriculture, silviculture and pasture with attributes of productivity, sustainability and adoptability is Agroforestry. The scope of agroforestry is wide in Bangladesh. Homestead, cropland, farm boundary, roadside, railway side, embankment side, charland, coastal area, deforested area, institutional premises, riverside etc. are major venues for agroforestry practices. Among them charland is the most important venue for practicing agroforestry systems. In small-scale farming areas boundary planting is usually enough to reduce wind speed and there is no need to establish windbreaks. Trees on boundaries which are regularly pollarded can meet most of a family's need for firewood and further it can be a big source of good quality wood. It helps in soil conservation and the boundary is effectively demarcated. The edges (boundary) of crop fields remain fallow. To utilize this fallow land, trees are planted on field boundary. When trees are established in field boundary, proper management practices are necessary, to reduce the harmful effect of tree on crop.

Mahogany (*Swietenia macrophylla*) is one of the world's most valuable timbers. It grows all over the country for their wider range of adaptability. Mahogany trees provide the largest amount of wood in the country. Excessive parts of this tree are used as fuel wood and other purposes. Being a deep root tree, it prevents soil erosion and for that it is very suitable for char areas. Mahogany is very popular tree species for boundary plantation surrounding the field. Growing of this economic tree zonally or sequentially along with crops on the same area of land that promising production system for maximizing yield and maintaining friendly environment known as "Agri-silvicultural system" (Craig and Elevitch, 2000).

Bangladesh has a long history of rice cultivation and it grown throughout the country except in the southeastern hilly areas. The agroclimatic conditions of the country are suitable for growing rice year-round. However, the national average rice yield is much lower (2.94 t/ha) than that of other rice-growing countries (BBS, 2012). Total rice production in Bangladesh is about 3 crore 38 lakh metric tons (BBS, 2018). Rice is the staple food for the people of the country. Vegetables are rich sources of essential vitamins such as A, C, niacin, riboflavin and thiamin and minerals such as calcium and iron. They contribute to the intake of essentials nutrients from other foods by making them more palatable. They provide dietary fiber necessary for digestion and health and are essential for maintaining health curing nutritional disorders (Terry and Leon, 2011). Among the different vegetables, Okra and Kangkong are the most important vegetables in Bangladesh. These are well known and very popular vegetables grown successfully during summer season in Bangladesh. In Bangladesh, the average per capita daily vegetable intake is 56g per day, whereas the recommended intake is 250g/day (FAO, 2015). The area under vegetable cultivation accounts for only 2.56% of the total cropped areas. From this small proportion of the cultivable land area, Bangladesh produces about 1.76 lac metric tons of vegetables annually, of which about 65% are produced in winter and the rest in summer. Therefore, production is not well distributed throughout the year and produce for domestic use is relatively scarce in the off-season (DAE, 2016). Considering the above-mentioned facts and potentiality present study was undertaken to investigate the Agroforestry practices under boundary planted mahogany trees in charland based farming system in the Char Kalibari in the bank of Old Brahmaputra River.

Materials and Methods

Experimental site: The experiment was conducted in Char South Kalibari of Old Brahmaputra River during the period from August, 2018 to July, 2019. The geographical position of South Char Kalibari located between 24˚45' - 24˚45'40" North and 90˚24'4" - 90˚24'44" East Latitude (Fig.1).

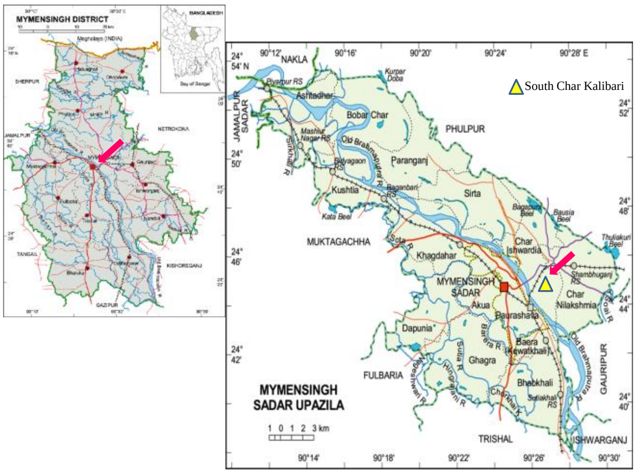

Figure 1. Geographical position South Char Kalibari

Tree and crop materials: In this study, seven years old mahogany tree was used as silvicultural component, rice (*Oryza sativa*)) was cultivated during aman season under irrigated condition, okra (*Abelmoschus esculentus*) and kangkong (*Ipomoea aquatica*) were cultivated during summer season as agricultural components.

Mahogany tree establishment and its management: Mahogany trees were planted in south, north and west direction of the experimental field during the year 2011 maintaining plant to plant distance 8ft. row to row distance 4 ft. In all directions mahogany trees are planted in double rows. Generally planting spacing of mahogany tree is 12 × 15 ft (plant to plant and row to row). As a result, number of trees under boundary plantation and normal plantation are almost same. Beginning of this study the age of mahogany trees was 7 (seven) years. Before crops (rice, okra and kangkong) cultivation necessary pruning for each mahogany tree was done to ensure light for cultivated companion crops during respective winter and summer season. To ensure proper growth of all mahogany trees, necessary management activities like watering, cleaning, weeding, fertilizing etc. were done in time. Growth and yield performance of mahogany trees were recorded with and without crops combinations.

Land preparation and crops cultivation: Land was prepared by ploughing during September 2018 for rice cultivation and for okra and kangkong cultivation it was prepared during March 2019. Rice (BRRI dhan 30), okra (BARI Dherosh-2) and kangkong (BARI Gimakolmi-1) after land preparation in each season following appropriate research method. Necessary cultural operations viz. thinning, gap filling, irrigation, pest and disease management were done for each crop in proper time.

Experimental design, layout and treatment combination: Single factorial Randomized Complete Block Design (RCBD) with three replications was used for winter and summer season crops cultivation. Layout of this experimental studies are shown in figure 2. Interaction effects of mahogany tree viz. shade effect and root competition were observed in south side, north side and west side separately. In each side i.e. south, north and west, three distances viz. 0-12 ft., 12-24 ft., 24-36 ft. etc. were selected for data collection which were considered as the different treatments of this study. Rice, okra and kangkong were also cultivated without mahogany tree combination which was the control treatment of this study. The treatments were- T_0 = Control area (without tree); T_1, T_2 and T_3 were 0-12 ft., 12-24 ft. and 24-36 ft., respectively distance from tree base at south orientation; T_4, T_5 and T_6 were 0-12 ft., 12-24 ft. and 24-36 ft. respectively distance from tree base at north orientation; T_7, T_8 and T_9 were 0-12 ft., 12-24 ft. and 24-36 ft. respectively distance from tree base at north-west/south-west orientation. Average of north-west and south-west considered as west direction. Total ten treatments {1 + (3×3) =10} in control, south, north and west side were defined as T_0, T_1, T_3, T_4, T_5, T_6, T_7, T_8 and T_9 respectively.

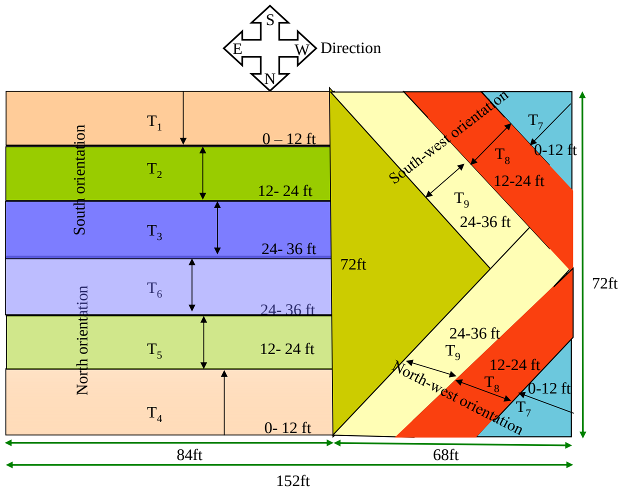

Figure 2. Layout of the experiment

Harvesting, Sampling and Data collection: Growth and yield of different studied crops were recorded following different procedure. Rice growth and yield parameters of were collected at harvesting stage. For data collection plant samples were selected randomly from all the treatments of the plots. The studied parameters were plant height, no. of tiller hill^{-1}, no. of panicle hill^{-1}, no. of filled grain hill^{-1}, no. of unfilled grain hill^{-1}, 1000 seed weight (g) and grain yield (t ha^{-1}). Rice was harvested after 90 days from the date of transplanting. Okra was harvested in several pickings when the fruits reached at edible size. The harvesting was stared at 45 days after planting (DAP) and ended at 101 DAPS. Plant height (cm), no. of fruits per plant, average single fruit weight (g) and fresh yield (t/ha) of okra were recorded. Kangkong was harvested four times at 15 days interval where the first harvest was done at 34 days after sowing. Plant samples of kangkong were collected randomly (1plant m^{-2} area) from the experimental field. Plant height (cm), no. of twig per harvest, weight per plant per harvest (g) and fresh yield (t/ha) of kangkong were recorded. Average total yield (volume) value of a mahogany tree was estimated with and without crops combinations by using the formula $\pi r^2 h$, where 'r' is average radius and 'h' is average bole height. Average 'r' value estimated from average GBH (Girth at Breast Height) values of all mahogany trees.

Land Equivalent Ratio (LER) and C:N ratio estimation: LER is the sum of relative yields of the component's species; i.e.,

$$LER = \sum_{i=1}^{m} (yi \div yii)$$

Where, 'yi' is the yield of the 'i' th component from a unit area of the intercrop; 'yii' is the yield of the same component grown as a sole crop over the same area; and (yi ÷ yii) is the relative yield of component i. In this study LER will be measured for mahogany-rice, mahogany-okra and mahogany-kangkong separately. Organic carbon and nitrogen content ratio (C: N) were determined by dividing the value of organic carbon content in soils by total nitrogen content in soils. For this purpose, soil samples were collected before winter season and after summer season. All collected soil samples was analyzed in the Humboldt soil testing laboratory, Department of soil science, Bangladesh Agricultural University, Mymensingh.

Statistical analysis: All recorded data of rice, okra and kangkong were compiled and analyzed by RCBD design to find out the statistical significance of the experimental results. The means for all recorded data of three studied crops were calculated and analyzed statistically by using 'WASP 2' software package to find out the statistical significance of the experimental results for all growth and yield parameters were performed. The mean differences were evaluated by Duncan's Multiple Range Test (DMRT) (Gomez and Gomez, 1984) at 5% level of significance and also by Least Significance Difference (LSD) test.

Results and Discussion

Performance of rice with mahogany trees:
Growth and yield performance of rice significantly influenced by mahogany trees in different orientation at different distances (Fig. 3). Growth, yield contributing characters and yield of rice of this study are separately presented as:

Figure 3. Rice cultivation in association with mahogany trees

Growth and yield contributing parameters:

Plant height: Plant height of rice in association with mahogany tree was affected significantly due to the effect of different treatments (Table 1). The results noted that the highest plant height 68.68cm (Table 1) were recorded control condition (T_0). The second highest plant heights were recorded as 67.25cm in treatment T_3 which were statistically similar with the treatment T_6 and T_9 where the values were found 67.21 and 66.76cm respectively. Relatively shorter plant (52.28cm) was produced in the treatment T_7 (Table 1). Near the tree base plant heights were lower may be due to competition for sunlight, different nutrient elements and moisture between the root system of rice and mahogany tree. Bithi *et al.* (2014) and Rakib *et al.* (2013) were observed lower plant height in brinjal and radish very near the base of *Xylia dolabriformis* and mango tree.

Table 1. Morphological and yield contributing parameters of rice in association with boundary planted mahogany trees

Treatments	Plant height (cm)	Number of tillers hill^{-1}	Number of Panicles hill^{-1}	No. of filled grains hill^{-1}	No. of unfilled grains hill^{-1}	1000 seed weight (g)
T_0	68.68 a	10.11 a	8.13 a	40.33 a	6.12 g	28.45 a
T_1	62.22 e	5.55 f	4.50 f	34.21 f	12.43 c	20.68 f
T_2	65.29 c	7.58 d	6.12 d	36.88 cd	10.76 d	23.35 d
T_3	67.25 b	9.12 b	7.65 b	38.49 b	7.93 f	25.61 b
T_4	63.42 d	5.28 f	4.34 f	34.16 ef	12.34 c	20.56 f
T_5	65.23 c	7.43 d	6.09 d	36.77 cd	10.68 d	23.28 d
T_6	67.21 b	9.09 b	7.43 b	38.42 b	7.88 f	25.56 b
T_7	52.28 e	4.04 g	3.25 g	33.76 f	15.25 a	18.38 g
T_8	64.26 cd	6.67 e	5.32 e	35.57 de	13.66 b	21.49 e
T_9	66.76 b	8.08 c	6.50 c	37.12 bc	8.36 e	24.76 c
$LSD_{0.01}$	1.09	0.277	0.311	1.34	0.308	0.484
Level of sign.	**	**	**	**	**	**
CV (%)	11.88	9.27	7.88	9.13	13.28	12.35

Mean in column followed by the different letter are significantly different by DMRT at P< 0.01; T_0 = Control area (without tree); T_1, T_2 & T_3 were 0–12 ft., 12-24 ft. & 24 - 36 ft. respectively distance from tree base at south orientation, T_4, T_5 & T_6 were 0-12 ft., 12-24 ft. & 24-36 ft respectively distance from tree base at north orientation, T_7, T_8 & T_9 were 0-12 ft., 12-24 ft. and 24-36 ft. respectively distance from tree base at west orientation.

No. of tillers per hill: Like plant height, number of tillers per hill of rice during combined production with mahogany tree was also affected significantly at different distances in different orientations (Table 1). The result indicted that the highest number of tillers per hill were 10.11 in control condition (T_0). The second highest number of tillers per hill were recorded as 9.12 in the treatment T_3 which was statistically similar with the treatment T_6 and T_9 where the values were found 9.09 and 8.08, respectively. The lowest number of tillers hill^{-1} were 4.04 produced by T_7. Singh *et al.* (1988) and Sutater (1987) also stated that the rice plants in shade free areas increases number of tillers and encouraged more photosynthesis resulting the higher production. In this study 7-8 years old mahogany trees created more shade which might be reduced photosynthesis assimilates as a results tillers production of rice reduced remarkably.

Number of panicles hill^{-1}: Significant variation in number of panicles hill^{-1} of *Aman* rice was also found due to different treatments grown in association with mahogany tree (Table 1). The result revealed that highest number of panicles hill^{-1} was 8.13 were produced by T_0 (control area). The number of panicles hill^{-1} 7.65 were produced by T_3 which were statistically similar with T_6 (7.43) and the lowest (3.25) was produced by T_7 i.e. 0-12 ft distance from tree base at west orientation. Control produces the best result due to the absence of negative interactions effects by mahogany trees. Vitryakon *et. al.* (1993) determined negative interactions of overstorey plant components increase non-effective tillers, decrease tiller and panicle number hill^{-1} and grains panicle^{-1} and also decreased grain yield of rice during intercropping with trees.

Number of filled grains hill^{-1}: As evidence from the results of this study, it was observed that number of filled grains hill^{-1} of rice in association with mahogany tree was significantly affected by different interaction effect (Table 1). The highest number of filled grains hill^{-1} (40.33) was produced by T_0 because control treatment shown the best result due to the absence of shading effect. The second highest number of filled grains hill^{-1} (38.49) was produced by treatment T_3 which was statistically similar with (38.42) was produced by treatment T_6 and the lowest (33.42) was produced by T_7 (0-12 ft distance from tree base at west orientation) which was statistically similar with T_1 (34.21). Singha *et al.* (2015), reported a smaller number of filled grain of rice during combined production with 5 years old *Acacia auriculiformis* tree due to different negative interactions of this trees.

Number of unfilled grains hill^{-1}: Unlike filled grain of no. of unfilled grains hill^{-1} of rice under mahogany tree was the significantly increases towards the mahogany tree base in different orientation (Table 1) where the more unfilled grains hill^{-1} (15.25) was recorded in T_7 followed by treatment T_8 (13.66). In north and south orientation number unfilled grain gradually decreased with increasing distances from mahogany tree base (Table 1). Due to more shade creation in west direction unfilled grain increases in this direction in other directions (north and south) shade cast relatively lower compare to west direction as a results unfilled grain of rice bit lower in these directions. But, competition for other growth resources (water and nutrients) was almost similar in all directions. Similar type of interaction was observed by Vitryakon *et. al.* (1993) and Milon (2009) in case of wheat with tree saplings.

1000 seed weight (g) and yield (t/ha): Similar type of effect of mahogany tree was observed for 1000 seed weight (Table 1) and yield (Fig. 4). Yield and yield contributing characters of rice gradually decreased towards the mahogany tree base in all direction (Table 1 and Fig. 4). But relatively higher reduction was recoded in west direction due to more shade cast. As earlier mentioned, competition for different growth resources are common things in agroforestry practices as a result yield performance of rice was lower near the base of mahogany trees.

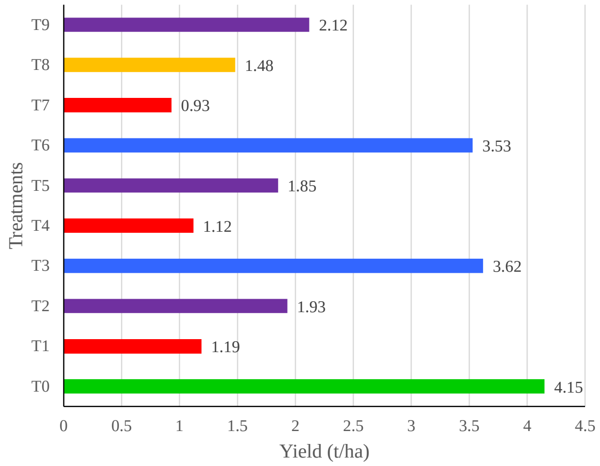

Figure 4. Yield of rice in different treatments with mahogany trees

Among the different orientation, highest yield reduction was found in west direction where 77.6, 64.3 and 48.9% reduction were recorded in 0-12, 12-24 and 24-36 ft. distance from tree base i.e. in the treatments T_7, T_8 and T_9. Similar type of yield reduction was recorded in south (T_1-71.3%, T_2-53.5% and T_3-12.8%) and north (T_4-73%, T_5-55.4%and T_6-14.9%) direction but numerically slight increase reduction was found in north direction (Fig. 4). Lower grain yields under shade were due to the cumulative effect of reduction in the number of effective tillers hill^{-1}, number of grains panicle^{-1} and increase in non-effective tillers hill^{-1}. Similar results have been reported by Jadhav (1987), Chaturvedi and Ingram (1989).

Performance of okra and kangkong with mahogany trees:

Growth and yield performance of okra and kangkong in association with mahogany trees effectively influenced (Fig. 5). Results regarding growth and yield of okra and kangkong are as:

Growth parameters of okra and kangkong: Different growth parameters of okra and kangkong significantly affected in different distances from mahogany tree base but effect of orientation was non-significant (Table 2). In case of okra, plant height (cm), number of fruits per plant, average single fruit weight (g) was recorded. It was found that, all studied parameters of okra shown similar trend of variation where highest values of all parameters recorded in control condition which were statistically similar with the treatment T_3, T_6 and T_9 (Table 2).

Figure 5. Okra and Kangkong cultivation in association with mahogany trees

Almost similar values were recorded in the treatments T_2, T_5 and T_8 which were the second highest values of all growth parameters of okra. Numerical values of these parameters of okra were lower and almost similar in the treatments T_1, $T_4$and T_7 which were nearest distances from mahogany trees in south, north and west direction (Table 2). In case of kangkong, number of twigs per harvest, weight per plant per harvest (g) were also significantly influenced by mahogany trees and trend variation was almost similar with variation trend of okra (Table 2).

Table 2. Morphological and yield contributing parameters of okra and kangkong in association with boundary planted mahogany trees

Treatments	Okra			Kangkong		
	Plant height (cm)	Number of fruits plant^{-1}	Av. Single fruit weight (g)	Plant height (cm)	No. of twig plant^{-1} harvest^{-1}	Weight plant^{-1} harvest^{-1}
T_0	153.55 a	58.50 a	13.5 a	29.75 c	10.35 a	301.83 a
T_1	123.45 c	47.00 c	10.85 c	32.40 b	8.31 c	243.04 c
T_2	132.75 b	50.54 b	11.66 bc	31.51 b	8.94 b	261.35 b
T_3	149.50 a	56.92 a	13.14 a	30.44 bc	10.07 a	294.33 a
T_4	123.87 c	47.16 c	10.89 c	33.22 a	8.34 c	243.88 c
T_5	133.50 b	50.83 b	11.73 b	31.84 b	8.99 b	262.83 b
T_6	150.00 a	57.11 a	13.18 a	30.75 bc	10.10 a	295.31 a
T_7	126.18 c	48.04 c	11.08 bc	35.10 a	8.50 c	248.43 c
T_8	135.14 b	51.45 b	11.87 b	32.16 b	9.10 b	266.06 b
T_9	152.03 a	57.88 a	13.36 a	31.17 b	10.24 a	299.32 a
$LSD_{0.01}$	5.74	2.57	1.14	2.43	0.43	17.70
Level of sign.	**	**	**	**	**	**
CV (%)	11.77	12.08	13.97	13.24	11.92	12.77

But variation in plant height (cm) was different where orientation affect or shade affect was present as a result tallest plants were observed in west orientation in treatment T_6 (35.10cm) and relatively shorter and stout plants (29.75) were found in without mahogany combination i.e. in control condition (Table 2). Kangkong plants were relatively taller in the shady area may be due to apical dominance of kangkong. Shade condition enhance apical dominance which results taller plants and less leaves plant^{-1}, twig plant^{-1}, stem girth (Hillman, 1994). Similar Phenomenon also found by Najafi *et al.* (1997) in soybean, Wadud *et al.* (2002) in red amaranth and Tanni *et al.* (2010) in tomato.

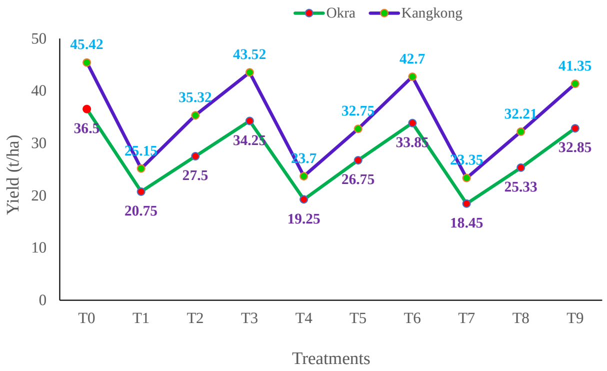

Figure 6. Yield of okra and kangkong in different treatments with mahogany trees

Yield of okra and kangkong: Like growth parameters, yield of okra and kangkong significantly influenced in different distances from mahogany tree base but effect of orientation was non-significant (Fig. 6). Statistically similar and highest values of okra and kangkong were recorded in the treatments T_0, T_3, T_6 and T_9 where the values were 36.50, 34.25, 33.85 and 32.85 t/ha and 45.42, 43.52, 42.7 and 42.35 t/ha, respectively (Fig. 6). Yield of both crops gradually decreased towards the base of mahogany trees in all orientations. As a result, relatively lower yield was recorded in the treatments T_1, T_4 and T_7 and the values were 20.75, 19.25 and 18.45 t/ha and 25.15, 23.70 and 23.35 t/ha, respectively (Fig. 6). Yield reduction of okra and kangkong in 0-12 ft., 12-24 ft. & 24-36 ft. distances area from mahogany tree base were 46.62-47.01, 27.32-26.41 and 7.81-6.38%, respectively, which indicates near the base of mahogany trees yield reduction of both crops was more prominent. This prominent yield reduction towards base mahogany trees might be due to competition for moisture and nutrients. Generally, in agroforestry system components yield reduce due to resource competition (Rao, *et al.* 1998; Puri and Bangarwa, 1992; Dhillon *et al.* 1998). Yield reduction in all orientation (south, north and west) was almost similar which indicates shade effect was not responsible for the yield reduction of these crops. Moreover, okra and kangkong can tolerate 25-30% shade condition reported by Wadud *et al.* (2000, 2001).

Land Equivalent Ratio (LER): The term LER is derived from its indication of relative land requirements for intercrops versus monocrops. LER help to evaluate the comparative efficiency of a component in a combination compared to single stands of that species. In this study, yield of rice, okra and kangkong were recorded separately as sole crops and intercrops also (Figures 4 and 6). During the end of this study mahogany tree was eight years old. Average total yield (volume) value of a mahogany tree was estimated with and without crops combinations (Table 3). In this study, LER of different mahogany-based agroforestry combination was estimated from the relative yield of different components species (Table 4). LER of mahogany-rice, mahogany-okra and mahogany-kangkong are 1.37, 1.62 and 1.63, respectively. LER values of all mahogany-based crop combinations are more than one which indicate better use of resources or positive interaction between the components. So, based on the LER results it may be concluded that all of these mahogany based agroforestry practices will be profitable for charland based farming system. Based on the above information, mahogany-rice-okra / mahogany-rice-kangkong will be the profitable cropping pattern for charland based agricultural production system. Based on LER analysis Faruk *et al.* (2018) and Alam *et al.* (2014) also developed guava and *Acacia auriculiformis* based agroforestry models for charland ecosystem.

Table 3. Average yield (volume) of a mahogany tree

Crop combination	Av. GBH (ft.)	Av. RBH (ft.)	Av. bole height (ft.)	Total yield (8years) (cft.)	Av. yield/years (cft.)
With crops	1.83	0.29	21.10	5.57	0.70
Without crops	1.86	0.30	22.10	6.25	0.78

GBH/RBH = Girth /Radius at beast height

Table 4. Land Equivalent Ratio (LER) of mahogany tree-based agroforestry models

Agroforestry model	RY of mahogany (a)	RY of rice/okra/kangkong (b)	LER (a + b)
Mahogany-Rice	0.89	0.48	1.37
Mahogany-Okra	0.89	0.73	1.62
Mahogany-Kangkong	0.89	0.74	1.63

RY = Relative yield

C:N ratio: Organic carbon (C) and total nitrogen (N) percentage of soil in this study was estimated before and after the crop growing season (Table 5). Based on Organic carbon (C) and total nitrogen (N) percent content in the soil C:N ratio was also estimated (Table 5). Existing C:N ratio was 9.75:1, after rice cultivation it was 9.96:1 and after end of all crops cultivation it was 10.10:1 (Table 5). C:N ratio slowly increased after the crop cultivation which indicate soil organic health not depleted by mahogany based agroforestry practices.

Table 5. C:N ratio of mahogany based agroforestry practices in charland ecosystem

Sampling	Org. C (%)	Total-N (%)	C:N Ratio
Before rice cultivation	1.199	0.123	9.75
Before okra/kangkong cultivation	1.205	0.121	9.96
After rice/okra-kangkong cultivation	1.212	0.120	10.10

Rice, okra and kangkong was cultivated under boundary planted mahogany trees in charland based farming system in different distances from tree base at south, north and west orientation. It was found that effect of orientation and distances was combinedly affected the performance of rice but effect of orientation was not found in the performance of okra and kangkong. Based on LER analysis all tested crops with tested trees viz. mahogany-rice, mahogany-okra and mahogany-kangkong was profitable due to better use of moisture and nutrients. C:N ratio analysis also confirm that soil organic carbon i.e. organic matter was slowly increased in mahogany based agroforestry practices. Moreover, established mahogany tree also tolerate flooding situation ≥ 15 days. Considering these facts mahogany-rice-okra and mahogany-rice-kangkong will be the profitable agroforestry models for charland based farming system.

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