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Transforming jackfruit orchard into agroforestry system with different crops for improving productivity, profitability and land uses

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ABSTRACT

Various traditional and new agroforestry systems are being practiced in different ecosystems of Bangladesh with unique opportunities for providing better services and benefits. Jackfruit based agroforestry systems are found in terrace ecosystem. Farmers are not getting the desired benefits from the system due to poor management and lack of knowledge. A jackfruit orchard was transformed into multistory agroforestry system to study the productivity and profitability of the system from 2011 to 2013 in terrace ecosystem of Bangladesh. In transforming, jackfruit trees were kept as upper-story and papaya and eggplant were grown as middle-story and lower-story crops, respectively. Good panting materials, inputs and improved technological supports were provided along with direct observation. Jackfruit yield was increased by 32.65% in agroforestry system due to benefits received from fertilizer and irrigation management used for the middle- and lower-story crops. On the contrary, papaya and eggplant yields were reduced by 22.8 and 17.4%, respectively, when grown in agroforestry system. However, the overall yield in multistory agroforestry system was increased remarkably. Better field environment in terms of soil moisture and temperature was positively maintained in jackfruit based multistory agroforestry system. At middle-story, light availability on papaya was 55.5%, while the light availability at lower-story crop (eggplant) was 30.8%. The benefit-cost ratio and land equivalent ration for jackfruit-papaya-eggplant based multistory agroforestry system were 5.47 and 2.59, respectively. Beside high productivity, multistory agroforestry system may also create employment opportunity, supply biomass and ensure income generation that ultimately improve the livelihood of the farmers living in terrace ecosystem.

Introduction

Increasing population and urbanization coupled with land degradation, soil salinization and global warming are causing food and nutritional insecurity in Bangladesh. Although the production of vegetables and fruits have increased remarkably in last couple of years, still there is large gap between demand and supply (BBS, 2013). On an average, an adult Bangladeshi consumes 166.1 g and 44.7 g of vegetables and fruits per day against the minimum dietary requirement of 200 g and 100 g, respectively (NFPCSP and DDP, 2013). To meet the demand, the country imported 124.28 million US$ of fruit and 573.76 million US$ of vegetables in 2013-14 financial year (Anonymous, 2015). The limited production exerted pressure on nutritional security especially women and children in Bangladesh (FAO, 2003). It is nearly impossible to expand vegetable and fruit growing areas in rice based agricultural system of Bangladesh. Therefore, a combined production system that sustains in providing food, timber, fuelwood, fodder, fruits and poles etc. should be introduced under changing climate.

A production model that offers higher production, ensures environmental and socioeconomic benefits and conserve plant diversity is being advocated (Harvey et al., 2008; Ouinasavi and Sokpon, 2008; Singh et al., 2015). Well-planned intervention with new crops, local knowledge and enterprises, and scientific approaches are important in development of production system (Agbogidi and Adolor, 2013). Agroforestry, the integration of trees and food crops on the same area of land, is a promising way to increase production (Nair, 1990). It ensures various products, services and shelters that sustains food production, increases household income and

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improves the ecological condition. Moreover, perennial component of agroforestry system can be considered as carbon sink, create landscape small forest alike, compared to monoculture (Rasul and Thapa, 2006). Agroforestry system having multipurpose tree plantation helps to increase soil fertility, supplies fuelwood, creates employment and improves socioeconomic condition of the farmers (Alam 2004).

Various traditional and new agroforestry systems are practiced in different ecosystems of Bangladesh. Although agroforestry systems are prevailed throughout the country, specific agroforestry systems are found in specific ecosystems due to variations in topography, soil, water and climatic reasons as well as socioeconomic settings. Nowadays, several new agroforestry production systems based on both fruit and timber species are practiced by the farmers (Miah and Hussain, 2005). Fruit tree-based systems are capable in providing higher economic return even under stressed growing conditions prevailing under the upland situations than the other annual crops (Bikash *et al.*, 2008). Many of the practices such as jackfruit-based system in terrace, date palm and palmyra palm-based system in southeast and mango-based system in northeast region are well suited on the smallholdings of Bangladesh characterized by sub-optimal management and subsistence farming conditions. These traditional agroforestry systems have been contributing to the livelihood systems of the rural households of Bangladesh by providing diversified products (Abedin and Quddus, 1990; Akter *et al.*, 1990).

Terrace ecosystem consists of 8% landmass of Bangladesh, which is considered as one of the most potential areas for agroforestry, because farmers practice different types of agroforestry systems from time immemorial. Agroforestry systems in terrace ecosystem have already become an integral part of the rural livelihood systems for centuries and play key role in providing household food and energy securities, cash income, employment generation, investment opportunities and environmental protection. Among the different systems, jackfruit-based agroforestry system is the most dominant one. Khan (2007) identified a large number of major and minor traditional and new agroforestry systems in terrace ecosystem of Bangladesh. Burmese grape-based agroforestry systems are also found as economically viable practice in some areas of terrace ecosystem (Alam, 2004). These systems are being managed traditionally with low technical and technological knowledges, which are responsible for low yields and benefits. Moreover, many sole jackfruit orchards are found widely, which are not well managed. These orchards usually featured with low capital inputs, poor yield due to using simple technology and integrating no cash crop. Therefore, it is imperative to suitable agroforestry model for augmenting the income and benefits of a farm. This study was designed to transform the jackfruit-based agroforestry system by transforming multistory system. This paper addresses the functional characteristics in terms of production, farm environment and economic return of jackfruit-based agroforestry system through transforming the existing practice.

Materials and Methods

The On-Farm study was conducted during 2011-2014 in Belabo upazila of Narsingdi district (Figure 1), which is under the terrace ecosystem of Bangladesh. A jackfruit orchard of 0.95 ha with 23 tree species was selected for the experimentation. The age of the trees varied from 10 to 25 years with unidentified varieties. Although the trees were not planted maintaining specific spacing, but there was enough space for growing understory crops. The owner was cultivating taro and turmeric in the orchard sporadically with minimum care and management. However, no management had been done for the jackfruit trees. Therefore, the productivity of orchard was poor.

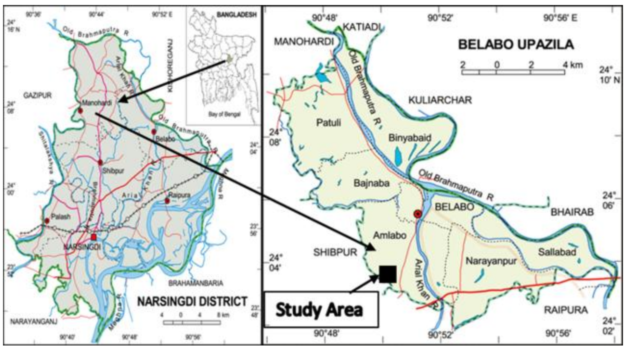

Figure 1: Location of the study area in Belabo upazila under Narsingdi district, terrace ecosystem of Bangladesh

The study area

The experimental site is situated at about 56 km away from the capital city Dhaka. The study site is located at the 23º 29´ North latitude and 90º10´ East longitude with a mean elevation of 8.0 m above sea level (FAO/UNDP, 1988). The soil of the experimental field belongs to the Madhupur Tract in agro-ecological zone (AEZ-28) and has been classified as shallow Red-Brown Terrace soil, which is nearly equivalent to Ustocharepts suborder under the order Inceptisol of USDA Soil Taxonomy (Brammer, 1971; Shaheed, 1984). The landscape comprises of upland, closely broadly dissected terrace associated with either shallow or deep valleys (BBS, 2011). Soils in the valleys are dark grey heavy clays. They are strongly acidic in reaction with low organic matter, moisture holding capacity and fertility level. The climate of the study area is characterized by tropical climatic with three distinct seasons; the monsoons or rainy season (June to October), the winter or the dry season (November to February) and the pre-monsoon or hot season (March to May). The average annual rainfall is 2050 mm with relative humidity of 60-70%. More than 80% rainfall occurs during monsoon. Most precipitation falls in June (more than 407 mm), while December is the driest month (4 mm of rain). The precipitation difference between the driest and wettest months is about 400 mm. The temperature varies from a maximum of 34.2 ºC to a minimum of 12.6 ºC with an average annual variation of 9.8 °C. May and January are the warmest (averages 28.9 °C) and coldest (average 19.1 °C) months of a year (http://en.climate-data.org/location/969840/).

Establishment of multistory agroforestry

The existing practice was transformed to multistory agroforestry by keeping jackfruit (*Artocarpus heterophyllus)* trees as top-story. Papaya (*Carica papaya*) was established as middle-story crop and eggplant (*Solanum melongena*) was grown as lower-story crops (Figure 2). The land was opened in early September 2011 and then prepared thoroughly by ploughing and cross ploughing with power tiller followed by laddering to obtaining a good tilth. The weeds and stubbles were removed from the field and bigger clods were broken into smaller pieces. The soil particles were pulverized and the land was leveled uniformly for the experimentation. Similar procedures were followed during each cropping season. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. At least one jackfruit tree and its surrounding area were considered as a unit plot for a single replication.

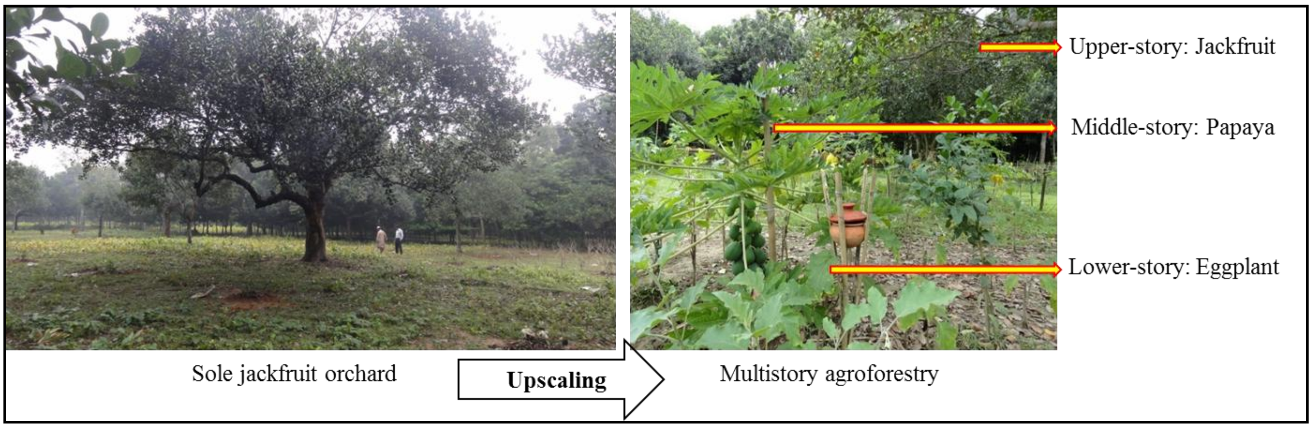

Figure 2: Transforming of jackfruit orchard to multistory agroforestry with jackfruit, papaya and eggplant

Test crops

Shahi papaya (released by Bangladesh Agricultural Research Institute) was used in first year (2012) experimentation, whereas a new variety BU papaya 1 (released by Bangabandhu Sheikh Mujibur Rahman Agricultural University) was planted in second year (2013). Shingnath, an elite eggplant variety, which is also locally popular, was used, which is released by Bangladesh Agricultural Research Institute (BARI). Pit size for papaya was 45 cm x 45 cm x 45 cm and row to row and plant to plant distances were 6 m and 2 m, respectively. The pits were prepared on January 24, 2012 for first year; and March 7, 2013 for second year. Forty days old seedlings were planted in pits on February 12, 2012 and March 22, 2013, respectively. Sufficient space between two rows of papaya plants were allowed for growing understory crop. The soils of the pit were mixed with fertilizer and decomposed cowdung, which were turned down again five days before transplanting the seedling. Thirty-five days old eggplant seedlings were transplanted on May 17, 2012 and May 05, 2013, respectively maintaining 75 cm x 75 cm spacing.

Management practices

In case of papaya, 15 kg decomposed cowdung, 210 g N, 100 g P, 225 g K, 45 g S, 3.5 g B and 7 g Zn were applied per pit. N and P were applied @ 50 g per pit in every month while new leaves appeared till flowering. After flowering, the rate of urea and MP application was doubled till final harvest (BARC 2012). Eggplant was fertilized at the rate of 5000 kg of cowdung, 115 kg N, 75 kg P and 78 kg K per hectare. The entire quantity of cowdung, P and half of N and K fertilizers were applied as basal dose at the time of final land preparation. The remaining N and K were applied in two equal installments at the time of flowering and fruiting.
Weeding for papaya and eggplant was done thrice (20, 40 and 60 days after sowing / transplanting) in a season for each crop. The plants were irrigated by watering-cane whenever required to supply sufficient soil moisture. Some seedlings of papaya and eggplant were attacked by virus that were uprooted and burnt immediately. Malathion 57 EC was applied at the rate of 2 ml l-1 for virus vector control each 25 days interval. Dithene M 45 was also applied at the rate of 2g lit-1 for protection against fungal disease after one month of seedling transplanting. Vilumeflexi Poison bait and sex pheromone were also used to reduce the infestation of insects.

Harvesting and data collection

Papaya was harvested twice a month from May 15 to November 15, 2012 and from April 02 to December 10, 2013. The eggplant was first harvested at 70 days after transplant (DAT). The second harvesting was done at 80 DAT, while the third, fourth, fifth and sixth harvestings were done at 90, 110, 130 and 150 DAT, respectively, in both the years.

Fruit length, fruit size and fruit weight of jackfruit, papaya and eggplant were measured during the harvests. Light was measured by LP-80 Accu PAR Ceptometer on each crop row as a function of distance from the tree base. It was done to determine the extent of shading by the tree species. Light intensities were measured above the canopy of crop in agroforestry plots and in the respective sole crop plots at 12:00-13:00 in every month.

Soil moisture was measured by PMS-714 Soil Moisture Meter and expressed as percent (%). Soil temperature was measured using Temp 4/5/6 Thermistor Thermometer. Soil moisture and temperature were measured at 10 cm depth adjacent to main root of crops in agroforestry plots and in the respective sole crop plots at 9:00-10:00 once a month and the collected data were averaged.

Analyses

Cost and benefit analysis was used to compare the benefits of the tested agroforestry systems with sole cropping. The costs and returns of each component (sole vegetables, vegetables in agroforestry systems, trees in agroforestry and sole trees) were analyzed. The fruit orchard establishment cost for individual fruit species was estimated based on the price prevailed in the year of 2011. Then fruit orchard establishment cost was divided by the orchard rotation period (life cycle) and found fixed cost for each year. The value of fixed cost was then added to the variable cost of experimental years and got total input cost per year. Finally, the total input cost for each year was calculated. The values of inputs and outputs used for the experimentations were calculated as prevailed in the local market during the study period. The labor wage rate was used that prevailed during the study period. The price of fuel wood was gathered from local dealers who used to buy from fuel wood producers and also from knowledgeable individuals who were aware about local market situation. The total cost included all cost items like labor cost, material cost, 9% interest of total cost, rental value of land and miscellaneous cost (5% of total cost).

Gross return is the monetary value of total products and by-products. Gross returns from by-products of vegetables, fruits and trees were calculated per hectare basis by multiplying the total amount of production by their respective market prices. Net return usually means the profit of the enterprises. Net return was calculated by deducting the total cost of production from the gross return.

Benefit-cost ratio (BCR) is the ratio of gross return with total cost of production. It was calculated by using the following formula (Islam *et al.*, 2004):

$$Benefit - cost\ ratio\ (BCR) = \frac{\text{Gross return}}{\text{Total cost of production}}$$

Land equivalent ratio (LER) is derived from its indication of relative land requirements for intercrops versus monocultures. LER helps finding the relative performance of a component of a crop combination compared to sole stands of that species (Mead and Willey, 1980). LER was measured as:

$$Land\ equvalent\ ration = \frac{Ci}{Cs} + \frac{Ti}{Ts}$$

Where, Ci is crop yield under agroforestry, Cs is crop yield under sole cropping, Ti is tree yield under agroforestry, and Ts is tree yield under sole cropping.

The data were statistically analyzed using the "Analysis of Variance" (ANOVA) technique with the help of computer package "Statistix 10.0" to examine the significant variation of the results due to different treatments. The mean differences were adjusted by Least Significant Different (LSD) at 5% level of significance (Gomez and Gomez, 1984).

Results

After transforming the sole jackfruit orchard, the new systems such as sole jackfruit, sole papaya, sole eggplant, jackfruit-papaya, jackfruit-eggplant and jackfruit-papaya-eggplant. In this paper, two-year performances of different systems of upscale agroforestry have been described.

Performance of jackfruit

Performance of jackfruit tree as upper-story component in terms of various parameters was measured before (sole) and after upscaling (agroforestry). The diameter at breast height (DBH) in sole system was 24.0 cm that rose to 24.6 cm in agroforestry system. Among 23 jackfruit trees in the field, about 60% trees gave economic production before transforming, which became more than 95% after transforming the system. Although individual fruit weight and fruit size decreased in agroforestry system compared to sole system, surprisingly the number of fruits per tree increased significantly in agroforestry system (52.26) over sole system (30.69). As a result, the total yield increased distinctly after transforming the sole jackfruit system.

Table 1: Performance of jackfruit tree in agroforestry system as compared to sole system during

Parameter	Year		Change (%)
	Before transforming (sole)	After transforming (agroforestry)	
DBH (cm)	24.0(±3.65)	24.6(±3.57)	2.4
Fruit bearing tree (%)	60.9(±2.44)	95.7(±2.86)	57.1
Fruit weight (kg)	16.3(±0.32)	12.7(±0.54)	-22.1
Fruit length (cm)	38.2(±2.04)	31.6(±1.43)	-17.3
Fruit width (cm)	76.3(±3.29)	60.3(±2.40)	-21.0
No. of fruits per tree	30.7(±4.21)	52.3(±3.98)	70.3
Total yield (kg tree^{-1})	499.1(±1.38)	662.1(±2.18)	32.7

Figures in parenthesis indicate the standard error (±SE) value

Performance of papaya

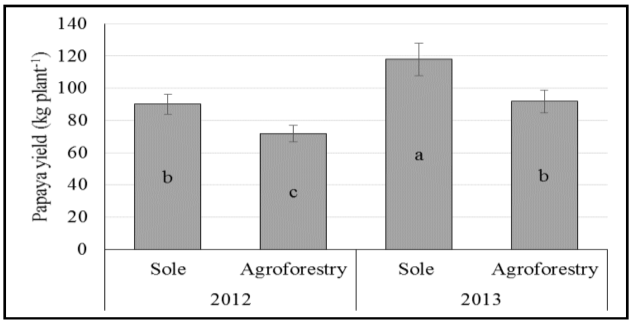

Figure 3: Fruit yield of papaya as sole and agroforestry crop in jackfruit based multistoried agroforestry system during 2012 and 2013. Columns followed by the same letter are not significantly different among the treatments at 5% level by LSD. Vertical bars indicate the ± SE values

Papaya yield was significantly (P<0.05) higher as sole crop than as agroforestry crop in both the years (Figure 3). Significantly the highest (117.97 kg) and lowest (71.75 kg) fruit yield per plant were recorded as sole in 2013 and as agroforestry crop in 2012, respectively. Yield difference in papaya between sole 2012 and agroforestry 2013 was insignificant (P<0.05).

Performance of eggplant

A significant (P<0.05) variation was observed in producing fruit yield per plant of eggplant as sole and agroforestry crops in both the years (Figure 4). The highest eggplant yield was noted when grown as sole crop in both the years, although it was significantly (P>0.05) higher in second year. Yield of eggplant reduced significantly (P<0.05) when grown in association with papaya and jackfruit tree as multistory crop. Eggplant yield did not vary significantly in both the years when grown only with jackfruit tree. Overall, significantly the highest (1.60 kg plant^{-1}) and lowest (0.61 kg plant^{-1}) yields were recorded as sole crop in 2013 and as multistory crop in 2012, respectively.

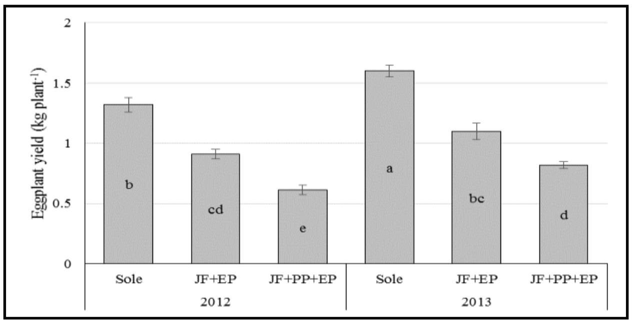

Figure 4: Fruit yield of eggplant as sole and agroforestry crop in jackfruit based multistoried agroforestry system during 2012 and 2013. Columns followed by the same letter are not significantly different among the treatments at 5% level by LSD. Vertical bars indicate the ± SE values. (JF-Jackfruit; EP-Eggplant; PP-Papaya)

Farm environment change

Light availability

Light in terms of photosynthetically active radiation (PAR) was measured at every month to know the light availability on associated crops in multistory agroforestry systems (Figure 5). Moreover, light intensity was measured at different layers of different components of the system. Light availability was found better during the months of April and September, which was lower during November to February. On the average, light availability reduced remarkably under jackfruit tree due to its dense crown cover. The average photosynthetically active radiation (PAR) was 1064.88 μmol m^{-2} s^{-1} in open condition (top of jackfruit tree), which was reduced to 506.30 μmol m^{-2} s^{-1} on papaya plant and the light interception was just over 50%. On the contrary, light availability at lower-story crop (eggplant) was severely reduced and the interception rate was 30.81% only.

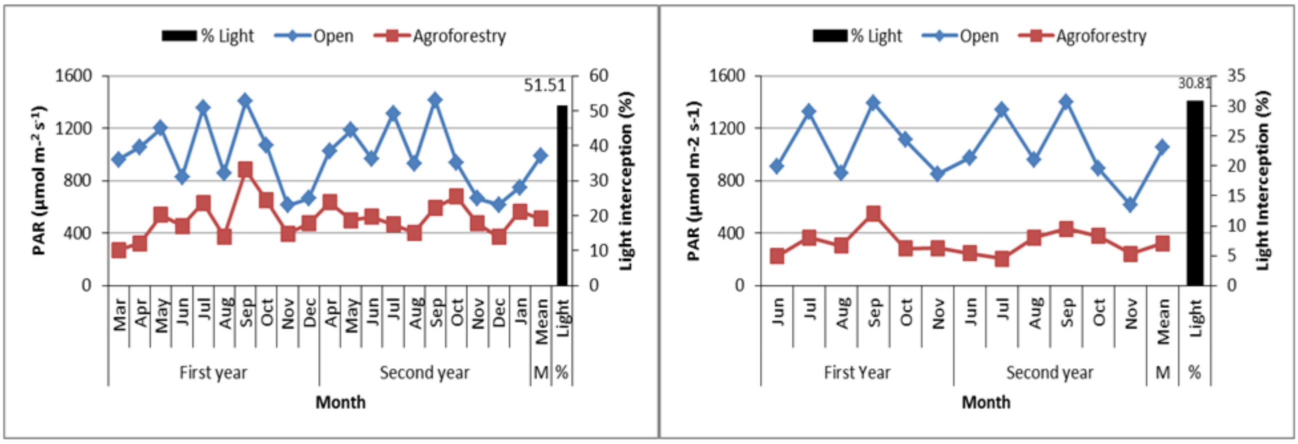

Figure 5: Light availability in jackfruit-papaya and jackfruit-papaya-eggplant agroforestry systems. Light in open condition was considered as same as on top of the jackfruit tree, while light in agroforestry was considered as the light interception by papaya plant

Soil moisture

An opposite trend was observed in case of soil moisture compared to light. In general, soil moisture content was lower in open field than that found in agroforestry systems (Figure 6). At all the measurement dates, the highest and lowest soil moisture contents were recorded in jackfruit-papaya-eggplant system and in open field, respectively, in both the cropping years. Soil moisture contents, regardless of the systems, were low during dry season (December through March), while the values were high during monsoon (June through August). However, the trends in both the years were almost similar. In most of the cases, soil moisture did not vary significantly ($P < 0.05$) between jackfruit-papaya and jackfruit-papaya-eggplant systems. Soil moisture in open field was significantly lower in open field compared to jackfruit-papaya-eggplant system. In the first year (2011-12), soil moisture was the lowest in December, whereas it was the lowest in January in the second year.

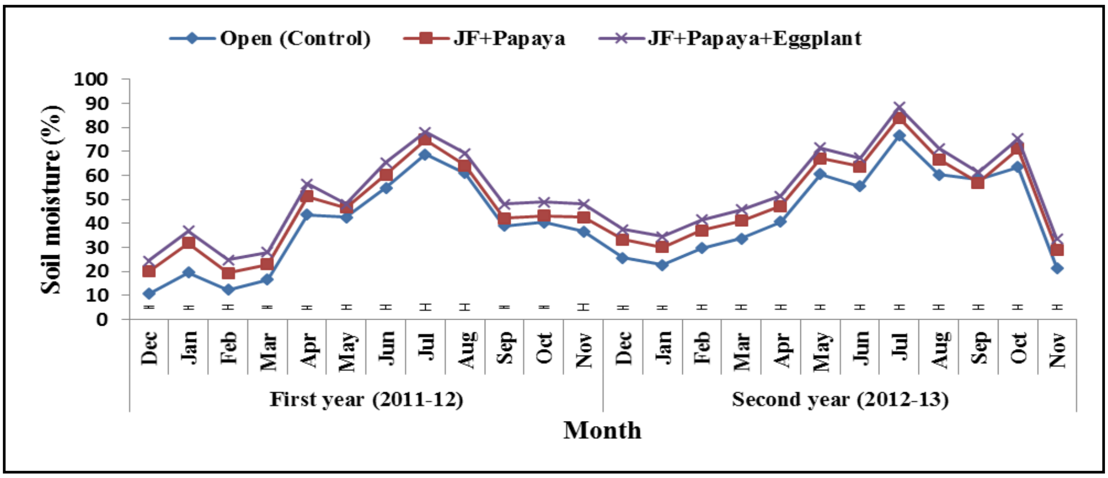

Figure 6: Soil moisture content in jackfruit-papaya and jackfruit-papaya-eggplant agroforestry systems. Soil moisture in open condition was considered as control treatment. Vertical bars indicate LSD values at 5% level of significance

Soil temperature

Monthly soil temperature was measured like light intensity and soil moisture content. It was observed that soil temperature in open field was remarkably higher than that of agroforestry systems. Overall soil temperature was low during winter and post monsoon seasons, while it was high during summer (pre monsoon) and monsoon seasons (Figure 7). From all the measurement dates, the different between jackfruit-papaya and jackfruit-papaya-eggplant was low, while it was high between open and jackfruit-papaya-eggplant systems.

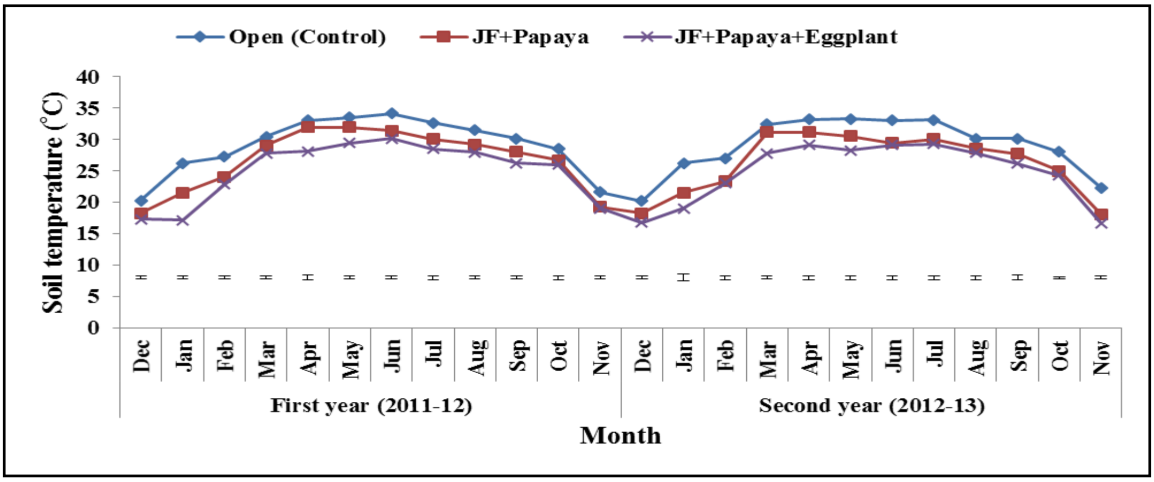

Figure 7: Soil temperature in jackfruit-papaya and jackfruit-papaya-eggplant agroforestry systems. Soil temperature in open condition was considered as control treatment. Vertical bars indicate LSD values at 5% level of significance

Economic benefit and land use

To know the economic performance and land use in jackfruit based multistoried agroforestry system over sole cropping, benefit cost ratio (BCR) and land equivalent ratio (LER) have been calculated and presented in Table 2. Benefit-cost ratio was higher in the second year (2013) as compared to the first year (2012) in all aspects and systems. The highest BCR was recorded in multistory agroforestry system (jackfruit-papaya-eggplant), which was followed by jackfruit-eggplant agroforestry system. The lowest BCR was noted in sole system and the ranking in view of understory crop's benefit was papaya followed by eggplant. In jackfruit based agroforestry systems, BCR was high when eggplant was cultivated as understory crop followed by papaya. The result revealed that multistory agroforestry system was economically profitable than the sole cropping.

Likely, LER was higher in agroforestry systems than sole cropping in both the years. The highest LER was noted in jackfruit-papaya-eggplant (2.59) multistory system followed by jackfruit-eggplant (1.82) and jackfruit-papaya (1.77) systems. However, the LER was remained same in both the years for jackfruit-eggplant system.

Table 2: Benefit-cost ratio (BCR) and land equivalent ration (LER) of different agroforestry systems and sole during 2012 and 2013

System	Benefit-cost ratio (BCR)		Land equivalent ratio (LER)	
	2012	2013	2012	2013
Jackfruit-papaya	3.64	4.80	1.76	1.78
Jackfruit-eggplant	4.63	5.26	1.82	1.82
Jackfruit-papaya-eggplant	5.32	5.62	2.58	2.60
Sole papaya	3.35	4.52	-	-
Sole eggplant	3.98	4.42	-	-

Discussion

Farmers in Bangladesh plant trees in their farms for income generation and household consumption. Farmers give emphasize on household income rather than food production in planting trees, while ecological functions of trees in the landscape are scarcely considered (Salam *et al.*, 2000). Labor requirement to establish and management of trees and lack of knowledge on growing crops in association with trees are considered as important constraints. Jackfruit tree-based agroforestry is being practiced in terrace ecosystem of Bangladesh since time immemorial (Miah and Hussain, 2005). Although some farmers are getting limited benefits from fruits, they are not managing the orchards scientifically to maximize the production. A jackfruit orchard of 0.95 ha was undertaken for upscaling existing system with scientific management packages including good planting materials, training, pruning, irrigation, fertilizers, pest control were followed to make the systems sustainable, profitable and productive. The study was conducted to evaluate the productivity and profitability of jackfruit based multistory agroforestry system at farmer's field. The multistory system was developed with jackfruit as upper-story, papaya as middle-story and eggplant as lower-story crops.

In general, farmers do not manage jackfruit orchards with irrigation, fertilizer and pest control. After transforming with improved management techniques, fruit bearing trees of jackfruit was increased by 57%. The number of fruits per tree of jackfruit was increased by 70.3% in agroforestry system over previous system and the total yield was increased by 32.7%. The yield improvement of jackfruit in agroforestry system may be explained by good crop management of the system by which jackfruit trees enjoyed irrigation water and fertilizer that were applied for middle and lower-story crops. Moreover, pest management was done to control trunk borer of jackfruit which also helped to reduce the fruit drop and increased the number of fruits per plant (Ahmed *et al.*, 2013).

A significant variation was found in fruit yield per plant of papaya and eggplant when grown in association with jackfruit tree compared to as sole crops. Papaya yield was significantly lower in agroforestry system, which was about 22%, compared to sole crop. Eggplant yield was 1.46 kg per plant, which reduced to 1.0 kg and 0.72 kg when grown in jackfruit and jackfruit-papaya based agroforestry systems. This is in good agreement with Sanou *et al.* (2012), who showed reduction of cereal production due to light reduction under tree crown. Yield reduction in agroforestry system was due to competition between tree and crop for light, water and nutrients. In this study, water and nutrient were not so much limited as these resources were applied for crop production. Therefore, light was the most limiting factor for multistoried agroforestry system. Moreover, the canopy of jackfruit tree was dense and light availability was low in agroforestry systems. Diffused light under agroforestry systems promoted the development of vegetative structures, while intense light favors the development of flowers, fruits and seeds (Weaver and Clements, 1973). Trees provide benefits to farmers and improve ecosystems by capturing and using water, light and/or nutrient resources, which may be underused in tree-less systems (Cannel *et al.*, 1996; Bellow, 2004). Yield improvement of tree component over crop component indicates the importance of the resources that are captured by the tree that the crop would never access (Bellow and Nair, 2003). Jackson *et al.* (2000), reported greater use of available soil moisture in agroforestry crops compared to sole crops. Water not used by the crops would be lost to evaporation or drainage, this equates with a more efficient use of available water resources in agroforestry.

Shade created by tree species certainly reduced the evaporation, while irrigation was done at regular interval that may increase the moisture status in agroforestry systems, whereas control plot contained lower soil moisture due to continuous evaporation. Soil temperature followed the opposite trend of soil moisture. Increasing soil moisture decreased the soil temperature under tree. In control plots, continuous evapo-transpiration correspondingly reduced soil moisture by increasing soil temperature. Therefore, higher soil moisture and favorable soil temperature conservation were observed in agroforestry system. This might be due to shade cast by the crown of jackfruit trees. In open field, sunlight was easily absorbed by the ground that penetrated to the root system, thus increased soil temperature; but in agroforestry system, light was first absorbed by the tree canopy and diffused light was absorbed by the ground that might be reason of low soil temperature in agroforestry system. Jonsson *et al.* (1999), found that soil temperature was decreased by 1 to 2 ºC under the dominant fruit trees of *Parkia biglobosa* (néré) and *Vitellaria paradoxa* (karité) in Burkina Faso. Reduced air temperature declines in vapor pressure deficits and relative humidity that can result in greater water use efficiency (Li *et al.*, 2002).

In the agroforestry systems, photosynthetically active radiation (PAR) is considered as the most limiting factor (Bayala *et al.*, 2008; Kessler 1992; Sanou *et al.*, 2012). Due to evergreen nature of jackfruit trees, understory crops and plants received about 30 - 60% light intensity compared to open field. Therefore, crop environment was favorable for understory crops. To increase light availability in agroforestry treatments, all the fruit tree species were pruned each year according to their tolerant level. Unlike other types of trees, fruit trees are often actively managed to present an open canopy allowing light and air penetration to fruiting sites and subsequently the crops beneath them (Horn, 1971). Light availability was found substantial (40-60%) in a pear orchard by Newman (1983); Marsal *et al.* (2002).

Between the agroforestry and sole systems, the highest net return from agroforestry system was observed because of good return from papaya and eggplant which was achieved because of less interaction effect for growth resources especially shade effect. Higher benefit-cost ratio has been reported in India when cash crop was introduced in fruit-tree-based systems (Appropriate Technology Centre, 2003). Likewise, land equivalent ratio (LER) helps in judging the relative performance of a component of a crop combination compared to sole stands of that species. The term Land Equivalent Ratio is derived from its indication of relative land requirements for intercrops versus monocultures (Mead and Willey, 1980; Vandermeer, 1998). The highest LER in jackfruit-papaya-eggplant multistory agroforestry system indicates about 2.59 times higher land would be required to get similar productions from sole cropping.

The overall yields from all components were increased significantly may be due to inputs supply, management practices and technological supports. A shallow tubewell was installed to ensure irrigation water even in dry season for all the components. The soils in the study field are acidic in nature and lime was used to neutralize the soil that made the soil environment favorable for crop cultivation. Lime application improves crop yield by eliminating the production constraints and favoring production factors related to nutrient availability (Rahman *et al.*, 2005). Yield improvement by applying lime in acidic soil was also reported for wheat (Rahman *et al.*, 2013; Kamaruzzaman *et al.*, 2013).

Conclusions

Fruit tree-based agroforestry systems have been found to increase production, income and production environment. Jackfruit yield was increased remarkably in agroforestry system due to benefits received from fertilizer and irrigation management for middle- and lower-story crops, while yields of associated crops (papaya and eggplant) reduced due to competition for resources among the components. Introduction of papaya as middle-story crop made the system more viable and economically profitable. The BCR and LER for jackfruit-papaya-eggplant system was the highest in both the years.

The study revealed that agroforestry practices would be lucrative than sole cropping for the farmers. Therefore, jackfruit orchards can be transformed to multistoried agroforestry system for maximizing production, generating income and conserving environment. Growing of vegetables throughout the year in association with trees may play significant additional benefits in increasing farm income and livelihood. This research may help increase farm productivity with vertical expansion of land use while yield sustainability is difficult to assess over a short period of time. A long-term study covering a number of farmers should be done to determine the sustainability of fruit tree-vegetable based multistoried agroforestry system. Below ground competition for nutrient was not intensively studied in this experiment, while the soil moisture and soil temperature were measured. The whole below ground competition for resources should be studied for better explanation of the findings as well as for efficient utilization of resources.

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