Original Research Article

Growth and productivity of Cauliflower in Aonla based Multistoried Agroforestry System

ABSTRACT

Fruit tree vegetable-based agroforestry systems (FVAS) are being introduced in highland cropping systems of Bangladesh. This combined production system is applicable against changing climate, ensuring nutritional requirements along with food security, ecological balance, and economic profitability. The present study explored the performance of cauliflower as lower story crop in aonla based multistoried agroforestry system. The experiment was laid out in randomized complete block design (RCBD) with four replication. The treatments were $\mathbf{T_1}$= Aonla + carambola + lemon + dragon fruit + cauliflower, $\mathbf{T_2}$**=** Aonla + dragon fruit + cauliflower, $\mathbf{T_3}$= Dragon fruit + cauliflower, $\mathbf{T_4}$= Cauliflower in the open field (Control). Among different combinations of agroforestry systems, the highest curd yield of cauliflower (15 t ha^{-1}) was recorded under dragon fruit-based system (T_3) whereas most of the morphological parameters were maximum in the aonla + carambola + lemon + dragon fruit-based system (T_1). The highest benefit–cost ratio (2.95) was noted in aonla+dragon+cauliflower-based system (T_2) followed by dragon fruit based system (T3), while the highest land equivalent ratio (3.78) was calculated in the aonla + carambola + lemon + dragon fruit-based system (T_1). This study revealed that, aonla + dragon + cauliflower based agroforestry system showed relatively higher economic returns and maximum land use efficiency in the upland cropping system.

Keywords: Aonla, Cauliflower, Growth, Land use system, Yield

1. INTRODUCTION

Bangladesh is a small deltaic country with 8.82 million hectares of arable land (147570 square kilometers) to feed more than 165 million people [1]. Due to its high population density, it has the lowest per capita arable land, which has risen in the previous fifty years despite a drop in the annual population growth rate from 2.02% in 1971 to 1.22% in 2022 [2] “Again, agricultural production is not increasing expectedly in the background of the overgrowing population. Around 80% of arable land is used for cereal crop cultivation, reducing the space available for other revenue crops. For ecological stability and sustainability, a country needs 25% of forest land of its total land area. Agricultural land makes up 65 % of its geographical surface, forest lands account for almost 17.58 %" [3]. FAO/WHO [4] recommended a minimum of 400 g of fruit and vegetables per day, whereas people eat only 36 and 167 g of fruit and vegetables per day [5]. Therefore, alternative, nutrient-sensitive, and climate-smart agricultural practices should be pursued to overwhelm the above-mentioned constraints in crop production.

"Agroforestry has been an integral part of rural life in many countries of the world, including Bangladesh, for centuries. It plays a vital role in maintaining the productivity of the land base and by ensuring household food and energy security, income and employment generation, investment opportunities, and environmental protection" [6,7,8]. Agroforestry can be identified as a promising option for meeting the demands of society and models of sustainable development due to its contribution not only to the economy and society but also to the ecology [9,10].

Aonla (*Emblica officinalis*) is a deciduous tree, fairly hardy, fruit-bearing, and profitable for farmers with marginal land in terrace ecosystem of Bangladesh. There is increased efficient and environmentally conscious use of natural resources, restoration of wastelands, and improved economic returns for farmers along with increased employment. Aonla is much admired for its nutritional properties. Edible fruit tissue alone has 3 times more protein and 160 times more ascorbic acid than an apple. It is rich in polyphenols, tannins, and minerals and contains a large amount of ascorbic acid, which it has next to the only Barbados cherry (*Malpighia glabra* L.) [11]. Carambola (*Averrhoa carambola*) is a dwarf plant and popular fruit in tropical and subtropical regions of the world. It is also high in reducing sugars, ascorbic acid, and minerals including potassium, calcium, magnesium, and phosphorus [12]. "Lemon (*Citrus limon*) is a vitamin C-rich fruit that can grow in a wide variety of soils, habitats, and cultural arrangements in more than 100 countries" [13]. "Dragon fruit (*Hylocereus* spp.), also known as pitaya or pitahaya, is gaining increasing interest in many countries. The benefits of dragon fruit for human health can be explained by its essential nutrients such as vitamins, minerals, complex carbohydrates, fiber, and antioxidants. Dragon fruit is also an essential source of betacyanin, which serves as a red/purple pigment with antioxidant properties" [14]. "Cauliflower (*Brassica oleracea* L. var. botrytis) is grown mainly as a Rabi crop in winter. The production of cauliflower is increasing day by day in Bangladesh. Among all vegetables produced in the country, cauliflower dominates the major share in terms of total planted area and production" [15]. "It has high nutritional value due to its low-calorie content and high content of fiber, fatty acids, and vitamins including B, C, E, and A nutrients such as P, Mg, Fe, and Mn" [16,17]. "In addition to its high nutritional value, the plant also has medical benefits, as its medicinal benefits lie in the fact that it contains compounds that protect against colon cancer, which are compounds produced by chewing cauliflower, vitamin A, useful for eyes, bones, and teeth, diindolylmethane, which is a face in the face of breast cancer cell growth, and the high percentage of fiber that helps build a healthy gut, galactose that prevents colon cancer-causing compounds, glucoraphanin that prevents heart disease" [18], "which increased the demand for its consumption and in recent years, it has attracted the attention of many farmers and amateurs in the country with interest and extension in its cultivation" [17].

The population is growing rapidly, but the amount of land is not increasing, but is decreasing every day. Despite the immense role of each crop component in food and nutritional security, merging them according to scientific measures in the same field as a form of agroforestry system based on fruit trees on vegetables is still elusive. The objective of this study was to evaluate the potential of an aonla-based agroforestry system by assessing: (i) cauliflower growth and yield, (ii) schematic relationships between crop yield and light availability in terms of photosynthetically active radiation (PAR), (iii) economic profitability in terms of benefit-cost ratio (BCR) and (iv) land use efficiency in terms of land equivalent ratio (LER) for comparing agroforestry systems and open field condition.

2. MATERIALS AND METHODS

2.1 Study Location and Climatic Conditions

The study was carried out at the experimental farm of the Department of Agroforestry and Environment, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Bangladesh (23° 59′ N, 90° 25′ E) from December 2020 to April 2021 (Fig. 1). The minimum and maximum temperatures of the study area throughout the experimental periods ranged from 7 to 38 °C during the growing season (Fig.2) and relative humidity 82.85% [19,20]. The physiographic unit of the soil of this land is silty clay loam in texture, representing the agro-ecological zone of Madhupur Tract (AEZ-28) [21,22].

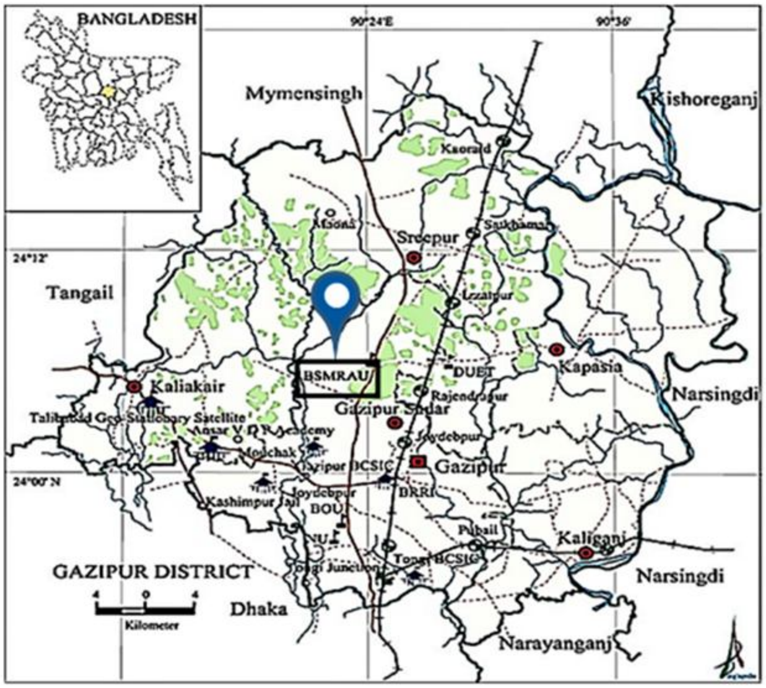

Fig.1. Location of the study area in Bangladesh (Ferdous, 2021)

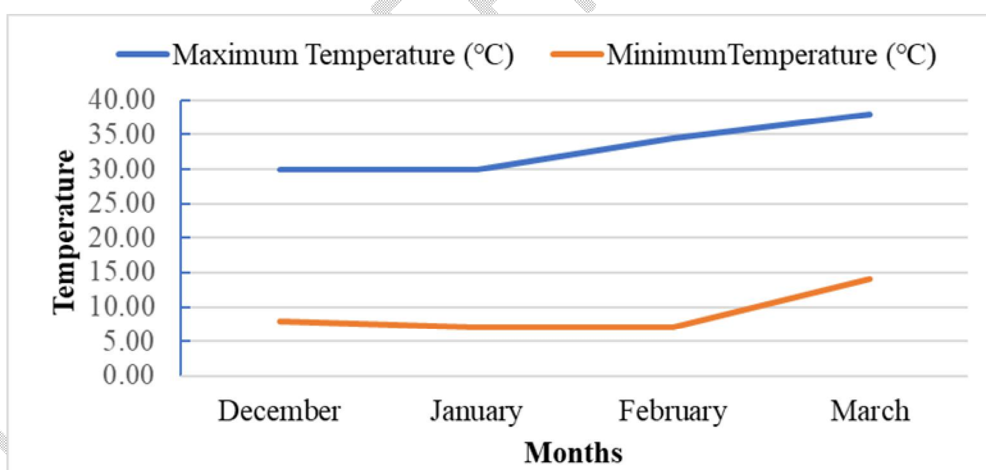

Fig.2. Monthly maximum and minimum temperature during the study period

2.2 Experimental Design and Treatment Composition

An existing twenty-one years-old aonla orchard was established in 2000 maintaining an 8m × 8m distance transformed into a multistoried agroforestry system. Aonla was treated as overstory component. Carambola and lemon are established in 2010 in between two aonla trees and formed middle storied. Two dragon fruit genotypes (Red and white-fleshed dragon fruit) were established in the alley of tree lines in September 2018. Cauliflower was grown in association with the dragon fruit plant, dragon fruit + aonla plant, dragon fruit + aonla + carambola + lemon plant (Fig. 3). Row-to-row and plant-to-plant spacing of cauliflower was 60 cm and 50 cm respectively. Cauliflower was tested in different combinations with four replication satisfying randomized complete block design. These treatments (Fig 4). were as follows-**T_1**: Aonla + carambola + lemon + dragon fruit + cauliflower**, T_2:** Aonla + dragon fruit + cauliflower**, T_3**: dragon fruit + cauliflower **and T_4**: Cauliflower in the open field (Control)

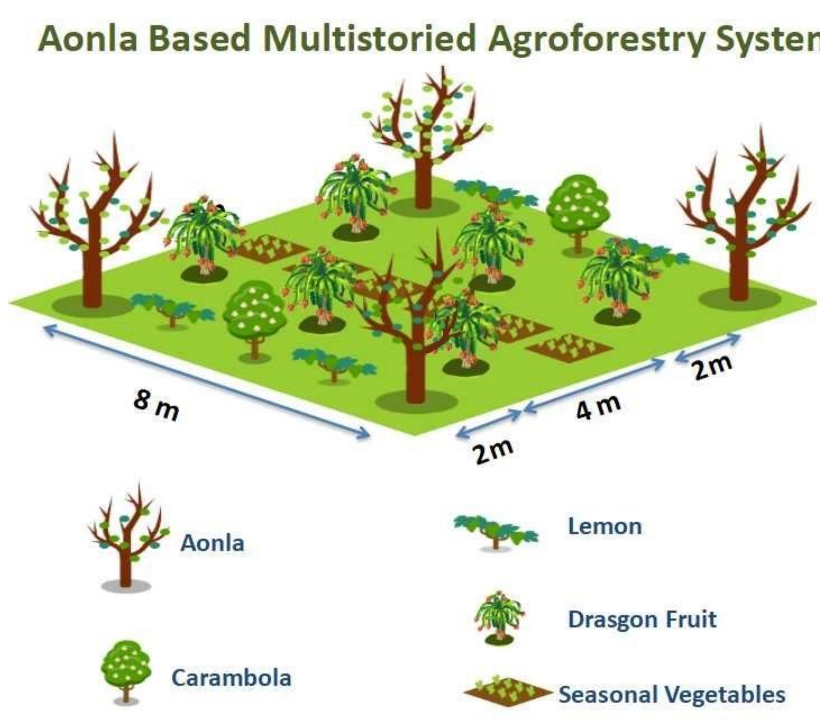

Fig. 3. Scamatic diagram of aonla-based multistoried agroforestry systems

2.3 Field Preparation, Fertilizer Application, and Intercultural Operation

The field was tilled with a disc rotavator, followed by a quadruple tractor cultivator, then harrowing and laddering to achieve a suitable soil condition. In the final soil preparation, vegetables were fertilized with cow dung (15 t ha^{-1} for each field), K_2O in the form of muriate of potash (250 kg ha^{-1}), and P_2O_5 in the form of triple superphosphate (200 kg ha^{-1} for cauliflower). Nitrogenous (N) fertilizer in the form of urea was applied at a dose of 300 kg ha^{-1} for cauliflower, of which 50% was applied as a basal dose during the final preparation of the plot. The remaining N, P, and K fertilizer was added before sowing and at fruiting in two equal doses (25% in each case). To ensure sufficient soil moisture, irrigation was done using a flexible hose pipe when necessary. They are weeded regularly to reduce competition between weeds and crops for resources. Every 25 days, Dursban 20 EC was applied for viral vector control. Very few seedlings in the plot were damaged after planting and these seedlings were replaced with new seedlings. The replacement was done with healthy seedlings in the afternoon with a bowl of soil. It is important to note that under the agroforestry system, other management practices, including fertilizer application were not applied to aonla, carambola and lemon trees, apart from pruning.

Fig. 4. Field view of Aonlabased multistoried Agroforestry systems with different treatments.

2.4 Harvesting and Data Collection

Harvesting of cauliflower started from 14th February 2021 to 1st March 2021.. Plants in the outer rows and at the end of the middle rows were excluded from the random selection to avoid a border effect. Five plants of cauliflower were randomly selected from a replication for the collection of data. Leaf length, leaf breadth, leaf weight, leaf number $plant^{-1}$, SPAD (Soil Plant Analysis Development) value of leaves, plant height, curd length, curd breadth, individual curd weight, marketable curd weight, only curd weight, dry weight of leaf and curd and yield were measured. The chlorophyll content of the leaf was measured from the selected plant by SPAD 502 plus Chlorophyll meter (Konica Minolta Sensing, Inc., Japan).

Photosynthetically active radiation (PAR) was measured on each crop row as functions of multi-strata and distances from the tree base using LP-80 Accu PAR Ceptometer to determine the extent of shading by the tree species. Such measurement was done at 9.30 am. 12.30 pm and 3.30 pm each day at a one-week interval. The measurement was taken at 14 days after transplanting (DAT) and continued up to 67 DAT.

2.5 Economic and Land Use Evaluation of Aonla-based Agroforestry System

Benefit-cost ratio (BCR) and land equivalent ratio (LER) were determined according to the equations followed by [8] in an aonla-based agroforestry system.

Benefit−cost ratio (BCR) = Gross return/Total cost of production.

"Land equivalent ratio=Ci/Cs+Ti/Ts, where, Ci is crop yield under agroforestry, Cs is crop yield under sole cropping, Ti is fruit yield under agroforestry, and Ts is fruit yield under sole cropping" [23].

2.6 Statistical Analysis

All data were processed, calculated, and analyzed using computer software such as MS Excel and STATISTIX 10. Data on different characteristics of cauliflower contributing to growth and yield were statistically analyzed to observe significant variation in results due to different agroforestry systems. Analysis of variance for each of the studied characters was performed by the F test. The mean-variance was adjusted by the LSD test at the 5% significance level.

3. RESULTS

3.1 Photosynthetically Active Radiation (PAR):

Light incidence under aonla-based multistoried agroforestry system was measured at 9.30 am. 12.30 pm and 3.30 pm each day at a one-week interval. The measurement was taken at 14 DAT and continued up to 67 DAT. Among different aonla-based multistoried agroforestry systems, the highest photosynthetically active radiation (PAR) was recorded in open filed condition (T_4) (989.15 µmol m^{-2} s^{-1} at 9.30 am, 1345.93 µmol m^{-2} s^{-1} at 12.30 pm, 750.43 µmol m^{-2} s^{-1} at 3.30 pm). The lowest PAR was recorded in aonla + carambola+lemon+dragon fruit-based system (T_1) (370.77 µmol m^{-2} s^{-1} at 9.30 am, 860.5 µmol m^{-2} s^{-1} at 12.30 pm and 300.34 µmol m^{-2} s^{-1} at 3.30 pm) (Table 1). The recorded PAR in aonla + dragon fruit-based system (T_2) and dragon fruit-based system (T_3) was varied between PAR in aonla + carambola + lemon + dragon fruit-based system (T_1) and open field condition (T_4). Thus, ultimately mean PAR of a day was also the highest (1028.19 µmol m^{-2} s^{-1}) (100%) in open field condition (T_4) followed by dragon fruit based system (T_3) (1005.74 µmol m^{-2} s^{-1}) (98 %), aonla+dragon fruit-based system (T_2) (809.92 µmol m^{-2} s^{-1}) (78%) and aonla + carambola+lemon+dragon fruit-based system (T_1) (508.87 µmol m^{-2} s^{-1}) (50%). Upper-storied plant aonla received 100 % PAR, but incident light was gradually decreased on carambola, lemon, dragon fruit, and cauliflower in multistoried conditions. Cauliflower growing in open field and aonla (upper storied component) received 100% PAR.

Table 1. Availability of Photosynthetically Active Radiation (PAR) in different aonla-based agroforestry systems

	Time			Average light (µmol m^{-2} s^{-1})	Percent of the open field light
Treatments	9:30 AM	12:30 AM	3:30 AM		
T_1: Aonla + Carambola+ Lemon + Dragon fruit+ Vegetables	370.77	860.50	300.34	508.87	50%
T_2: Aonla + Dragon fruit+ Vegetables	783.65	1130.57	515.56	809.92	78%
T_3: Dragon fruit + Vegetables	977.67	1316.79	722.77	1005.74	98%
T_4: Vegetables in an open field (Control)	989.15	1345.93	750.43	1028.19	100%

3.2 Growth parameters of cauliflower

The superior performance of cauliflower in terms of plant height (57.16 cm), total leaves number (16.21), leaf length (63.07 cm), and leaf breadth (28.52 cm) was found in (T_1) aonla + carambola + lemon + dragon fruit-based system (Table 2), while SPAD value (59.19) was found highest in open field condition (T_4). In contrast, the lowest plant height (48.39 cm), total leaves number (10.47), leaf length (45.52 cm), and leaf breadth (22.57 cm) was found in open field condition while SPAD value (52.70) was found in aonla + carambola + lemon + dragon fruit-based system (T_1).

Table 2. Growth parameters of cauliflower in aonla-based agroforestry system.

Systems	Plant height cm	Total leaves number	Leaf length cm	Leaf breadth cm	SPAD value
T_1: Aonla + Carambola+ Lemon + Dragon fruit + Cauliflower	57.16a	16.21a	63.07a	28.52a	52.70d
T_2: Aonla + Dragon fruit + Cauliflower	54.41b	14.50b	60.50b	25.95b	55.39c
T_3: Dragon fruit + Cauliflower	52.08c	11.38c	59.30b	26.37b	57.55b
T_4: Cauliflower in an open field (sole)	48.39d	10.47d	45.52c	22.57c	59.19a
CV (%)	3.69	0.68	3.95	3.59	0.81

In a column, means followed by the same letter (s) are not statistically different at a 5% level of significance by LSD. CV = coefficient of variance.

3.3 Yield attributes of cauliflower

Yield attributes of cauliflower in aonla based agroforestry system depicted in Table 3. The highest fresh leaf weight (990.20 g), curd length (9.91 cm), curd breadth (16.55 cm), individual curd weight (2.34 kg), marketable curd weight (1.50 kg), only curd weight (1.05 kg) and yield (49.99 t ha^{-1}) was found in dragon fruit-based system (T_3). In contrast, the lowest leaf weight (487.40 g), curd length (7.15 cm), curd breadth (12.25 cm), individual curd weight (1.20 kg), marketable curd weight (0.85 kg), only curd weight (0.50 kg) and yield (28.33 t ha^{-1}) was found in aonla + carambola + lemon + dragon fruit-based system (T_1).

Table 3. Yield attributes of cauliflower in aonla-based agroforestry system.

Systems	Fresh leaf weight (g $plant^{-1}$)	Individual curd weight (kg /)	Marketable curd weight (kg)	Only curd weight (kg/)	Curd length (cm)	Curd breadth (cm)	Marketable curd yield (t ha^{-1})
T_1:Aonla+Carambola+ Lemon+ Dragon fruit + Cauliflower	990.20a	1.20d	0.85d	0.50d	7.15d	12.25c	28.33

T_2:Aonla+Dragon fruit+ Cauliflower	889.80b	1.65c	0.95c	0.61c	8.02c	14.05b	31.66
T_3: Dragon fruit + Cauliflower	671.42c	2.34a	1.50a	1.05a	9.91a	16.55a	49.99
T_4: Cauliflower in an open field (sole)	487.40d	2.10b	1.33b	0.90b	8.92b	14.47b	44.33
CV (%)	7.88	9.46	10.75	12.14	5.18	6.64	

In a column, means followed by the same letter (s) are not statistically different at a 5% level of significance by LSD. CV = coefficient of variance.

3.4 Leaf and curd dry weight

Leaf dry weight (64.08 g) was relatively higher in dragon fruit-based agroforestry system (T_3) which was superior to other systems (Fig. 5). The moderate leaf dry weight was found in open field conditions (T_4) (60.10 g) and aonla+dragon fruit-based system (T_2) (51.49 g). The lowest leaf dry weight was found (44.89 g) in aonla + carambola + lemon + dragon fruit-based agroforestry system (T_1). At harvest, the highest curd dry weight (47.77g) was found in the dragon fruit-based system (T_3) and the lowest curd dry weight (28.73 g) was found in Aonla + Carambola + Lemon + Dragon fruit-based agroforestry system (T_1). The moderate curd dry weight was found in aonla+dragon fruit-based system (T_2) (33.31g) and open field condition (T_4) (44.23 g).

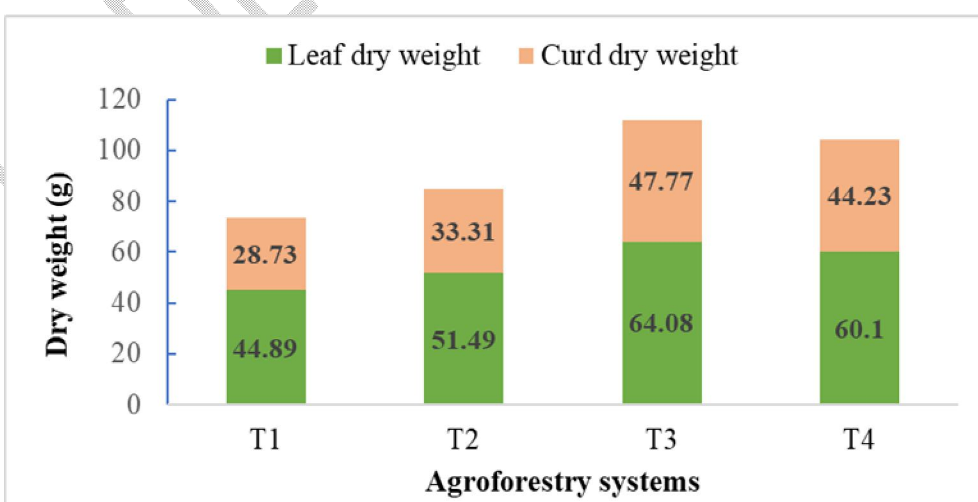

Fig. 5. Leaf dry weight and curd dry weight plant^{-1} of cauliflower is grown under different aonla-based multistoried agroforestry systems.

3.5 Linear relationship between PAR (%) in the agroforestry system and the yield of cauliflower

There was a linear relationship between PAR (%) in the agroforestry system and the yield of cauliflower (Fig. 6.) was noted and estimated as Y = 0.3964X+6.2727, the findings of the equation revealed that increasing PAR (%) increased the yield of cauliflower. The R^2 value (0.8045) was positive and significant, which indicated that the contribution of 80.45% of cauliflower yield could be attributed to PAR (%) of the agroforestry system. The relationship also stated that the yield of cauliflower was increased at the rate of 0.3964 t ha^{-1} per unit changing of light intensity (PAR μ mol m^{-2} s^{-1}).

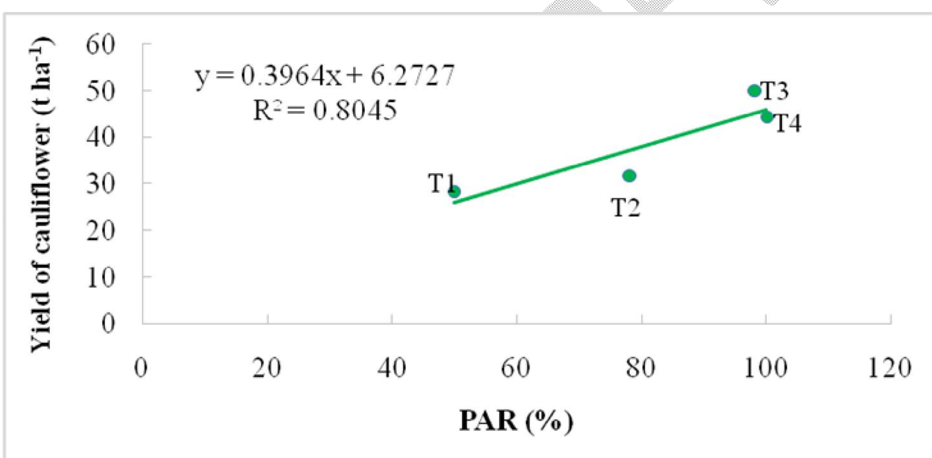

Fig. 6. Relationship between PAR (%) of agroforestry system and yield of cauliflower in aonla-based multistoried agroforestry systems.

3.6 Land Equivalent Ratio (LER) and Benefit Cost Ratio (BCR)

The result in table 4 stated that the highest LER (3.20) was recorded in aonla + carambola + lemon + dragon fruit-based agroforestry system (T_1) and the lowest LER (2.17) was recorded in the dragon fruit-based system (T_3). The moderate LER (3.05) was recorded in the aonla+dragon fruit-based system (T_2). Considering gross income, the highest income (1185125 Tk ha^{-1}) was recorded in aonla + carambola + lemon + dragon fruit-based agroforestry system (T_1), and the lowest income (999980 Tk ha^{-1}) in open field conditions (cauliflower sole crop). On the other hand, the highest benefit-cost ratio (BCR) (2.62) was found in the dragon fruit-based system (T_3) and the lowest benefit-cost ratio (BCR) (1.97) was found in the open field condition (cauliflower sole crop).

Table 4. Economic and land use performances of cauliflower for the different production system

Systems	Gross income (Tk ha^{-1})	Rank	The total cost of production (Tk ha^{-1})	BCR	LER
Cauliflower sole (T_4)	504680	4th	444315	1.13	--
Aonla + Carambola + Lemon + Dragon fruit + Cauliflower(T_1)	1130420	2nd	526568	2.15	3.78
Aonla + Dragon fruit + Cauliflower (T_2)	1261384	1st	426298	2.95	3.63
Dragon fruit + Cauliflower (T_3)	1116420	3rd	384237	2.90	2.06

4. DISCUSSIONS

"Fruit tree vegetables-based agroforestry systems in Bangladesh have recently gained the attention of environmentalists, ecologists and farmers as the country has faced the problem of shrinking arable land and thus limited space for expanding arable land and cropping intensity" [8],24, 23]. "Growth parameters of cauliflower were found to be significant in an aonla-based multistoreid agroforestry system when compared to sole cropping system. Light availability is the most important limiting factor for underground crops in any multistory agroforestry system. The extent of light interception by tree crowns and competition for light are also limiting factors for the success of component crops in a multistory agroforestry system. It is reported that, agroforestry systems received different levels of light due to the different sizes and shapes of the overstory canopy" [25]. The research revealed that plant height, and leaf number was the highest in the agroforestry system. [26] observed that "plants grown in low light conditions have greater apical dominance than plants grown in high light environments, resulting in taller plants in partial shade". Leaf length and breadth are also highest in agroforestry systems because in the shade, leaves obtain more light for photosynthesis by increasing their surface area, so length and breadth are also higher. Simillar result also found in okra [27] and tomato [28]. This due to the stimulation of cell expansion and cell division of the leaf in the shade [29]. “Leaf dry weight and curd dry weight are important yields contributing characters that were found to be influenced by different aonla-based agroforestry systems and highest in dragon fruit-based system because being in intense shade may result in a decreased mobilization of reserve absorption to the reproductive organs” [30]. Fresh leaf weight was higher in open field condition. Similar to our results, [31] also noted that under high light conditions, the thickness of leaves, palisade parenchyma and spongy parenchyma is greater, stomata frequency and stomata area per unit leaf area were also higher. Yield parameters of cauliflower were found to be significant in dragon fruit based system. These results might be due to higher photosynthetic production in full light conditions and lower competition of water and nutrients in dragon fruit-based system which caused higher curd yield as compared to that of open field condition, aonla + carambola + lemon + dragon fruit-based agroforestry system and aonla+dragon fruit-based system. “Furthermore, the most notable point is that under open field conditions, a large number of cabbage plants were combined compared to the agroforestry systems, which eventually heightened their overall BCR. Apart from this, the BCR of the agroforestry system was protuberant, whereas aonla+dragon fruit-based agroforestry system had the highest BCR (2.95) compared to the other systems. The LER, on the other hand, is a measure of the relative performance of a crop in an intercropping system compared to that of sole cropping, and the LER values above 1 showed the benefit of intercropping concerning the use of environmental resources for plant growth” [8]. Our study showed a high LER value in aonla + carambola + lemon + dragon fruit-based agroforestry system (3.78), which indicated that 3.78 times higher land would be needed to obtain comparable products from the sole cultivation of similar components. To summarise, the aonla-based agroforestry system not only provides fruit and vegetable products to ensure food and nutrition security, but also increases economic returns and ensures maximum land use. As a result, this system may be regarded as a sustainable agricultural system and may be applicable to other parts of the country.

5. CONCLUSION

In a resource-constrained country like Bangladesh, aonla-based agroforestry systems can play a vital role in producing multiple yield components throughout the year. Despite the single cropping system of seasonal crops providing higher yield than their respective agroforestry, but total system production was higher in dragon fruit-based agroforestry. The net return to benefit-cost ratio was better in the aonla+dragon fruit agroforestry system and the land equivalent ratio was better in the aonla+carambola+lemon+dragon fruit-based agroforestry system compared to the single crop systems. Thus, seasonal and annual crops could be successfully grown in aonla-based agroforestry and farmers could be encouraged to practice these systems for higher production, income generation, and maximization of land use.

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