Performance of Spices as Lower-Storey Crop in Jackfruit-Papaya Multistorey Agroforestry System in Bangladesh

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Performance of Spices as Lower–Storey Crop in Jackfruit–Papaya Multistorey Agroforestry System in Bangladesh

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Jackfruit tree associated agroforestry systems are dominating in terrace ecosystem of Bangladesh, which are poorly managed by the farmers. As a result, real benefits of the systems are untapped. An On–Farm experiment was conducted during April 2017 to April 2018 in jackfruit orchards by transforming into multistorey agroforestry system (MAFS) in terrace ecosystem of Bangladesh to evaluate the productivity, economic and ecological performances of the system. Three spices (turmeric, ginger and chili) and papaya were grown as lower– and middle–storey crops, respectively. Established jackfruit trees were kept as top–storey crop. Four distances from tree base (1 m, 2 m, 3 m, and 4 m) and open field (non–agroforestry) were considered for the performances of spice crops, while performances of papaya and jackfruit were compared between agroforestry and non–agroforestry systems. The findings of the study revealed that the yields of chili and papaya were reduced by 15.06% and 26.83%, respectively, in MAFS than non–agroforestry. In contrast, the yields of turmeric, ginger and jackfruit were increased by 8.19%, 14.72%, and 27.06%, respectively. Results also showed that understory crop yields were increased with increasing distances from tree base. Light availability on understory crops varied between 15 and 35% at different distances from tree base. Soil moisture and soil temperature showed reverse pattern in agroforestry and non–agroforestry systems. Despite, some adverse effects on yield parameters of under–storey crops, the net return, benefit cost ratio (BCR) and land equivalent ratio (LER) were remarkably higher in MAFS than non–agroforestry system.

Key words: Benefit cost ratio, distances, light availability, non–agroforestry system, multistorey agroforestry

INTRODUCTION

Bangladesh hoard 162.7 million of people on its small land area of 147,570 km^2 and positioned 8th as the most populous country in the world (BBS, 2018). Reports anticipated that population of Bangladesh will augment to 220 million by the year of 2050 (UN, 2017). To feed the growing population, food crop production needs to be doubled by intensification of agriculture. Though the production of fruits and vegetables have been increased in last couple of years, yet the production is not enough and there is a huge demand (BBS, 2017). Although, Bangladesh agriculture contributed 17% to the countries national GDP (BBS, 2017), but nowadays it has been threatened by climate change and other anthropogenic effects. Bangladesh will be one of the worst sufferer nations to climate change due to its disaster prone and low elevation geography. Furthermore, rapid shrinking of arable land as manifested by the reduction from 0.174 to 0.048 ha in 1961 to 2016, respectively, makes agriculture more challenging (World Bank, 2017). Decreasing natural resources and increasing climate vulnerability appeared as the great challenges to keep pace of food production in the background of increasing population (Kabir *et al.*, 2015). Therefore, it is an urgent need to maintain consistent progress in agriculture sector which depends on efficient and sustainable agricultural production system. Low input, location specific, eco–friendly, demand oriented and climate resilient agricultural technologies would apparently ensure sustainable growth of agriculture (Chowdhury and Hassan, 2013). Since there is neither scope for expanding forest area nor sole cropped areas, the country must expand combined production system integrating trees and crop which is now being called agroforestry system. As, Bangladesh is a land deficient country, multistorey agroforestry system could be a win–win production system and has a broad potential. In multistorey agroforestry system, generally it is expected that the total production of the system will be higher than mono cropping system, since growth resources like light, water and nutrients are used efficiently.

Terrace landscape is reckoned as one of the most exalted areas for agroforestry in Bangladesh. Majority of the farmers of this area depends on the production of fruits in their garden for subsistence. Though farmers are interested in growing more remunerative fruits, jackfruit is one of the preferred fruit species because of its high nutritious value. In Bangladesh, 1,049,912 MT jackfruit were produced from 35,342 ha of land during 2016–17 (BBS, 2017). Unfortunately, most of the farmers

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keep the jackfruit orchards fallow. Only a few farmers cultivate some crops in their orchard without following scientific methods. In general, jackfruit trees were not planted in a systematic manner, it has enough space to grow under–storied–crops and reported to increase the overall production (Miah *et al.*, 2018). Since jackfruit–based agroforestry system is not practiced scientifically in the terrace ecosystem, farmers are not getting desired benefits (Rahman *et al.*, 2018). Haque (2001) reported that jackfruit plant is sensitive to both water logging and drought conditions. It was observed that the growth and production are seriously hampered in the years when spring and early summer remains dry. So, jackfruit trees are supposed to perform better by enjoying water and nutrients that will be applied for vegetable crops.

Therefore, it was aimed to utilize the jackfruit orchard for maximizing land productivity as well as to provide year–round economic returns. Turmeric (*Curcuma longa*), Ginger (*Zingiber officinale*), Chili (*Capsicum annuum*) and Papaya (*Carica papaya*) are the most important and ancient spices and vegetable in Indian sub–continent. The production of these crops are very low as compared to the demand in Bangladesh and these can be grown under multistorey agroforestry system (MAFS) due to their shade tolerant nature. In MAFS, ginger and turmeric are compatible crop due to their shade loving nature (Bhuiyan *et al.*, 2012). Microclimate is greatly modified under tree, which has a great influence on the performance of understory crops. Previously jackfruit–based agroforestry systems have been modestly studied, so that, the potential benefits of the system are remaining untapped. Therefore, the present study was carried out to evaluate the performance and economic return of some shade tolerant spice crops and one vegetable as well as microclimatic variability in jackfruit–based MAFS.

MATERIALS AND METHODS

Geographical status and climatic conditions of the study area

An On–Farm experiment was conducted at different existing jackfruit orchards from April 2017 to April 2018 in Shibpur upazila of Narsingdi district (Fig. 1). The study site is a good representation of central terrace ecosystem of Bangladesh and located at 24˚ 04' N latitude, 90˚ 50' E longitude and 8.5 m above mean sea level. The soil of the study area belongs to Madhupur Tract (AEZ–28) and classified as shallow red–brown under Inceptisol soil category according to USDA Soil Taxonomy (Brammer, 1971; Shaheed, 1984). The land topography of the terrace landscape is characterized by level upland and closely linked to narrow–valleys. However, the soil of terrace are better drained, friable clay loam to clay overlying friable clay substratum at varying depths. This area is characterized by a sub–tropical climate with mild–summer and winter. The minimum and maximum mean temperatures during the winter various from 19°C to 23.7°C and 26°C to 29°C in summer. The average annual rainfall is 2376 mm with the relative humidity of 60–70% and generally the rainfall is heavy during July and August.

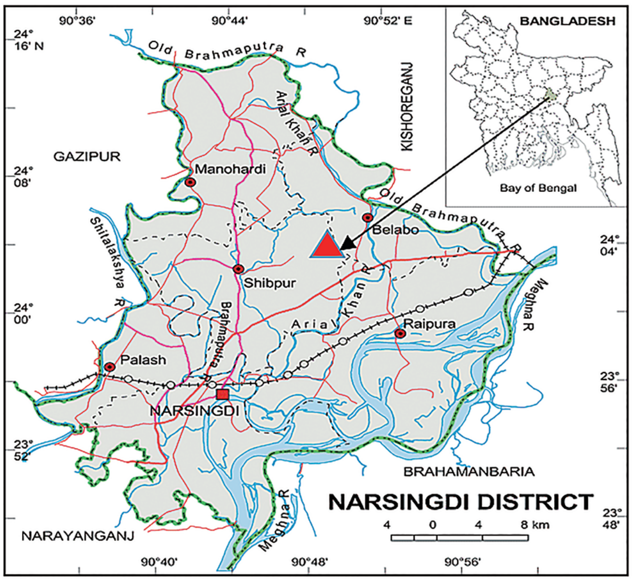

Fig. 1. Map showing experimental site in Shibpur upazila of Narsingdi district, Bangladesh.

Experimental design and treatments

The experiment was carried out in a Randomized Complete Block Design (RCBD) with three replications. An individual jackfruit tree was considered as a single replication. The plot size of each replication was not uniform and varied between 20 to 42 m^2. There were five treatments for all lower–story crops such as open field (sole/non–agroforestry); 1–meter distance from tree base (1 m); 2–meter distance from tree base (2 m); 3–meter distance from tree base (3 m); 4–meter distance from tree base (4 m). Performances of papaya and jackfruit were compared for agroforestry with non–agroforestry systems. Economic and land use performances were compared for different agroforestry practices.

Development of jackfruit–papaya multistorey agroforestry system (MAFS)

Previously unmethodically established jackfruit orchards having heterogeneous trees between the ages of 15 to 26 were chosen to convert into MAFS in order to evaluate the productivity and profitability of turmeric (var. *Danna*), ginger (var. *Kalinjira*) and Chili (var. *Jhillick)* as lower–storey crops and papaya (var. *Top lady*) as middle–storey crop; where jackfruit (local cultivar) tree considered as top–storey crop (Fig. 2). Papaya was planted in the borderline to maximize the land use and get more profit. Thirty five days old healthy seedlings of papaya were transplanted in pits of 1.5 × 1.5 × 1.5 ft^3 (L × W × D) by maintaining plant to plant distance of 1.5 m. Seed–rhizome of turmeric and ginger were planted at a spacing of 45 × 25 cm^2 and 40 × 25 cm^2, respectively with a depth of 6 to 7 cm. Healthy 30 days old seedlings of Chili were transplanted in the experimental field on 25 October 2017 at a spacing of 60

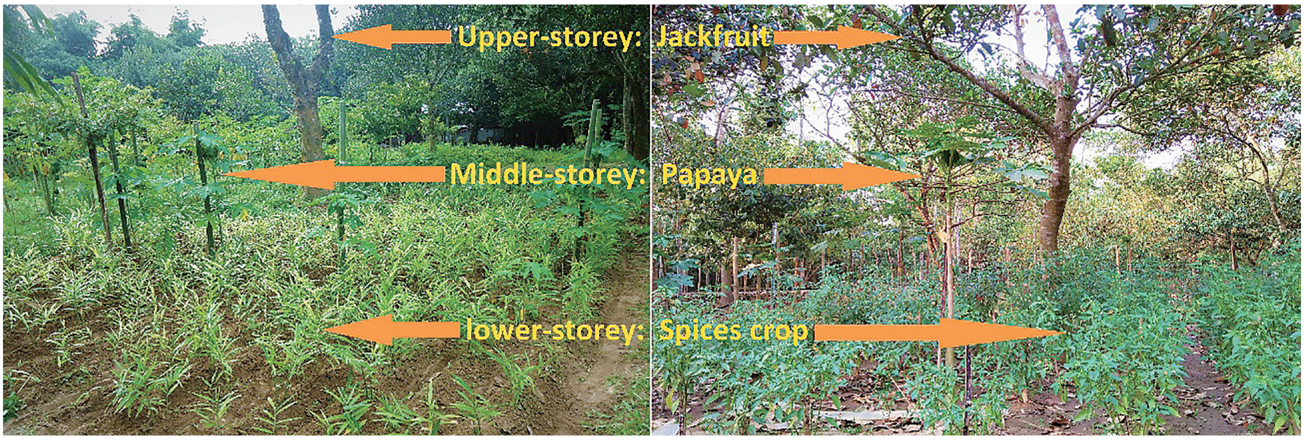

Fig. 2. Established jackfruit–papaya multistorey agroforestry systems (MAFS).

× 60 cm². All understory crops were fertilized according to fertilizer recommendation guide (BARC, 2012). No additional fertilizer was applied to jackfruit. All agronomic management practices were done regularly.

Data recorded

Crop parameters

In case of turmeric and ginger, the plant height, number of tillers per hill, rhizome weight per hill and yield per hectare were measured. In case of Chili, growth characters like plant height, number of primary and secondary branches per plant were counted. Yield and yield attributes like number of fruits, fruit weight, fruit length, fruit diameter, yield per plant of Chili as well as yield per hectare were recorded after harvesting of fruits. Yield contributing data of papaya and jackfruit were recorded during harvesting and then yield per hectare were calculated.

Microclimatic parameters

Photosynthetically active radiation (PAR) on the understory crops in MAFS and open field were recorded by sunfluxceptometer as per treatment variables in terms of μmol m^{-2} s^{-1}. Soil temperature (°C) was measured by Temp 4/5/6 Thermistor Thermometer and soil moisture percentage were recorded by DSMM500 soil moisture meter in non–agroforestry and MAFS fields. All microclimatic data had been taken during 12.00 to 2.00 pm.

Economic and land use analysis

Cost and benefit analyses as well as land use performances were used to compare the benefits of the tested agroforestry systems with the respective monoculture system. For exploring the potentiality of spices coupled jackfruit–papaya MAFS, the Benefit Cost Ratio (BCR) and Land Equivalent Ratio (LER) were calculated according to the procedure of Miah *et al*. (2018).

Statistical analysis

The collected data were statistically analyzed to find out the significant variation of the experimental results due to different treatments by using the "Analysis of Variance" (ANOVA) technique with the help of computer package "Statistix 10". The mean differences of treatments were compared at by LSD test at 5% level of significance.

RESULTS

Performance of lower–storey crops

Turmeric

Turmeric planted under tree shade grew more vigorously than those grown in open field (Table 1). Height of the turmeric plant decreased gradually with the increase of planting distances from tree base. However,

Table 1. Growth, yield and yield contributing characters of turmeric in MAFS and sole turmeric field

Treatments	Plant height (cm)	No. of tillers per hill [NS]	Rhizome weight per hill (g)	Yield (ton/ha)
1 m	111.55 ± 5.54 a	2.61 ± 0.52	114.77 ± 2.25 c	10.17 ± 0.18 c
2 m	106.55 ± 4.16 b	3.11 ± 0.11	123.27 ± 3.49 b	10.95 ± 0.30 b
3 m	103.89 ± 4.30 c	3.27 ± 0.14	133.16 ± 4.96 a	11.83 ± 0.44 a
4 m	101.78 ± 4.89 c	3.22 ± 0.11	133.44 ± 4.06 a	11.87 ± 0.36 a
Sole Turmeric	97.33 ± 4.79 d	3.13 ± 0.08	116.13 ± 2.17 c	10.25 ± 0.24 c

Values are means ± standard errors (n=3).
Different alphabetical letters with standard errors within the same column indicates significant differences among various treatments according to a least significant difference test (LSD) ($P < 0.05$).
[NS] Non–significant.

the enhancement of plant height was observed at 1 m distance by 14.61%, followed by 2 m (9.47%), 3 m (6.74%), and 4 m (4.57%) at 210 DAS, as compared to that of sole turmeric. In comparison to sole field, number of tillers increased by 4.46% and 2.87% in 3 m and 4 m; while, decreased by 16.61% and 0.64% at 1 m and 2 m distances from tree base respectively, in MAFS. Rhizome weight per hill and the yield of turmeric were significantly influenced by different planting distances from tree base. As compared to sole turmeric field, rhizome weight was increased by 6.15, 14.66, and 14.91% at 2 m, 3 m, and 4 m distances respectively; while, decreased by 1.17% at 1 m distance from tree base in MAFS. However, the yields of turmeric were increased by 6.83, 15.41, and 15.80% in 2 m, 3 m, and 4 m distances, respectively; while, reduced by 0.78% at 1 m distance from tree base under MAFS as compared to sole turmeric field.

Ginger

Jackfruit based MAFS had a positive effect on both growth and yield parameters of ginger (Table 2). The plant height of ginger was increased by 22.81% at 1 m distance followed by 2 m (18.90%), 3 m (12.42%), and 4 m (7.18%) distances from tree base, respectively, in MAFS at 210 DAS as compared to that of non–agroforestry field. Statistically planting distance from tree base had a little effect on the number of tillers per hill. Number of tillers per hill of ginger was increased by 4.50 and 11.27% at 3 m and 4 m distances; while, decreased by 17.17 and 3.21% at 1 m and 2 m distances from tree base respectively in MAFS, compared to sole field. Rhizome weight of ginger per hill were augmented by 9.66, 27.37, and 35.10% at 2 m, 3 m, and 4 m distances respectively; while, reduced by 19.85% at 1 m distance from tree base under MAFS as compared to sole field. The yield of ginger was augmented by 10.23, 27.91, and 34.78% in 2 m, 3 m, and 4 m distances from tree base, respectively; while, reduced by 19.49% in 1 m distance from tree base under MAFS as compared to sole field.

Chili

Growth and yield contributing characters of chili were significantly differed among different treatments (Table 3). The plant height of chili were enhanced by 21.49, 17.48, 10.87, and 3.29% respectively, at 1, 2, 3, and 4 m distance from the tree base as compared to that of open field plants. Number of primary and secondary branches are the very important growth characters of chili. Significantly, both the highest number of primary branches (7.16) and secondary branches (22.51) were found in open field followed by 4 m, 3 m, 2 m and 1 m distance from tree base respectively, in MAFS. In comparison with open field, the number of fruits were reduced by 34, 19, 5, and 1% in 1, 2, 3, and 4 m distance from the tree base respectively. Individual fruit weight was non–significant in MAFS and sole chili field. However, all these features to drop fresh yield per plant by 32.45, 18.79, 5.78, and 0.92% at 1, 2, 3, and 4 m distance from the tree base, respectively as compared to open field used as control. The changing pattern of fresh yield per hectare of chili was like as the fresh yield per plant.

Table 2. Growth, yield and yield contributing characters of ginger in MAFS and sole ginger field

Treatments	Plant height (cm)	No. of tillers per hill	Rhizome weight per hill (g)	Yield (ton/ha)
1 m	66.33 ± 3.15 a	9.55 ± 0.29 b	60.46 ± 2.42 d	5.74 ± 0.23 d
2 m	64.22 ± 2.85 a	11.16 ± 0.72 ab	82.72 ± 1.62 b	7.86 ± 0.15 b
3 m	60.72 ± 3.36 b	12.05 ± 0.82 ab	96.08 ± 2.76 a	9.12 ± 0.26 a
4 m	57.89 ± 2.30 b	12.83 ± 0.78 a	101.19 ± 1.33 a	9.61 ± 0.12 a
Sole Ginger	54.01 ± 2.45 c	11.53 ± 0.24 ab	75.43 ± 2.64 c	7.13 ± 0.25 c

Values are means ± standard errors (n=3).
Different alphabetical letters with standard errors within the same column indicates significant differences among various treatments according to a least significant difference test (LSD) ($P < 0.05$).

Table 3. Growth, yield and yield contributing characters of chili in MAFS and sole cropping system

Treatments	Plant height (cm)	Primary branches	Secondary branches	No. of fruit per plant	Single fruit weight ^{NS} (g)	Fresh yield /plant (g)	Fresh yield (ton/ha)
1 m	135.20 ± 3.42 a	5.70 ± 0.22 b	19.70 ± 0.51 c	159.33 ± 3.48 c	4.55 ± 0.04	742.5 ± 0.53 d	20.56 ± 0.30 d
2 m	130.73 ± 3.13 ab	5.72 ± 0.30 b	20.83 ± 0.60 bc	195.67 ± 5.55 b	4.53 ± 0.02	893.2 ± 1.42 c	24.73 ± 0.82 c
3 m	123.38 ± 1.28 b	6.33 ± 0.39 b	20.53 ± 0.59 bc	229.00 ± 6.81 ab	4.52 ± 0.04	1035.4 ± 1.17 b	28.68 ± 0.67 b
4 m	114.94 ± 1.48 c	6.44 ± 0.24 ab	21.97 ± 0.17 ab	238.67 ± 5.90 a	4.56 ± 0.04	1089.7 ± 1.84 a	30.17 ± 1.06 a
Sole Chilli	111.28 ± 2.53 c	7.16 ± 0.08 a	22.51 ± 0.57 a	241.00 ± 3.46 a	4.55 ± 0.03	1099.9 ± 0.97 a	30.46 ± 0.56 a

Values are means ± standard errors (n = 3).
Different alphabetical letters with standard errors within the same column indicates significant differences among various treatments according to a least significant difference test (LSD) ($P < 0.05$).
^{NS} Non–significant.

Performance of middle–storey crop (Papaya)

Different spice crop association in Jackfruit based MAFS had a negative effect on yield and yield contributing characters of papaya as compared to open field (Table 4). In comparison to that of sole papaya field, the number of fruits per plant were decreased by 29, 26.80, and 18.60% respectively, and the individual fruit weight were reduced by 3.62, 1.63, and 1.9% respectively in turmeric, ginger, and Chili associated MAFS. The changing pattern of yield per plant of papaya was similar to the number of fruits per plant. However, it is worthy to mention that a very few numbers of papaya plant might be planted in one hectare of agroforestry field due to lack of available space as compared to sole papaya field which led to massive yield reduction by 58.30, 56.16, and 51.35%, respectively in turmeric, ginger, and Chili compounded jackfruit orchard.

Performance of upper–storey crop (Jackfruit)

Development of MAFS had a beneficial influence on the yield of jackfruit (Table 5). Under MAFS, the number of fruits per tree enhanced by 85.72, 119.85, and 46.38%, respectively in turmeric, ginger, and Chili associated jackfruit trees in comparison to that of non–agroforestry jackfruit trees while individual fruit weight showed the opposite trend and reduced by 41.55, 29.83, and 11.02%, respectively. Interestingly, compared to sole jackfruit, fruit yield increased by 5.20, 44.85, and 22.55% respectively in turmeric, ginger, and Chili associated multistorey jackfruit orchard.

Microclimatic variation in MAFS

Photosynthetically active radiation (PAR) was recorded during the whole cropping period on the associated spice crops canopy in MAFS and respective sole crop field to observe light availability. Though, light availability was extensively influenced by canopy distribution and volume, it was evident that the cumulative average PAR increased significantly with increasing distance from tree base (Fig. 3a). The changing pattern of cumulative average soil temperature was similar to light intensity of MAFS. The highest soil temperatures were recorded as 31.55˚C, 30.68˚C, and 25.72˚C in sole field of turmeric, ginger, and Chili respectively, and significantly the lowest temperatures were recorded at 1 m distance from tree base in each crop associated MAFS (Fig. 3b). The cumulative average soil moisture content throughout the cropping season was greatly influenced by jackfruit–based agroforestry. The higher moisture was recorded in each crop associated MAFS than their respective sole spices crop field. Though, higher moisture content were recorded in MAFS but irregular increasing pattern were observed in that system compared to sole cropping (Fig. 3c).

Relationship between crop yield and PAR

Linear relationships between ginger, turmeric, and chili yields with PAR represented weak to moderate association as evident by r^2=0.018, 0.162, and 0.435, respectively (Fig. 4). The regression line showed that ginger and turmeric yields were reduced by 0.0005 and 0.0008 ton ha^{-1} in response to per unit increment of PAR, while chili yield was enhanced by 0.007 ton ha^{-1} with respect to per unit enhancement of PAR.

Economic and land use performance of MAFS

To estimate the economic and land use performances of different crop–associated MAFS over sole

Table 4. Yield and yield contributing attributes of papaya in different crop–associated MAFS

Systems	No. of fruits per plant	Single fruit weight (g)	Yield (kg/plant)	Yield (ton/ha)
Jackfruit + Turmeric + Papaya	20.50 ± 0.64 b	687.83 ± 4.73 b	14.09 ± 0.48 c	21.15 ± 0.72 c
Jackfruit + Ginger + Papaya	21.13 ± 0.88 b	702.03 ± 1.41 ab	14.53 ± 0.60 c	22.24 ± 0.90 bc
Jackfruit + Chili + Papaya	23.50 ± 0.52 b	700.17 ± 4.14 ab	16.45 ± 0.35 b	24.68 ± 0.53 b
Sole Papaya	28.87 ± 0.92 a	713.68 ± 7.16 a	20.65 ± 0.45 a	50.73 ± 1.16 a

Values are means ± standard errors (n = 3).
Different alphabetical letters with standard errors within the same column indicates significant differences among various treatments according to a least significant difference test (LSD) (P < 0.05).

Table 5. Yield and yield contributing attributes of jackfruit in different crop–associated MAFS

Systems	No. of fruits per tree	Single fruit weight ^{NS} (kg)	Yield (kg/tree)
Jackfruit + Turmeric + Papaya	20.30 ± 3.33 ab	5.78 ± 0.78	113.16 ± 11.67 b
Jackfruit + Ginger + Papaya	24.03 ± 4.69 a	6.94 ± 1.30	155.81 ± 13.44 a
Jackfruit + Chili + Papaya	16.00 ± 1.93 ab	8.80 ± 2.34	131.83 ± 18.27 ab
Sole Jackfruit	10.93 ± 1.09 b	9.89 ± 0.87	107.57 ± 11.79 b

Values are means ± standard errors (n = 3).
Different alphabetical letters with standard errors within the same column indicates significant differences among various treatments according to a least significant difference test (LSD) (P < 0.05).
^{NS} Non–significant.

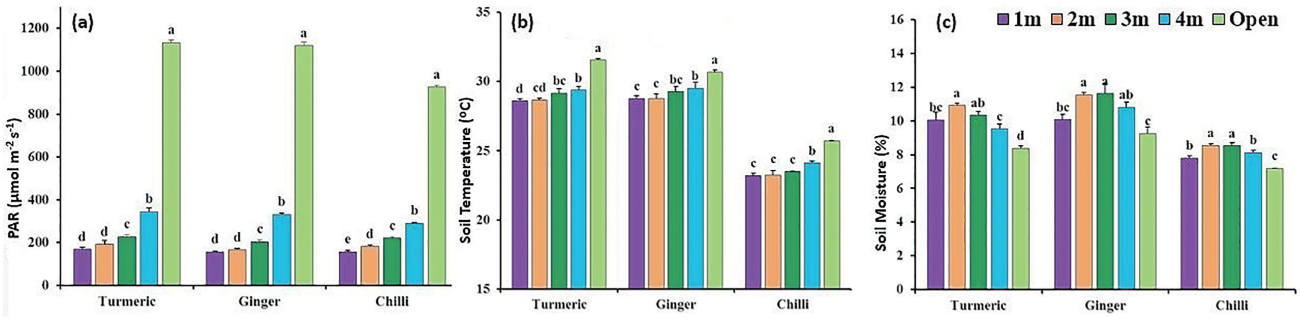

Fig. 3. PAR (a), Soil temperature (b) and moisture percentage (c) in turmeric, ginger, and chili associated MAFS at different distant regimes and open crop field during the experimental period. (Vertical bars indicate standard error and different alphabetical letters indicate significant differences among various treatments).

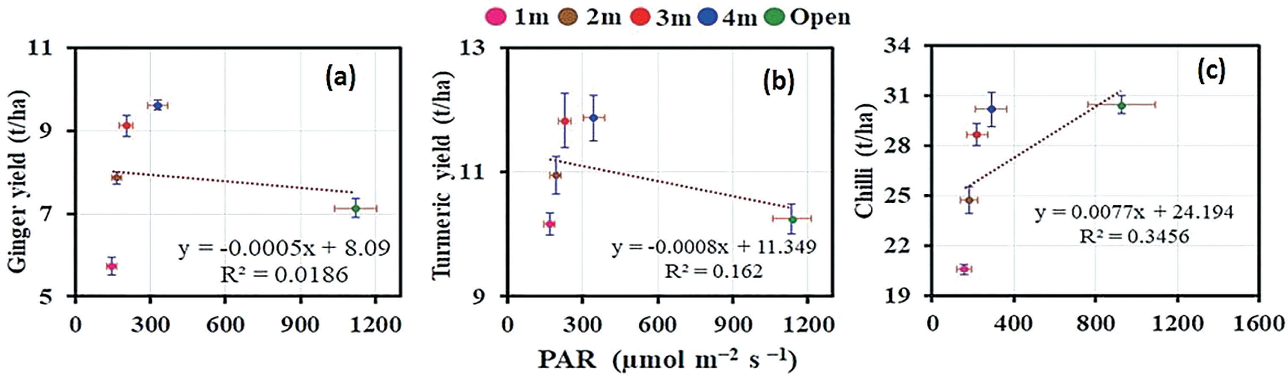

Fig. 4. Linear relationship of ginger yield with PAR (a), turmeric yield with PAR (b), and chili yield with PAR (c) in different distant regimes from tree base. Vertical and horizontal bars indicate standard errors.

cropping, net return, BCR and LER had been calculated and demonstrated in Table 6. Among all crop combinations of MAFS, the maximum net return (BDT 605, 605) and the highest BCR (2.33) were calculated in jackfruit + chili + papaya association. It was evident that different MAFS provided higher net income and BCR over their respective sole cropping system. The LER was also remarkably higher in jackfruit–spice crops–based MAFS over mono–cropping system.

DISCUSSION

The potentiality of agroforestry system depends on various factors like crop variety, edaphic, biotic and environmental factors. Growth and yield of crops in agroforestry system were influenced by tree canopy spread and light interceptions. Plant height of understory crops were significantly decreased with increasing of distances of plant from tree base. The probable causes of this findings might be due to variations of light percentage in different distances from tree base. Crops grown in low light levels usually exhibit apical dominance due to high auxin production in shaded condition (Hillman, 1984). Wang and Zhang (1998) recorded the maximum plant height of turmeric at 80% shading. Similar result was reported by Amin *et al.* (2010) and Islam *et al.* (2013).

Turmeric and Ginger cultivated in MAFS grew more vigorously than sole cropping system. The present experiment showed that the highest number of tillers were found in 3 m and 4 m distances from tree base which indicated that tiller production was higher under partial shade condition. Diffused or partial light in agroforestry systems promoted the vegetative growth of plants, but adversely affected the reproductive development (flowers, fruits and seeds) of plants (Weaver and Clements, 1973). The present results are consistent with the previous study of Islam *et al.* (2013) and Bhuiyan *et al.* (2012). The lower number of branches per plant of Chili in agroforestry system may be explained by higher auxin production in low light condition, which ultimately suppressed the growth of lateral branches of plant. This phenomenon was also supported by Dey and Datta (2009); Shapla (2001).

The yield augmentation of turmeric and ginger may be due to reduced light intensity in MAFS with higher light use efficiency (LUE) and favorable microclimatic conditions under jackfruit trees. The light use efficiency is defined as the efficiency of conversion of light into biomass. LUE values of crops were higher in agroforestry system than sole cropping system (Zhang *et al.*, 2014). The over yielding of intercropping might be the result of light use efficiency (Gao *et al.*, 2010). These effects were extensively studied by Bikash *et al.* (2008), Pandey *et al.* (2017) and Khan *et al.* (2015).

Table 6. Economic and land use performances of spices crop associated jackfruit–papaya MAFS as compared to mono–cropping systems

Systems	Total Cost (BDT/ha)*	Gross Income (BDT/ha)*	Net return (BDT/ha)*	BCR	LER
Jackfruit + Turmeric + Papaya	349,964	743,700	393,736	2.12	2.57
Jackfruit + Ginger + Papaya	420,024	931,260	511,236	2.21	2.81
Jackfruit + Chili + Papaya	455,625	1,061,230	605,605	2.33	2.47
Sole Turmeric	220,347	307,500	87,153	1.40	–
Sole Ginger	290,407	427,800	137,393	1.47	–
Sole Chili	333,008	700,580	367,572	2.10	–
Sole Papaya	343,234	709,940	366,706	2.07	–
Sole Jackfruit	–	–	110,200	–	–

* 1US$= 83 Bangladesh Taka (BDT).

The fresh yield of chili was significantly increased with increasing planting distances from jackfruit tree base and the highest yield was found in open field. These findings might be due to decreasing competition of available resources (PAR, water and nutrients) sharing between tree and crop component with increasing the distances from tree base. In this experiment, the yield of papaya was lower in MAFS in contrast with sole cropping system. Similar yield reduction in chili (Dey and Datta, 2009; Islam *et al.*, 2008), and in papaya (Miah *et al.*, 2018) were reported under agroforestry system.

Competition for light was an important factor in reducing yields in maize plants grown closest to the trees (Everson *et al.*, 2004) as the shade of tree canopy induces stress conditions to the understory crops (Dufour *et al.*, 2013). The yield reduction differs and strongly depends on the level of shade (Peri *et al.*, 2007). Competition for water and nutrients are another negative impact of trees on associated crops (Ong *et al.*, 2002). Rao *et al.* (1991) and Chamshama *et al.* (1998) reported that the concentration of roots in the upper soil profile caused intense belowground competition for resources which, in turn, resulted in decreased crop productivity.

In this present study it was observed that number of fruits per tree and yield of jackfruit were higher in MAFS than sole jackfruit orchard. Despite fruit weight varied due to varietal variation, the single fruit weight was higher in non–agroforestry jackfruit tree over MAFS; this might be due to a smaller number of fruits produced in sole jackfruit trees. However, external inputs like fertilizers, irrigation and crop residues in MAFS may help increase number of fruits and jackfruit yield per plant. Similar findings were reported by Miah *et al.* (2018) and Rahman *et al.* (2018).

Light interception under tree in MAFS was greatly reduced by 70–85% than sole–cropped field due to broad leaves and dense canopy of the evergreen jackfruit tree. Similar results were observed by Rivest *et al.* (2009) and Singh *et al.* (2012). There had a notable difference both in the soil temperature and moisture content in respect of different distances from tree base due to the variations of light availability. Soil temperature in MAFS was significantly lower than that of open crop field. This might be due to shade provided by the crown of the jackfruit trees. At first PAR was absorbed by tree canopy and consequently diffused light reached to the soil surface which leads to lower soil temperature. Lower temperature under tree canopy reduces water stress and increase biomass of understory crops (Rahman *et al.*, 2018). The present study also demonstrated higher soil moisture in agroforestry systems than open crop field, which might be responsible for causing lower rate of evaporation of water from the soil surface in MAFS. Continuous shedding of litter from jackfruit tree acts as mulching and promotes infiltration as well as increases water holding capacity through adding organic matter. Several researchers reported that soil temperature was substantially lower and soil moisture content was higher in agroforestry systems than open crop field. (Miah *et al.*, 2018; Lin *et al.*, 2015; Jonsson *et al.*, 1999).

This experiment revealed that different spice crops associated MAFS provided higher economic benefit than sole cropping system. This finding might be due to excellent yield from turmeric, ginger and jackfruit without additional management practices as well as satisfactory yield of Chili and middlestorey crop. Many authors have been reported higher benefits in different agroforestry system (Miah *et al.*, 2018; Das *et al.*, 2008; Zhang *et al.*, 2017; Ong *et al.*, 2004; Hossain *et al.*, 2015).

CONCLUSIONS

Based on BCR and LER, it was observed that jackfruit–spice crops–based MAFS was highly profitable farming system than non–agroforestry jackfruit farming as well as other sole farming of tested crops. So, the traditional jackfruit orchards could be transformed into MAFS by introducing shrubby plant species in the mid–storey and seasonal crops in the lower–storey. Partial shade loving and shade tolerant high value spice crops could be successfully grown in jackfruit orchard. However, the findings of the present study were achieved based on one season trial only, which may not be sufficient to assess the sustainability of the results. So, similar experiments should be repeated to confirm the potentiality of the system.

AUTHOR CONTRIBUTIONS

Zabid Al RIYADH, performed the research, collected and analyzed the data, and wrote the first draft of the manuscript. Md. Abiar RAHMAN, Md. Giashuddin MIAH and Satya Ranjan SAHA, formulated and designed the experiment, and supervised the research work. Md. Mezanur RAHMAN and Md. Azizul HOQUE, helped in data analysis and manuscript preparation. Ikuo MIYAJIMA, reviewd the manuscript, provided suggestions and comments on the manuscript. All authors assisted in editing the manuscript and approved the final version.

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