Performance assessment Of Indian Spinach (Basella alba) as an Under Storey Crop in Aonla-Lemon Based Multistoried Agroforestry System Manuscript Draft

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Research Article

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Abstract	Multistoried agroforestry in Bangladesh is decisive to deal with the challenge of shrinking arable land and repeated climatic hazards together with a handsome economic benefit to the farmers of the country. This research aimed to investigate the performance of Indian spinach in an aonla-based multistoried agroforestry which was contrasted alongside the production of open field condition of five different Indian spinach varieties that were also inspected for best-performing varieties. The results reveal that with the differences in Photosynthetically Active Radiation (PAR) various growth and yield-related attributes get affected as a result yield decreased in T_1 (Aonla+Lemon+Indian Spinach) followed by T_2 (Aonla+Indian Spinach) than T_3 (Open field) which could be attributed to competition for above and below ground resources. But in fact, the total output of T_1 was highest followed by T_2 than T_3 because diversified products in the Agroforestry system added to the total output and ratified the superiority of the agroforestry system over the sole crop. Whereas in case of different varieties BARI puishak 2 proved its supremacy over other four varieties. Among the treatment combinations, BARI puishak 2 in combination with T_1 agroforestry system (T_1V_2) proved best performing in respect of the benefit-cost ratio (BCR) of 3.68 and Land Equivalent Ratio (LER) value of 3.56. In a nutshell, the study concluded that agroforestry practices with Indian spinach could be an excellent alternative to ensure higher financial benefit, protect and preserve the environment and promote food and nutritional security to the impoverished farmers of Bangladesh.

Keywords:	Keywords: Multistoried agroforestry · Indian spinach · Benefit Cost Ratio (BCR) · Photosynthetically Active Radiation (PAR) · Land Equivalent Ratio (LER)
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Competing interest:	There is no conflict of interest to anyone else with this research.
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1. INTRODUCTION

Bangladesh harbor circa 165.16 million people which delineates most susceptible region of recurrent natural hazards and listed in seventh position out of 180 countries in global climate risk index[1]–[3]. Agriculture is the backbone of its economy also ensures food-security and it determines sustenance of the mass [4], [5]. The periodic climate disasters such as extreme high temperature, severe drought, flash flood, cyclone etc. hampers growth of the agricultural sector and also menace food security of the country[6], [7]. Due to the increase in climate variability and recurrent extreme weather events; alternate adoption options are needed to help the most vulnerable people[8]. Although Bangladesh has done tremendous improvements in different dimensions of agricultural sector in last few years but the people facing hunger are still around 24.2m[9][10]. In addition, rapid urbanization, development of new housing for a rapidly growing population and new development projects decrease a significant proportion of agricultural land by 80,000 ha per year[11]–[13]. Moreover, 40 million people faces food insecurity, a significant number of children are affected by severe to acute malnutrition, about half of the women suffer from anemia and it costs US$ 16.78 per capita each year to lose productivity for malnutrition[14]. The country needs 13.25 million metric tons of vegetables per year, contrarily it produces 3.73 million metric tons only. In Bangladesh per capita daily consumption of fruit and vegetables is 56g but WHO and FAO recommend 400g[15], [16]. Aonla is native to the Indian subcontinent, a symbol of sacred fruit popularly known as Amritphal and mentioned in ancient literature. It is characterized by the Euphorbiaceae family also known as Indian gooseberry. This fruit is familiar in different regions of the world such as India, Pakistan, Srilanka, Malaysia, the USA, Cuba and the West Indies[17]. Aonla popularly known for its great nutritive potentiality contains ascorbic acid (300-900mg/ 100g), amino acids and various valuable phytochemicals like tannin, polyphenol, linoleic acid, emblicol, corilagin, phyllemblin and rutin [18]. A Mediterranean-grown citrus species mainly native to Asia Lemon (Citrus limon) belongs to the Rutaceae family which is very well known for its food and medicinal uses. It contains various vitamins and minerals, dietary fibres, organic acid, flavonoids, carotenoids, essential oils etc. Another well-accepted component of agroforestry system in this country is Lemon which is admired for its wide range of health benefits like anti-carcinogenic properties in addition to used to produce ethnic herbal medicine for decades in different parts of the world [19]. Indian spinach (*Basella alba*) is a member of Basellaceae family. It is distinguished for it's herbaceous, perennial and usually short lifespan, succulent stem[20]. It contains vitamins like A, C, B9, minerals like calcium, magnesium and iron, dietary fibre, phenols, antioxidants, various bioactive compounds, essential amino acids[21], [22]. Agroforestry integrates perennial plants with crops and or animals in spatial arrangement or temporal sequence on a unit of land with an ecologically diversified management system that must be socially, economically and environmentally accepted. With uniting the gap between agriculture, forestry and animal husbandry agroforestry provides immense ecosystem services including climate change mitigation as well as individual befits for smallholders[23]–[26]. Agroforestry provides the gateway to resolve the issue of economic, environmental and social benefits as well as nutritional security, improving rural livelihoods of poor farmers of the country[27]. Additionally, the incorporation of woody perennials in cropland boosts soil properties physically, chemically and biologically through accelerating decomposition of organic matter[28]. Although agroforestry is a long-term investment and needs appropriate planning for the complex systems that seems difficult to predict quick outcomes which hinders the adoption to the poor and needy farmers[29].

Multistoried agroforestry gaining popularity gradually for its sustainable land use system that actually combines woody perennials and or crops in it's layer successfully decreasing soil degeneration, improve fertility of soil and quality of water, conserve biodiversity and most importantly initiate carbon acquisition to relieve global warming[30]. In Bangladesh, climatic conditions, soil fertility, water regimes, topography, and socioeconomic conditions are the key determinant factors to explore the conventional as well as contemporary agroforestry systems. Fascinatingly, the peoples of Bangladesh currently practicing several modern fruit tree-based multistoried agroforestry systems namely jackfruit (*Artocarpus heterophyllus* L.), mango (*Mangifera indica* L.), guava (*Psidium guajava* L.), litchi (*Litchi chinensis* Sonn.), and aonla (*Phyllanthus emblica* L.) based system due to short-term juvenile stage, higher selling price, contribution to family dietary and nutrition as well as tolerant to various biotic and abiotic stressed conditions[31]. Among the popular fruit tree-based agroforestry systems, aonla (*Phyllanthus emblica* L.) based multistorey agroforestry system (AMAFs) is increasingly recognized as a highly profitable and sustainable system in Bangladesh as aonla is deciduous in nature, therefore having fewer impacts on understory crops, including regular fruit bearing habits, sustain and thrive in adverse environmental conditions, and requires low management and inputs[32]. Furthermore, aonla fruits are reported to have antioxidant, antimicrobial, antibacterial, anti-viral, anti-tumour, and anti-inflammatory properties[33]. Despite having enormous nutritional benefits and promising agroforestry system, their combination with scientific harmonization in a unit of land as fruit tree-based multistorey agroforestry is yet inadequate. On that account, this experiment intended of investigating future potentiality for the aonla-based multistoried agroforestry through evaluating: i) the performance for different Indian spinach varieties or genotypes in agroforestry systems ii) the relationship between crop yield and light (PAR %) in different agroforestry system, iii) economic profitability in respect to BCR and iv) the capability of land usefulness as LER. The outcomes of this research will help us to get insights into better management strategies for the future along with the selection of compatible species to boost agricultural yields.

2. MATERIALS AND METHODS

2.1 Experimental site:

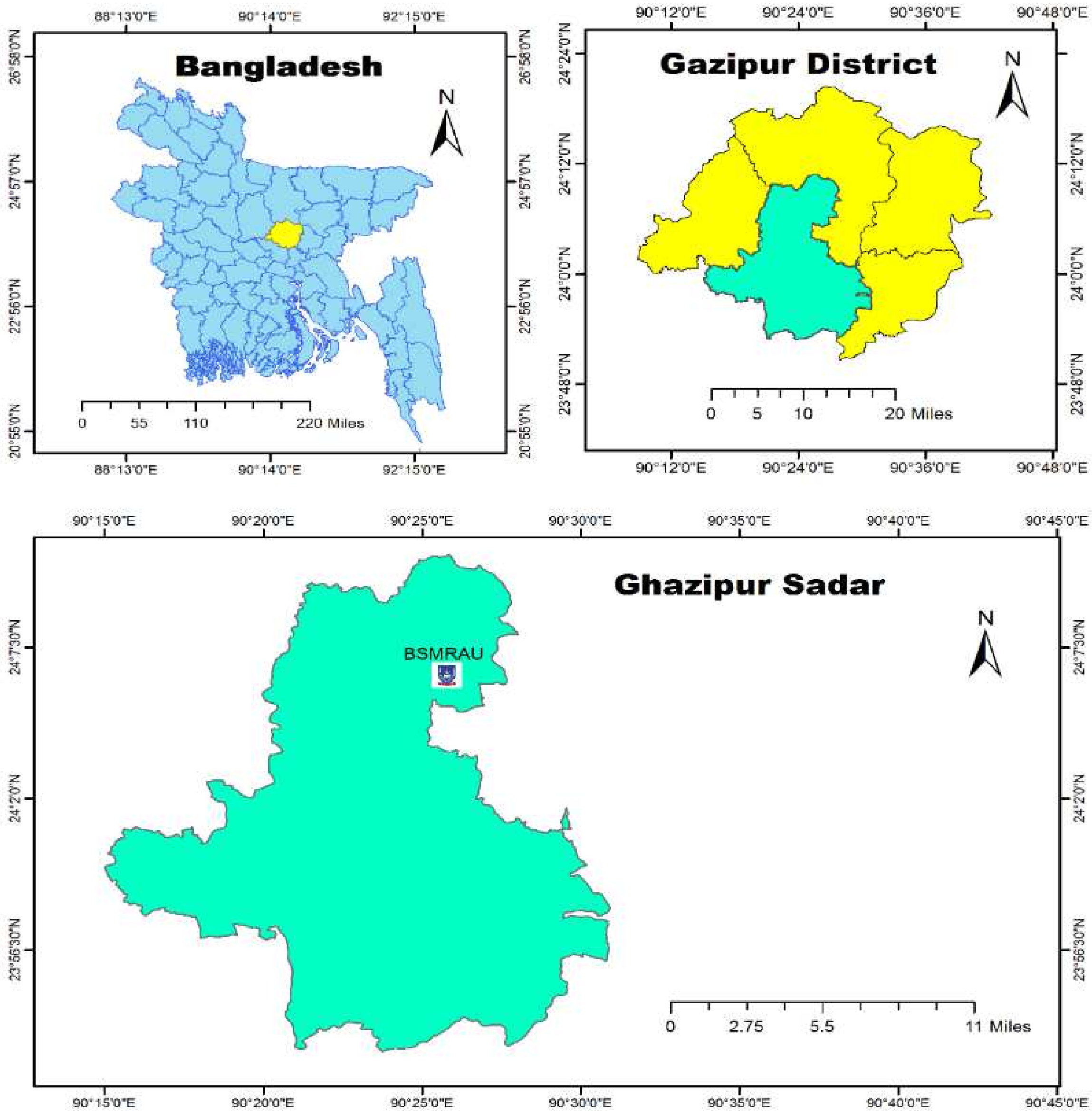


Fig 1 Study area location in the map

This research was accomplished under plio-pleistocene terrace deposits area which is geologically the Madhupur tract at Aonla orchard in BSMRAU, Gazipur (Fig-1) from May 2014 to August 2014. The study area located at 24.09^{o} N latitude and 90.26$^{o'}$ E longitude accompanied by an elevation of 8m. The site is under agroecological zone 28 which is the Inseptisol order and Ustocharpets suborder of USDA soil taxonomy. The soil series is well known as the Salna series of Shallow-Red-Brown terrace soil in Bangladesh[34]. The landscape is located in a level upland, dissected terraces related with shallow, broad or deep basins. The soil is strongly acidic with low status of organic substances, low moisture holding capacity and low fertility. Maximum and minimum temperature of the experimental site is 34^{0} C and 11.9^{0} C respectively with 2070mm annual rainfall.

2.2 Description of the farm:

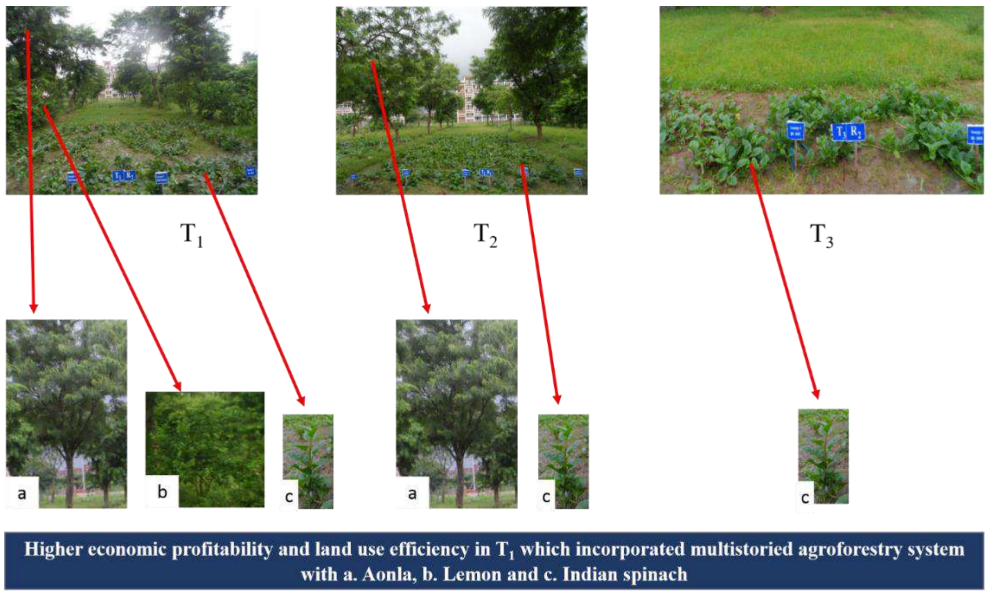


Fig 2 Experiment field where T_1 (a. Aonla, b. Lemon and c. Indian spinach), T_2 (a. Aonla, and c. Indian spinach), T_3 (c. Indian spinach)

The 14-year-old aonla orchard was established maintaining an 8 m x 8 m distance and lemon plants were planted in between aonla trees as a middle storey. As lower storey crop Indian spinach was grown. Aonla trees as an upper storey, lemon as middle and Indian spinach as lower storey crops comprise the whole Multistoried Agroforestry System (MAFS) (Fig-2). The aonla plant's average height was 5.56m to 5.64m, base diameter 20.02cm to 20.06cm, diameter at breast height 14.66cm to 15.62cm, and canopy diameter 3.36m to 3.44m. The lemon plants' average tree height was 83.20cm to 83.40 cm, base diameter 15.13mm to 15.20 mm, canopy diameter (North-South) 47.40 cm to 48.20 cm, and canopy diameter (East-West) 49.20 cm to 49.80 cm. This race of Aonla was local and lemon was BARI developed seedless lebu. Five Indian spinach genotypes (BARI Puishak 1, BARI Puishak 2, Genotype-10450, Genotype -10451 and Genotype 10452) were collected from Plant Genetic Resources Centre (PGRC), BARI, Joydebpur, Gazipur and were evaluated in the vacant spaces of the aonla orchard.

2.3 Outline of the Experiment and Treatment combinations:

Two-factor RCBD with four replications was practiced as experimental design. Factor A: Agroforestry Systems, T_1 = Aonla + Middle storied tree species (Lemon), T_2 = Aonla only and T_3 = Open Field (control). Factor B: Five different indian spinach varieties, V_1 - BARI Puishak- 1, V_2 - BARI Puishak- 2, V_3 - Genotype-10450, V_4 - Genotype -10451, V_5 - Genotype -10452. Each Indian spinach varieties were interacted with three agroforestry systems and made 15 different treatment combinations.

2.4 Crop establishment and management practices:

Before sowing seeds of Indian spinach land preparation was done by ploughing and laddering to have quality tilt. All activities of land preparation (e.g. ploughing, levelling, removal of weeds and stubbles etc) were done by the 10th of May. The recommended doses of fertilization @ 21 kg ha^{-1} of N as Urea, 20 kg ha^{-1} of P as TSP, 30 kg ha^{-1} of K as MOP, and 7.20 kg ha^{-1} of S as Gypsum for Indian spinach was done as basal dose. Indian spinach seed was sown maintaining 30 x 20 cm spacing on 12 May 2014. Different intercultural operations such as Irrigation, weeding, and thinning was done as required. To restrict the spread of leaf spot disease in Indian spinach Dithane M-45 @ 2gm/liter was spayed.

2.5 Collection of the samples and data recording:

Indian Spinach was harvested three times at 20 days intervals: 45 DAS, 65 DAS and 85 DAS. After harvesting vine samples were collected for data collection. Vine length, number of leaves per vine, base girth, weight of leaves per vine, and weight of stem was measured at every harvesting time. Fresh yield and dry yield were estimated. For calculating the dry yield 200g subsample was oven dried at 70^0 C for 12 hours. The following formula was used to determine the Total dry weight.

$$\text{Total dry weight} = \frac{\text{Subsample oven dried weight}}{\text{Subsample fresh weight}} \times \text{Total fresh weight}$$

2.6 Light measurements

Sunflex Ceptometer (LP-80 AccuPAR) was used to estimate light in every two weeks to quantify shading over understory crops.

2.7 Economic Performance

In Agroforestry BCR is applied to predict the relative profit of a system over other conventional systems. The initial cost for establishing the plantation was computed for both fruit species (Aonla and Lemon) then the fixed cost per year was obtained by dividing the amount with life span of the trees. By adding the fixed cost with variable cost total input cost was estimated. All values of input and outputs were calculated by market values of that period. The total input cost consists of the rental value of land, material cost, labour cost, 9% interest of the total cost and miscellaneous cost. Gross return was estimated to know the market value of total products byproducts by multiplying total production with the market price of the products and byproducts. Net return justifies the profitability of the MAFS which is derived from deduction of total cost with gross return. Then the following formula was used to estimate BCR[35]:

$$Benefit\ Cost\ Ratio\ (BCR) = \frac{Gross\ return}{Total\ cost\ of\ production}$$

LER reflects comparative land requirement of an intercrop with mono-crop of the species.

$$\text{Land Equivalent Ratio (LER)} = \frac{Ci}{Cs} + \frac{Ti}{Ts}$$

Where Ci denotes crop product obtained from Agroforestry, Cs denotes crop product obtained from sole crop of that species, Ti denotes tree product obtained from Agroforestry, and Ts denotes tree product obtained from sole crop of that species[36].

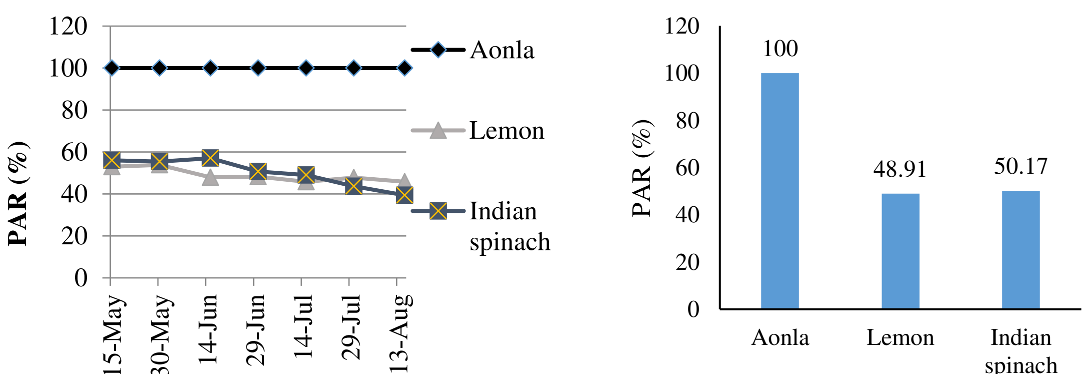
2.8 Statistical analysis

The data of all crop components about the morphological and physiological parameters were analyzed with Statistics 10 software to figure out the significant variations to each of the treatments by the LSD (Least Significant Difference) at 5% levels of significance[37].

3. RESULTS

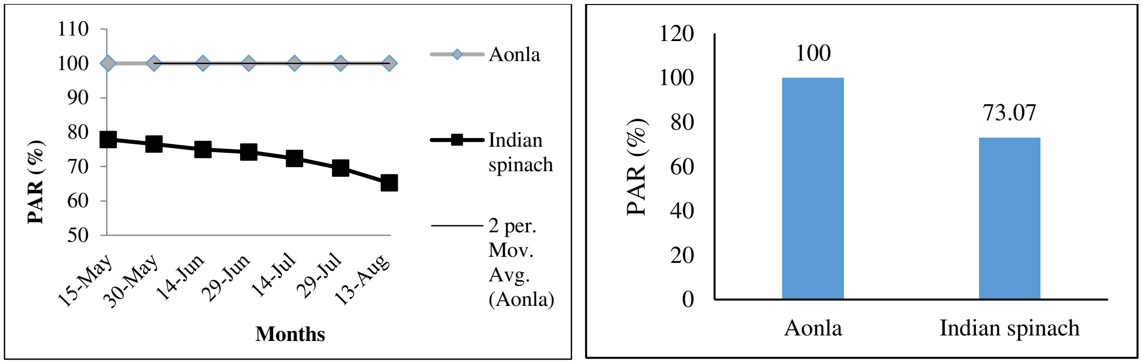
3.1 Availability of Photosynthetically Active Radiation

Light is unquestionably one of the most important yield-contributing resources. Accessibility of PAR at different strata of the Multistoried Agroforestry System was different. In the Aonla+Lemon+Indian spinach-based Agroforestry system incidents of PAR on lower-storied Indian spinach and lemon were 48.91% and 50.17% respectively (Fig. 3 A and B) and in the Aonla+Indianspinach-based Agroforestry system lower storied Indian spinach received 73.07% PAR (Fig. 4 A and B) amid Indian spinach growing season.



(A) Month wise (B) Average

Fig 3 Availability of Photosynthetically Active Radiation (PAR) at different strata of Indian spinach growing season in Aonla + Lemon + Indian spinach based Agroforestry system.

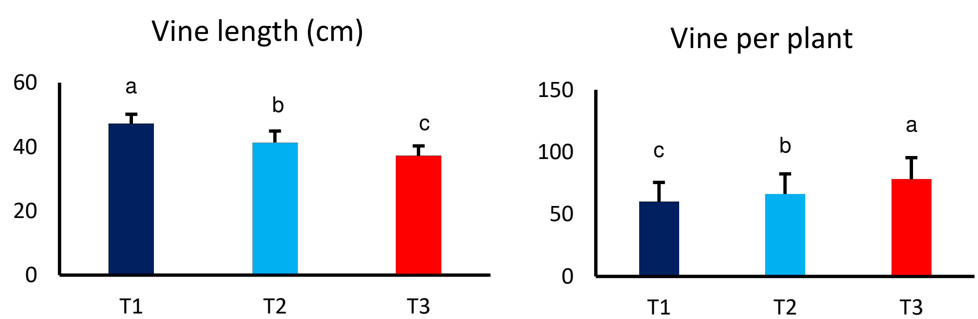


(A) Month wise (B) Average

Fig 4 Availability of Photosynthetically Active Radiation (PAR) at different strata of Indian spinach growing season in Aonla + Indian spinach based Agroforestry system.

3.2.1 Performance of Indian Spinach in different Agroforestry systems

In contrast with control (T_3) Indian Spinach grown in different agroforestry systems T_1 (Aonla+ Lemon+ Indian Spinach), T_2 (Aonla+ Indian Spinach) demonstrated depletion of leaf per vine (by 23.01%, 14.99%), base girth (by 13.73%, 12.12%), leaf fresh weight (by 17.63%, 10.01%), leaf dry weight (by 22.07%, 13.08%), leaf stem ratio (by 12.57%, 7.02%) and stalk weight (8.65%, 3.95%) and yield (by 13.88% and 7.48% respectively), contrarily an augmentation was noticed on vine length (by 26.92%, 11.25%) and SPAD value (by 2.51% and 0.43% respectively) Fig. 5.



(a) **(b)**

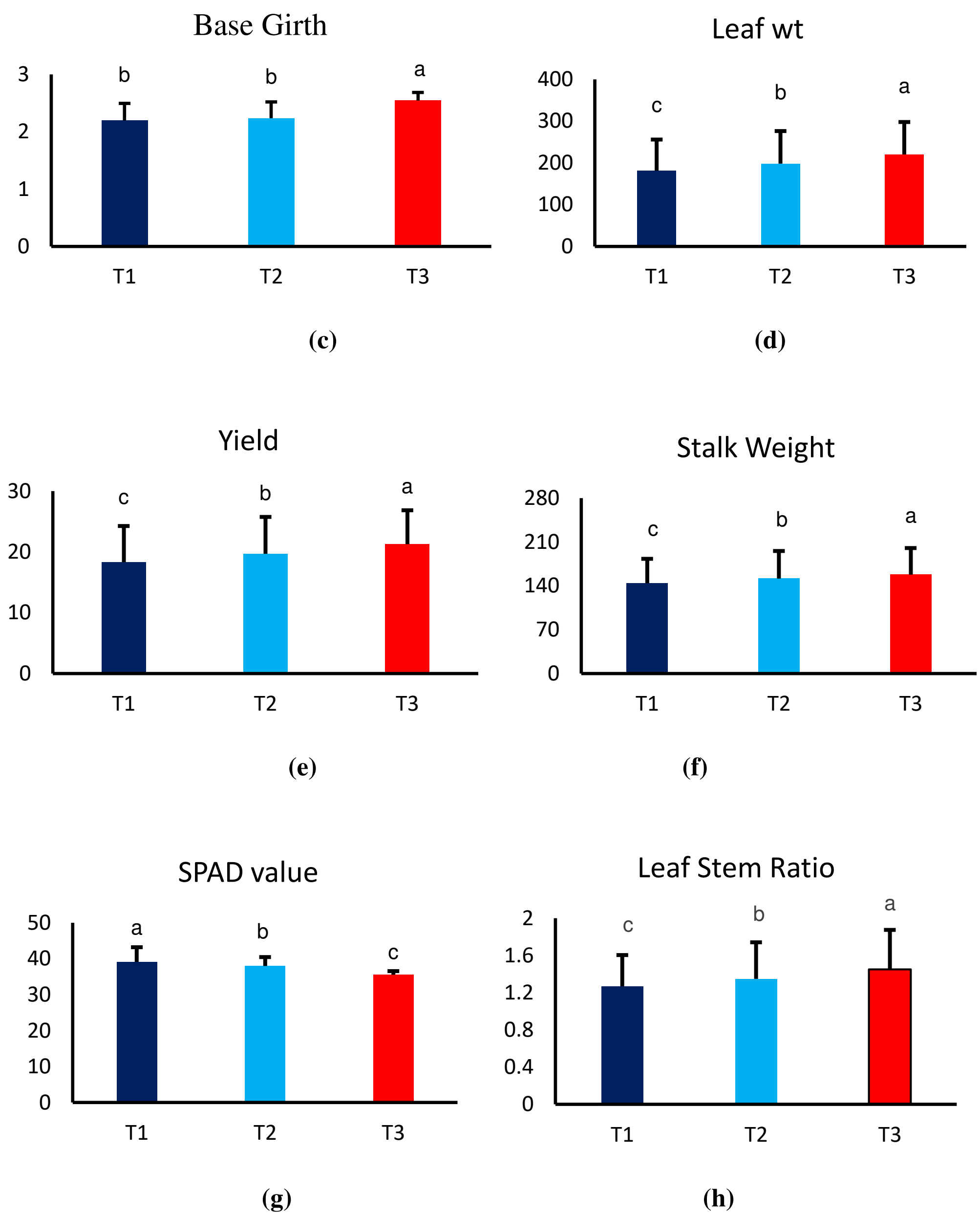
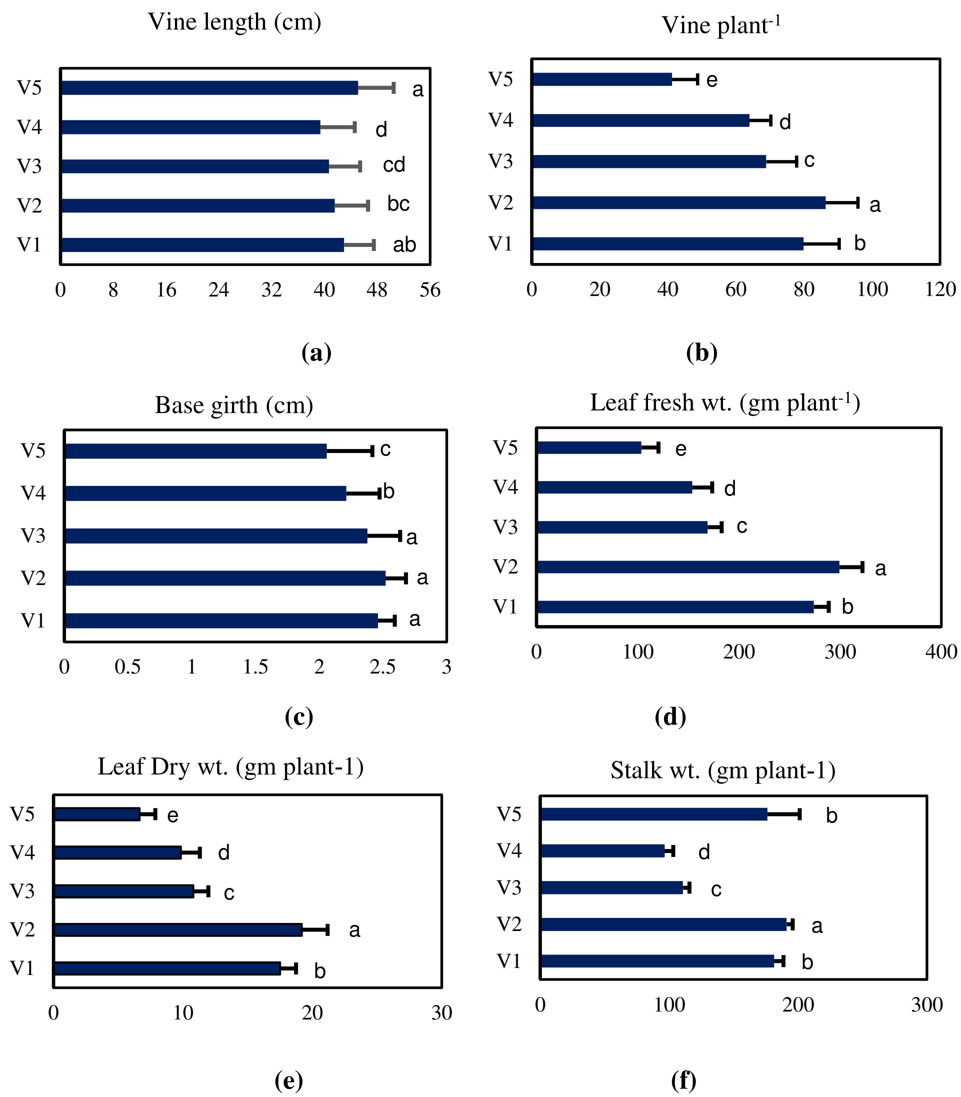
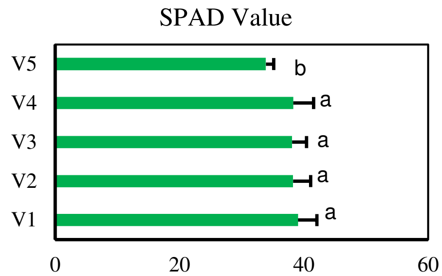


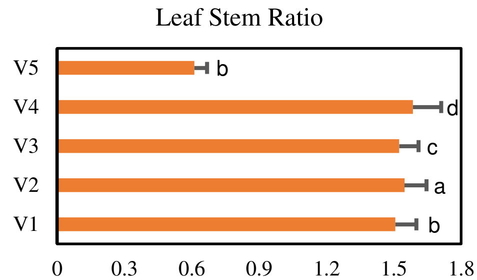
Fig 5 Evaluating performances of Indian spinach under different agroforestry systems (T_1 aonla+lemon+indian spinach, T_2 aonla+indian spinach), and T_3 (control). **a** vine length (cm), **b** vine per plant^{-1}, **c** base girth (cm), **d** leaf wt (gm), **e** yield (ton/ha), **f** SPAD value, **g** stalk wt. (gm), **h** leaf stem ratio. Value= means ± SEs, replications n = 4. Variation of alphabets over bars specifies significant differences (P < 0.05) within various treatments signifies LSD test.

3.2.2 Response of different varieties

Indian Spinach varieties exhibited significant differences in performances among themselves in which V_5 produced the highest (45.07cm) vine length and V4 produced the lowest (39.35cm), significantly V_2 produced highest (86.36 plant^{-1}) leaf per vine and V_5 produced the lowest (41.23 plant^{-1}), V_2 exhibited highest (2.52cm) base girth which is non-significant to V_1 and V_3 whereas V_5 exhibited lowest (2.06cm), V_2 produced highest (299.39gm) leaf fresh weight and V_5 produced lowest (103.68gm) as well as V_2 produced highest (19.181gm) leaf dry weight and V_5 produced lowest (6.64gm). V_2 also produced the highest stalk weight (191.23gm) and V_4 produced the lowest, V_1 exhibited the highest (39.07) SPAD value which was non-significant to V_2 (38.28), V_3 (38.12) and V_4 (38.3) whereas V_5 produced the lowest (33.9). The significantly highest yield (27.6ton hac^{-1}) was produced by V_2 and V_4 produced the lowest yield (14.07ton hac^{-1}). But interestingly leaf stem ratio (LSR) was highest in V_2 (1.59) among different treatment combination (Fig. 6).

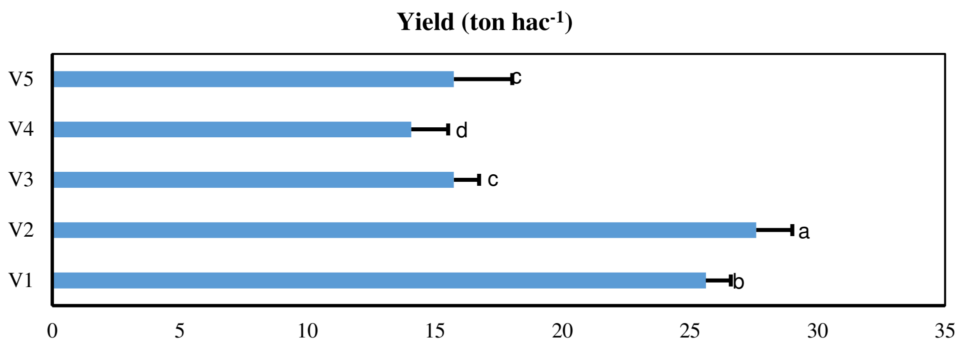






(g)

(h)



(i)

Fig 6 Responses of varieties of Indian spinach under different agroforestry systems (T_1 aonla+lemon+indian spinach, T_2 aonla+indian spinach), and T_3 (control). **a** vine length (cm), **b** vine plant^{-1}, **c** base girth (cm), **d** leaf fresh wt. (gm plant^{-1}), **e** leaf dry wt. (gm plant^{-1}) , **f** stalk wt. (gm), **g** SPAD value, **h** leaf stem ratio, **Ii** yield (ton hac^{-1}). Value= means ± SEs, replications n = 4. Variation of alphabets over bars specifies significant differences (P < 0.05) within various treatments signifies LSD test.

3.2.3 Relationships between agroforestry systems with varieties

Interaction effect of Agroforestry systems and varieties of Indian spinach on different growth and yield contributing characters manifested significant variation among the treatment combinations. In comparison with control (T_3), different Indian Spinach varieties V_1, V_2, V_3, V_4 and V_5 grown at different agroforestry systems exhibited augmentation of vine length by (18.27%, 27.36%, 27.27%, 30.45%, 31.94% in T_1 but 4.41%, 9.18%, 16.51, 7.71% and 18.64% respectively in T_2 treatment) augmentation of SPAD value by (17.86%, 13.69%, 8.32%, 15.21%, 5.42% in T_1 and 11.51%, 8.51%, 8.15%, 2.41% in T_2) abatement of leaf per vine by (23.46%, 20.46%, 25.39%, 16.28%, 33.19% in T_1 and 17.79%, 11.11%, 11.86%, 16.95%, 19.42% in T_2) reduction of Base girth by (4.80%, 10.41%, 12.83%, 15.78%, 25.82% in T_1 and 0.40%, 8.92%, 18.11%, 12.70%, 20.90% in T_2) depletion of leaf fresh wt. by (11.02%,15.92%, 16.25%, 24.54%, 29.77% in T_1 and 2.49%, 9.92%, 11.15%, 16.61%, 16.56% in T_2) leaf dry wt. by (14.97%, 21.14%, 21.06%, 28.22%, 33.62% in T_1 and 5.33%, 13.77%, 14.20%, 18.78%, 19.23% in T_2) stalk wt. by (-1.91%, 2.29%, 3.84%, 9.42%, 26.34% in T_1 and -7.13%, 1.90%, 4.90%, 10.78%, 11.58% in T_2) abatement of leaf stem ratio by (12.96%, 12.65%, 11.73%, 16.37%, 1.59% in T_1 and 8.64%, 7.23%, 5.56%, 5.85%, 6.35% in T_2) and finally reduction of yield by (6.10%, 10.87%, 11.55%, 19.00%, 27.63% in T_1 and -1.15%, 6.95%, 8.76%, 14.46%, 13.43% in T_2) Table١.

Table ١: Interaction among different treatment combinations on vine length, leaf per vine, base girth and SPAD value

Interaction	Vine length (cm)	Leaf per vine^{-1}	Base girth (cm)	Leaf fresh weight. (g plant^{-1})	Leaf dry weight. (g plant^{-1})	Stalk weight. (g plant^{-1})	Leaf Stem Ratio	Yield (ton hac^{-1})
T_1V_1	47.25± 0.71^{ab}	70.86±0.74^{e}	2.38±0.031^{cde}	255.42±0.6^{e}	15.96±0.04^{e}	179.44±3.91^{cd}	1.41±0.012^{e}	24.46±0.08^{d}
T_1V_2	47.16± 0.61^{b}	76.77±1.14^{cd}	2.41±0.029^{bcd}	275.45±0.53^{d}	17.12±0.03^{d}	189.49±2.26^{b}	1.45±0.008^{de}	26.15±0.05^{c}
T_1V_3	45.18± 0.53^{bc}	58.71±0.6^{f}	2.31±0.045^{cdef}	155.84±0.58^{i}	9.67±0.04^{i}	109.76±1.83^{fg}	1.43±0.015^{de}	14.94±0.05^{h}
T_1V_4	45.54± 0.36^{b}	60.25±0.48^{f}	2.055±0.055^{fgh}	134.45±1.3^{j}	8.37±0.08^{j}	93.66±4.7^{hi}	1.43±0.022^{de}	12.83±0.13^{i}
T_1V_5	50.89± 0.35^{a}	33.40±0.48^{i}	1.81±0.059^{h}	86.11±0.89^{m}	5.35±0.06^{l}	148.58±12.29^{e}	0.62±0.089^{f}	13.2±0.14^{i}
T_2V_1	41.71± 0.87^{cd}	76.11±0.97^{cd}	2.49±0.04^{abc}	279.86±1.19^{cd}	17.77±0.08^{c}	188.64±4.9^{bc}	1.48±0.03^{cd}	26.35±0.12^{c}
T_2V_2	40.43± 0.53^{de}	85.80±0.85^{b}	2.45±0.026^{abc}	295.11±1.02^{b}	18.72±0.06^{b}	190.26±7.52^{b}	1.54±0.06^{c}	27.3±0.12^{b}
T_2V_3	41.36± 0.66^{d}	69.36±0.28^{e}	2.17±0.034^{defg}	165.33±0.82^{h}	10.51±0.05^{h}	108.55±4.98^{fg}	1.53±0.03^{c}	15.41±0.11^{gh}
T_2V_4	37.60± 0.45^{ef}	59.77±0.2^{f}	2.13±0.053^{efg}	148.59±1.41^{i}	9.47±0.09^{i}	92.25±4.52^{i}	1.61±0.03^{b}	13.55±0.13^{i}
T_2V_5	45.76± 0.19^{b}	40.28±0.68^{h}	1.93±0.067^{gh}	102.31±1.47^{l}	6.51±0.09^{k}	178.36±14.11^{d}	0.59±0.047^{f}	15.79±0.22^{gh}
T_3V_1	39.95± 0.72^{de}	92.58±1.28^{a}	2.5±0.01^{abc}	287.02±0.93^{c}	18.77±0.06^{b}	176.08±6.7^{d}	1.62±0.045^{b}	26.05±0.13^{c}
T_3V_2	37.03± 0.7^{ef}	96.52±1.25^{a}	2.69±0.018^{a}	327.62±0.58^{a}	21.71±0.04^{a}	193.94±1.59^{ab}	1.66±0.015^{ab}	29.34±0.04^{a}
T_3V_3	35.50± 0.42^{f}	78.69±0.92^{c}	2.65±0.025^{ab}	186.07±1.56^{f}	12.25±0.1^{f}	114.14±6.17^{f}	1.62±0.026^{b}	16.89±0.17^{f}
T_3V_4	34.91± 0.77^{f}	71.97±0.76d^{e}	2.44±0.027^{abc}	178.18±1.43^{g}	11.66±0.09^{g}	103.4±5.14^{gh}	1.71±0.039^{a}	15.84±0.14^{g}
T_3V_5	38.57± 0.31^{def}	49.99±0.63^{g}	2.44±0.027^{abc}	122.61±2.1^{k}	8.06±0.14^{j}	201.71±8.02^{a}	0.63±0.024^{f}	18.24±0.22^{e}

values are described as mean± se, replication n=4, and the alphabetic letters denote significant differences ($p<0.05$; lsd test).

3.3 Economic as well as land use performance

Gross return of Indian Spinach found to be increased in T_1 and T_2 agroforestry system than control T_3 and it was highest in T_1V_2 (222,768/- tk) treatment combination and lowest in T_3V_4 (95,034/- tk) treatment combination similarly net return was also highest in T_1V_2 (162,268/- tk) treatment combination and lowest in T_3V_4 (34,534/- tk) treatment combination. In contrast with control higher BCR was exhibited by T_1 followed by T_2 at the same time as gross return and net return, BCR was also found to be highest in T_1V_2 (3.68) treatment combination and lowest in T_3V_4 (1.57) treatment combination. Afterwards, LER was also observed as higher in the T_1 agroforestry system than the T_2 agroforestry system and interestingly LER was found highest in T_1V_2 (3.56) but lowest in T_2V_4 (2.17) Table ٢.

Table ٢: Estimation of Benefit cost ratio (BCR) and Land equivalent ratio (LER)

Treatment combination	Gross return (Tk ha^{-1})	Net Return (Tk ha^{-1})	BCR	LER
T_1V_1	204766	144266	3.38	3.51
T_1V_2	222768	162268	3.68	3.56
T_1V_3	172840	112340	2.86	3.51
T_1V_4	165992	105492	2.74	3.43
T_1V_5	170712	110212	2.82	3.35
T_2V_1	189218	128718	3.13	2.32
T_2V_2	186412	125912	3.08	2.24
T_2V_3	129936	69436	2.15	2.22
T_2V_4	116622	56122	1.93	2.17
T_2V_5	127028	66528	2.10	2.18
T_3V_1	156294	95794	2.58	-
T_3V_2	176028	115528	2.91	-
T_3V_3	101322	40822	1.67	-
T_3V_4	95034	34534	1.57	-
T_3V_5	109458	48958	1.81	-

3.4 Relationship between PAR (%) and yield of Indian spinach varieties

The light interception (PAR) in the Agroforestry system through the Aonla canopy is positively correlated (correlation coefficient 81%) with the yield of Indian Spinach. Regression analysis was done to elucidate the interrelationship between Photosynthetically Active Radiation (PAR) with crop yield. From the results, we determine that canopy volume-induced PAR interception of the Aonla plant under agroforestry systems moderately influences the yield of Indian Spinach as evidenced by the r2 value 0.66 (Fig. 5).

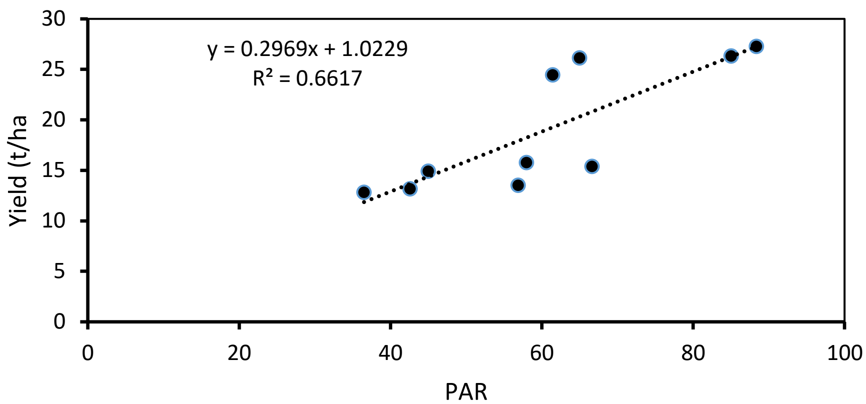


Fig 7 Interrelationship of PAR (%) with yield of Indian spinach varieties under aonla-based multistoried Agroforestry systems.

4. DISCUSSION

The successful outcome of agroforestry relies on effective combination of crop, woody perennials and or animals to maximize the profitability of an unit land to feed a fast growing population with shrinking arable land like Bangladesh. Aonla possesses tremendous advantage due to its deep-rooted, deciduous nature and sparse foliage making it convenient for the understory crop to grow auspiciously which aids to raise farmers income in a unit area of land[38]. As a tree aonla exert some negative aspects to the understory crop. Different growth parameters of lower-storied Indian spinach were affected significantly by upper-storied Aonla and middle-storied lemon and as a consequence, the yield of Indian spinach was curtailed (Table-1). This phenomenon could be described as competitiveness of two or more component for the limited resources especially for light, water and nutrition[39]. Reduction of yield is directly linked with the reduction of PAR whereas, in T_1 treatment, Indian spinach receives less PAR than T_2 treatment. Consequently, yield reduction is greater in T_1 than T_2 treatment. In Treatment T_3 (open field condition), under full sunlight which supports better photosynthetic assimilation and growth indices yielded the highest. Subsequently, this ensures higher yield while on the contrary, in T_1 and T_2 treatments, shading reduces PAR % at lower level directing to less carbon assimilation emanating less leaf per vine, less leaf fresh wt., less stalk wt. which would finally decrease the yield. Similar results were corroborated by L. S. Pingkiet *et al.* in cauliflower and also by J. Ferdous *et al.* in radish under Aonla-based Multistoried Agroforestry System[40],[41]. Besides, yield in cereals is reduced by the shading of almond trees[42].

Nonetheless, yield reduction also happens for below ground competition for resources. However, this effect is reduced to a minimum in the long term[43]. Though, water and nutrients was provided for the crop as recommended but especially in T_1 treatment where yield reduction is maximum the profuse root systems of Aonla trees snatch most of the resources. This kind of crop yield depletion also coincided with the results of A. K. Das *et al.* [44]. Interestingly vine length of Indian spinach was increased significantly in T_1 compared to T_2 and T_3 treatment which might be associated with apical dominance in low light conditions also stated by Z. Al Riyadh increase in plant height for apical dominance because of higher auxin production under the shady state of turmeric, ginger and chilli in Jackfruit-papaya based multistoried agroforestry system[45].

Being a leafy vegetable, Indian spinach can be a great option to grow as an under-storey crop which will maximize income and also meet the nutritional demand of farmers. Higher economic return in agroforestry systems might be correlated with several reasons. For instance, to grow Aonla fruit, no additional input (water and fertilizer) was applied but yielded better than sole aonla plantation as well as middle-storied lemon also yielded better with no additional inputs[46]. Trees in crop fields have some advantages on crop productivity such as continuous deposition of mulch and nutrient-enriching topsoil[47]. Additional resources from trees such as fruits, firewood, timber and non-timber also add to the income table. Aonla and lemon thus two fruits with higher market demand as well as Indian spinach as a popular leafy vegetable in Bangladesh around the year mainly contributed to the higher economic return (BCR) in agroforestry system (T_1) over T_2 (Aonla with Indian spinach) and T_3 (Aonla Only).

The land equivalent ratio (LER) figure more than 1 indicates the advantage of intercropping above the sole crop[48]. In our study, the highest LER value (3.56) in the T_1V_2 treatment combination indicates the benefit of intercropping is 3.56 times higher than sole cropping and also stipulates 3.56 times more land would be needed to achieve that comparable product with sole crop. Here we found V_2 (BARI puishak 2) in combination with T_1 treatment performed better over all the other varieties in any treatment combination concerning the BCR (3.68) and LER (3.56).

5. CONCLUSIONS

In the early stage of aonla orchard farmers will not get a fair benefit from it, over the years the economic output increases significantly as a result of higher market demand in the local market throughout the year. The economic turnover of this aonla-based multistoried agroforestry will be significantly escalated which is closely related to i) the amalgamation of Indian spinach in its unused spaces, specially BARI puishak 2 variety as it proved its superiority in terms of yield, BCR and LER over other Indian spinach varieties, ii) though the accessibility of PAR% decreases which ultimately declining the yield in agroforestry system compared to open field condition but total output remains highest due to its combined out-turn of the whole agroforestry system, iii) increment in BCR supports the statement that associated crop with aonla orchard created this system economically competitive iv) higher LER in agroforestry system also ensured better land use. Certainly, field trails in various locations for better viability of this system should be carried out. In a nutshell, it can be concluded that aonla based multistoried agroforestry has the potentiality to uplift the financially vulnerable peasants as well as safeguard the environmental sustainability.

REFERENCES

[1] A. Tasnuva, Q. H. Bari, A. R. M. T. Islam, and G. M. M. Alam, "Livelihood and climate vulnerability of coastal communities to natural disaster in south-western Bangladesh," *Int. J. Sustain. Dev. World Ecol.*, vol. 30, no. 3, pp. 295–318, 2023, doi: 10.1080/13504509.2022.2142691.

[2] D. Eckstein, V. Künzel, and L. Schäfer, *Global climate risk index 2021: who suffers most from extreme weather events? Weather-related loss events in 2019 and 2000–2019*, no. March. 2021. [Online]. Available: http://germanwatch.org/en/download/8551.pdf

[3] Bangladesh Bureau of Statistics (BBS), "Population & Housing Cencus 2022, Preliminary report," *Minist. Planning, Gov. People's Repub. Bangladesh*, p. 11, 2022.

[4] B. Hossain, M. S. Sohel, and C. M. Ryakitimbo, "Climate change induced extreme flood disaster in Bangladesh: Implications on people's livelihoods in the Char Village and their coping mechanisms," *Prog. Disaster Sci.*, vol. 6, p. 100079, 2020, doi: 10.1016/j.pdisas.2020.100079.

[5] T. Rahman, S. Ara, and N. A. Khan, "Agro-information Service and Information-seeking Behaviour of Small-scale Farmers in Rural Bangladesh," *Asia. Pac. J. Rural Dev.*, vol. 30, no. 1–2, pp. 175–194, 2020, doi: 10.1177/1018529120977259.

[6] A. Parven *et al.*, "Impacts of disaster and land-use change on food security and adaptation: Evidence from the delta community in Bangladesh," *Int. J. Disaster Risk Reduct.*, vol. 78, 2022, doi: 10.1016/j.ijdrr.2022.103119.

[7] N. C. Dey, M. Parvez, and M. R. Islam, "A study on the impact of the 2017 early monsoon flash flood: Potential measures to safeguard livelihoods from extreme climate events in the haor area of Bangladesh," *Int. J. Disaster Risk Reduct.*, vol. 59, no. April, p. 102247, 2021, doi: 10.1016/j.ijdrr.2021.102247.

[8] M. S. Uddin, C. E. Haque, M. N. Khan, B. Doberstein, and R. S. Cox, "'Disasters threaten livelihoods, and people cope, adapt and make transformational changes': Community resilience and livelihoods reconstruction in coastal communities of Bangladesh," *Int. J. Disaster Risk Reduct.*, vol. 63, no. April, p. 102444, 2021, doi: 10.1016/j.ijdrr.2021.102444.

[9] A. Quddus and J. D. Kropp, "Constraints to agricultural production and marketing in the lagging regions of Bangladesh," *Sustain.*, vol. 12, no. 10, pp. 1–24, 2020, doi: 10.3390/SU12103956.

[10] A. Das, M. Rahman, S. Saha, N. Sarmin, M. Hoque, and F. Bhuiyan, "Transforming Malta Orchard into Agroforestry System with Different Crops for Improving Productivity, Profitability and Land Uses," *Ann. Bangladesh Agric.*, vol. 24, no. 1, pp. 113–125, 2021, doi: 10.3329/aba.v24i1.51940.

[11] L. Wang, "Analyzing Urban Sprawl and Sustainable Development in Dhaka, Bangladesh," *J. Econ. Sustain. Dev.*, vol. 11, no. 6, pp. 9–20, 2020, doi: 10.7176/jesd/11-6-02.

[12] I. Islam *et al.*, "Dynamics of Tree outside Forest Land Cover Development and Ecosystem Carbon Storage Change in Eastern Coastal Zone, Bangladesh," *Land*, vol. 11, no. 1, 2022, doi: 10.3390/land11010076.

[13] N. N. Dey, A. Al Rakib, A. Al Kafy, and V. Raikwar, "Geospatial modelling of changes in land use/land cover dynamics using Multi-layer perception Markov chain model in Rajshahi City, Bangladesh," *Environ. Challenges*, vol. 4, no. May, p. 100148, 2021, doi: 10.1016/j.envc.2021.100148.

[14] M. Ali, M. R. Amin, J. Jarl, N. Chisholm, and S. Saha, “Maternal health status and household food security on determining childhood anemia in Bangladesh -a nationwide cross-sectional study,” *BMC Public Health*, vol. 21, no. 1, pp. 1–11, 2021, doi: 10.1186/s12889-021-11581-3.

[15] M. M. Rahman, D. Zhou, S. Barua, M. S. Farid, and K. T. Tahira, “Challenges of value chain actors for vegetable production and marketing in North-East Bangladesh,” *GeoJournal*, vol. 86, no. 4, pp. 1957–1967, 2021, doi: 10.1007/s10708-020-10170-y.

[16] U. Nations, *Food and nutrition in numbers: 2014*, vol. 52, no. 12. 2015. doi: 10.5860/choice.191448.

[17] A. K. Singh, S. Singh, and P. L. Saroj, “Aonla Scientific,” no. October, 2020.

[18] K. Parveen and B. S. Khatkar, “Physico-chemical properties and nutritional composition of aonla (Emblica officinalis) varieties,” *Int. Food Res. J.*, vol. 22, no. 6, pp. 2358–2363, 2015.

[19] R. K. Saini *et al.*, “Bioactive Compounds of Citrus Fruits: A Review of Composition and Health Benefits of Carotenoids, Flavonoids, Limonoids, and Terpenes,” *Antioxidants*, vol. 11, no. 2, 2022, doi: 10.3390/antiox11020239.

[20] G. Olaniran Adegoke, “Phytochemical, Antioxidant and Antimicrobial Activities in the Leaf, Stem and Fruit Fractions of <i>Basella Alba</i> and <i>Basella Rubra</i>,” *Plant*, vol. 5, no. 5, p. 73, 2017, doi: 10.11648/j.plant.20170505.11.

[21] P. C. Kumar, H. S. Oberoi, and S. Azeez, “Basella- an Underutilized Green Leafy Vegetable with a Potential for Functional Food Development,” *Food Rev. Int.*, vol. 38, no. S1, pp. 456–473, 2022, doi: 10.1080/87559129.2021.1874410.

[22] J. V. V. Tongco, A. D. Añis, and J. P. Tamayo, “Nutritional analysis, phytochemical screening, and total phenolic content of Basella alba leaves from the Philippines,” *Int. J. Pharmacogn. Phytochem. Res.*, vol. 7, no. 5, pp. 1031–1033, 2015.

[23] S. Shin, K. T. Soe, H. Lee, T. H. Kim, S. Lee, and M. S. Park, “A systematic map of agroforestry research focusing on ecosystem services in the Asia-Pacific region,” *Forests*, vol. 11, no. 4, pp. 1–23, 2020, doi: 10.3390/F11040368.

[24] Pantera, M. R. Mosquera-Losada, F. Herzog, and M. den Herder, “Agroforestry and the environment,” *Agrofor. Syst.*, vol. 95, no. 5, pp. 767–774, 2021, doi: 10.1007/s10457-021-00640-8.

[25] J. Bettles *et al.*, “Agroforestry and non-state actors: A review,” *For. Policy Econ.*, vol. 130, p. 102538, 2021, doi: 10.1016/j.forpol.2021.102538.

[26] R. S. Baliton *et al.*, “Ecological services of agroforestry systems in selected upland farming communities in the Philippines,” *Biodiversitas*, vol. 21, no. 2, pp. 707–717, 2020, doi: 10.13057/biodiv/d210237.

[27] R. Akter, M. K. Hasan, K. H. Kabir, D. Darr, and N. A. Roshni, “Agroforestry systems and their impact on livelihood improvement of tribal farmers in a tropical moist deciduous forest in Bangladesh,” *Trees, For. People*, vol. 9, no. April, p. 100315, 2022, doi: 10.1016/j.tfp.2022.100315.

[28] K. K. Islam, M. Saifullah, and K. Hyakumura, “Does Traditional Agroforestry a Sustainable Production System in Bangladesh? An Analysis of Socioeconomic and Ecological Perspectives,” *Conservation*, vol. 1, no. 1, pp. 21–35, 2021, doi: 10.3390/conservation1010003.

[29] H. Do, E. Luedeling, and C. Whitney, "Decision analysis of agroforestry options reveals adoption risks for resource-poor farmers," *Agron. Sustain. Dev.*, vol. 40, no. 3, 2020, doi: 10.1007/s13593-020-00624-5.

[30] M. M. U. MIAH, M. H. UDDIN, M. G. MIAH, M. M. RAHMAN, M. AHMED, and M. MATSUMOTO, "Changes of Soil Physical and Chemical Properties in Aonla (Phyllanthus emblica L.) based Multistoried Agroforestry System," *J. Fac. Agric. Kyushu Univ.*, vol. 67, no. 1, pp. 39–51, 2022, doi: 10.5109/4772340.

[31] M. G. Miah, M. M. Islam, M. A. Rahman, T. Ahamed, M. R. Islam, and S. Jose, "Transformation of jackfruit (Artocarpus heterophyllus Lam.) orchard into multistory agroforestry increases system productivity," *Agrofor. Syst.*, vol. 92, no. 6, pp. 1687–1697, 2018, doi: 10.1007/s10457-017-0118-1.

[32] V. C. Pande, R. S. Kurothe, G. Kumar, H. B. Singh, and S. P. Tiwari, "Economic assessment of agri-horticulture production systems on reclaimed ravine lands in Western India," *Agrofor. Syst.*, vol. 92, no. 1, pp. 195–211, 2018, doi: 10.1007/s10457-016-0025-x.

[33] H. M. Tag, O. E. Kelany, H. M. Tantawy, and A. A. Fahmy, "Potential anti-inflammatory effect of lemon and hot pepper extracts on adjuvant-induced arthritis in mice," *J. Basic Appl. Zool.*, vol. 67, no. 5, pp. 149–157, 2014, doi: 10.1016/j.jobaz.2014.01.003.

[34] Z. F. Bony, M. A. Rahman, Z. Al Riyadh, S. R. Saha, and M. Zakaria, "Productivity and Profitability Assessment of Lemon Based Agroforestry Systems in Bangladesh," *Asian Res. J. Agric.*, vol. 14, no. 2, pp. 42–49, 2021, doi: 10.9734/arja/2021/v14i230123.

[35] M. Hasan, G. Rahman, R. Akter, S. Hemel, and M. Islam, "Economic assessment of lemon-based agroforestry systems established in Madhupur Sal forest area of Bangladesh," *Progress. Agric.*, vol. 31, no. 1, pp. 45–55, 2020, doi: 10.3329/pa.v31i1.48311.

[36] N. Khasanah *et al.*, "Oil Palm Agroforestry Can Achieve Economic and Environmental Gains as Indicated by Multifunctional Land Equivalent Ratios," *Front. Sustain. Food Syst.*, vol. 3, no. January, pp. 1–13, 2020, doi: 10.3389/fsufs.2019.00122.

[37] S. Awalin, M. Shahjahan, A. Roy, A. Akter, and M. Kabir, "Response of Bell Pepper (Capsicum annuum) to Foliar Feeding with Micronutrients and Shoot Pruning," *J. Agric. Ecol. Res. Int.*, vol. 11, no. 3, pp. 1–8, 2017, doi: 10.9734/jaeri/2017/31620.

[38] S. Z. Hussain, B. Naseer, T. Qadri, T. Fatima, and T. A. Bhat, *Fruits Grown in Highland Regions of the Himalayas*. 2021. doi: 10.1007/978-3-030-75502-7.

[39] D. S. Akoto, S. T. Partey, M. Denich, M. Kwaku, C. Borgemeister, and C. B. Schmitt, "Towards bamboo agroforestry development in Ghana: evaluation of crop performance, soil properties and economic benefit," *Agrofor. Syst.*, vol. 94, no. 5, pp. 1759–1780, 2020, doi: 10.1007/s10457-020-00493-7.

[40] L. S. Pingki, T. Ahamed, M. M. U. Miah, M. A. R. Khan, and S. Mondal, "Growth and Productivity of Cauliflower in Aonla Based Multistoried Agroforestry System," *Asian J. Res. Agric. For.*, vol. 8, no. 4, pp. 311–321, 2022, doi: 10.9734/ajraf/2022/v8i4190.

[41] J. Ferdous, T. Ahamed, M. M. U. Miah, and M. M. Rahman, "Performance of Radish in Aonla based Multistoried Agroforestry System," *Eur. J. Agric. Food Sci.*, vol. 4, no. 3, pp. 9–16, 2022, doi: 10.24018/ejfood.2022.4.3.459.

[42] A. Abbasi Surki, M. Nazari, S. Fallah, R. Iranipour, and A. Mousavi, "The competitive effect of almond trees on light and nutrients absorption, crop growth rate, and the yield in almond–cereal agroforestry systems in semi-arid regions," *Agrofor. Syst.*, vol. 94, no. 3, pp. 1111–1122, 2020, doi: 10.1007/s10457-019-00469-2.

[43] A. Swieter, M. Langhof, and J. Lamerre, "Competition, stress and benefits: Trees and crops in the transition zone of a temperate short rotation alley cropping agroforestry system," *J. Agron. Crop Sci.*, vol. 208, no. 2, pp. 209–224, 2022, doi: 10.1111/jac.12553.

[44] A. K. Das *et al.*, "Scaling up of jujube-based agroforestry practice and management innovations for improving efficiency and profitability of land uses in Bangladesh," *Agrofor. Syst.*, vol. 96, no. 2, pp. 249–263, 2022, doi: 10.1007/s10457-021-00656-0.

[45] Z. Al Riyadh, "Performance of Spices as Lower – Storey Crop in Jackfruit – Papaya Multistorey Agroforestry System in Bangladesh," vol. 65, no. 2, pp. 223–231, 2020.

[46] A. K. Das, M. A. Rahman, S. S. Keya, S. R. Saha, and M. M. Rahman, "Malta-based agroforestry system: an emerging option for improving productivity, profitability and land use efficiency," *Environ. Sustain.*, vol. 3, no. 4, pp. 521–532, 2020, doi: 10.1007/s42398-020-00139-5.

[47] Y. A. Silvianingsih, M. van Noordwijk, D. Suprayogo, and K. Hairiah, "Litter Decomposition in Wet Rubber and Fruit Agroforests: Below the Threshold for Tropical Peat Formation," *Soil Syst.*, vol. 6, no. 1, 2022, doi: 10.3390/soilsystems6010019.

[48] Z. Xu, C. Li, C. Zhang, Y. Yu, W. van der Werf, and F. Zhang, "Intercropping maize and soybean increases efficiency of land and fertilizer nitrogen use; A meta-analysis," *F. Crop. Res.*, vol. 246, no. 2, p. 107661, 2020, doi: 10.1016/j.fcr.2019.107661.

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