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RESEARCH ARTICLE

Integrating Indian Spinach (*Basella alba*) as a Lower Storey Crop in Multistoried Fruit Orchard: A Management Intervention for Improved Productivity and Economic Profitability

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ABSTRACT

In Bangladesh, multistoried agroforestry is needed to address the challenges of declining cultivable land and recurring climatic threats, while also providing farmers with a sizable financial gain. Therefore, a field investigation was performed at the Gazipur Agricultural University in Bangladesh, with the goal of examining Indian spinach productivity in an aonla-established multi-storied agroforestry system. The experiment was designed as a two-factor randomized complete block design (RCBD) with three replications of factor A (T_1: Aonla + lemon + Indian spinach; T_2: Aonla + Indian spinach; T_3: Sole Indian spinach) and factor B (V_1: BARI Puishak-1; V_2: BARI Puishak-2; V_3: Genotype-10450; V_4: Genotype-10451; V_5: Genotype-10452). The findings showed that different growth and yield-related attributes were affected by variations in Photosynthetically active radiation (PAR). Consequently, the yield declined in T_1 (aonla + lemon + Indian spinach) and T_2 (aonla + Indian spinach) compared to that in T_3 (sole Indian spinach), which could be explained by the competition of the components for above- and below-ground resources. Fascinatingly, the T_1 system provided the overall highest output compared to the others, as the agroforestry system's multiple products contributed to the total output and confirmed its superiority over a single crop. Among the varieties, BARI Puishak 2 outperformed the other four. With a benefit-cost ratio (BCR) of 3.68 and a land equivalent ratio (LER) of 3.56, BARI Puishak 2, in conjunction with the T_1 agroforestry system (T_1V_2), exceeded the other treatment combinations. In summary, it can be concluded that using Indian spinach in multistoried agroforestry systems could be a magnificent approach to guarantee greater financial gain and support food and nutritional security in the economically insolvent farming communities of Bangladesh.

Keywords: Benefit cost ratio (BCR), Indian spinach, land equivalent ratio (LER), multistoried agroforestry.

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1. Introduction

A vast population of over 169.83 million people and 8.09 million hectares of arable land pose a simultaneous threat to Bangladesh's ability to provide its citizens with a sufficient supply of food and nutrition [1], [2]. In addition, with a phenomenal growth rate of 1.2%, the population is constantly expanding, placing a significant strain on limited land resources, and is expected to grow to 192.6 million by the end of 2050 [3], [4]. Therefore, it is necessary to increase crop production by at least double to feed this persistently enlarging population in the near future. Recently, Bangladesh has improved agricultural production but 24.2 million people are still fighting food shortages [5], [6]. Most people are directly or indirectly involved in agriculture, which is the most conventional profession; however, it has recently been plagued by anthropogenic and climatic hazards [7], [8]. Moreover, the combined effects of rapid urbanization, industrialization, and the construction of new homes for a rapidly expanding population and new development projects are shrinking agricultural land at a rate of 69,000 hectares annually [9], [10]. Furthermore, most arable land in Bangladesh encompasses less than 1.5% organic matter, although a minimum of 2.5% is required for optimum soil composition [11], [12]. Therefore, research should be conducted on climate-smart, demand-driven, and nutrient-sensitive sustainable agricultural methods to address these challenges in agricultural production.

In such conditions, it is imperative to expand agricultural land bases vertically so that they can produce poles, food, fuelwood, and other items from the same piece of ground. Bangladesh would undoubtedly benefit economically and environmentally by combining both production strategies, as there is a limited scope to expand forest areas separately. Agroforestry, a combined cultivation method for agricultural crops and woody perennials (trees and shrubs) on the same land, may be a suitable approach to solve the problem of sustainable production and overcome obstacles in the future. Agroforestry is a mixed cropping system in which woody perennials and annual herbaceous crops are planted together in a certain spatial and temporal arrangement [13], [14]. According to Patle *et al.* [15], the system makes better use of natural resources, including light, water, and nutrients, both above and below ground, which is not feasible in monocropping systems. Agroforestry also enhances soil fertility, water quality, biodiversity conservation, and most importantly, sequestrates carbon to mitigate global warming [16]. There are many new and traditional agroforestry systems practiced in Bangladesh, of which fruit-tree-based agroforestry is the most common, and aonla (*Phyllanthus emblica* L.)-based multistory fruit orchards are becoming popular as a lucrative and highly profitable system.

Aonla, popularly known as 'wonder fruit for health' exerts little negative effects on understory crops because of its deciduous nature, which is capable of producing yield under hostile environments and demands little inputs and management [17], [18]. Aonla fruit contains a tremendous amount of vitamin C, which also has anti-inflammatory, antibacterial, and antioxidant properties [19]. In addition to amino acids and other healthy phytochemicals such as rutin, emblicol, corilagin, linoleic acid, tannin, and polyphenol, aonla also contains ascorbic acid (300–900 mg/100 g) [20]. Lemons, which are widely recognized for their numerous health benefits, including their ability to prevent cancer, and their usage as a source of raw materials for the creation of ethnic herbal medicines [21], could be another suitable component of multistoried agroforestry systems. Lemon is also the richest source of vitamin C, which can grow under diverse environmental conditions including partial shade; hence, it has the potential to form the middle story of a multistoried fruit orchard. Finally, multistoried agroforestry should have a lower-story component based on the structural layout. Indian spinach (*Basella alba*), a popular leafy vegetable rich in vitamins A, C, and B_9 could be a wonderful choice for cultivation as a lower-story crop. It also contains dietary fiber, phenols, antioxidants, different bioactive chemicals, important amino acids, and minerals including calcium, magnesium, and iron [22], [23]. Given the potential and advantages of multistoried agroforestry systems, it would be extremely beneficial to investigate an economically and environmentally viable model that considers Indian spinach (as a summer vegetable), carambola, lemon (as a fruit tree), and aonla (as a medicinal plant). Considering the above-mentioned facts, the authors conducted the present study to assess Indian spinach productivity in an aonla-established multistoried agroforestry and evaluate the economic profitability along with land use performance compared to sole cropping. The findings of this study might assist in choosing compatible species to increase agricultural output and inform future management plans.

2. Materials and Methods

2.1. General Description of the Study Area

This research was conducted in the departmental research field under the Department of Agroforestry and Environment, Gazipur Agricultural University, Bangladesh, which is geologically relevant to the agro-ecological zone 28, specifically the Madhupur tract (Fig. 1). The study area is located at 24° 9′ N latitude and 90° 26′ E longitude, with an elevation of 8.2 meters above sea level. According to the United States Department of Agriculture's (USDA) soil taxonomy, the study site's soil is categorized as shallow red-brown terrace soil under the order *Inceptisols* [24]. Throughout this experiment, the study area experienced a maximum and minimum temperature of 34°C and 11.9°C, respectively, with 243 mm annual rainfall.

2.2. Establishment of the Farm

A multistoried fruit orchard was established in 2000 with a spacing of 8 m × 8 m, where aonla trees formed the upper-story, lemon trees were positioned between aonla trees as a middle story, and Indian spinach was grown as a lower story crop. The aonla plant's average height was from 5.56 m to 5.64 m, its base diameter was between 20.02 cm and 20.06 cm, its breast height diameter was between 14.7 cm and 15.6 cm, and its canopy diameter was between 3.36 m and 3.44 m. Lemon plants range in height from 83.2 cm to 83.4 cm, base diameter from 15.1 mm to 15.2 mm, canopy diameter from 47.4 cm to 48.2 cm (North-South), and canopy diameter from 49.2 cm to 49.8 cm (East-West). The lemon was BARI Lebu-4, and the aonla race was local. The Plant Genetic Resources Centre (PGRC), BARI, Joydebpur, Gazipur, provided five Indian spinach genotypes (BARI Puishak 1, BARI Puishak 2, Genotype-10450, Genotype-10451, and Genotype-10452), which were then assessed in the aonla orchard's vacant areas.

2.3. Experimental Design and Treatments

The experimental design was a two-factor randomized complete block design (RCBD) with three replicates.

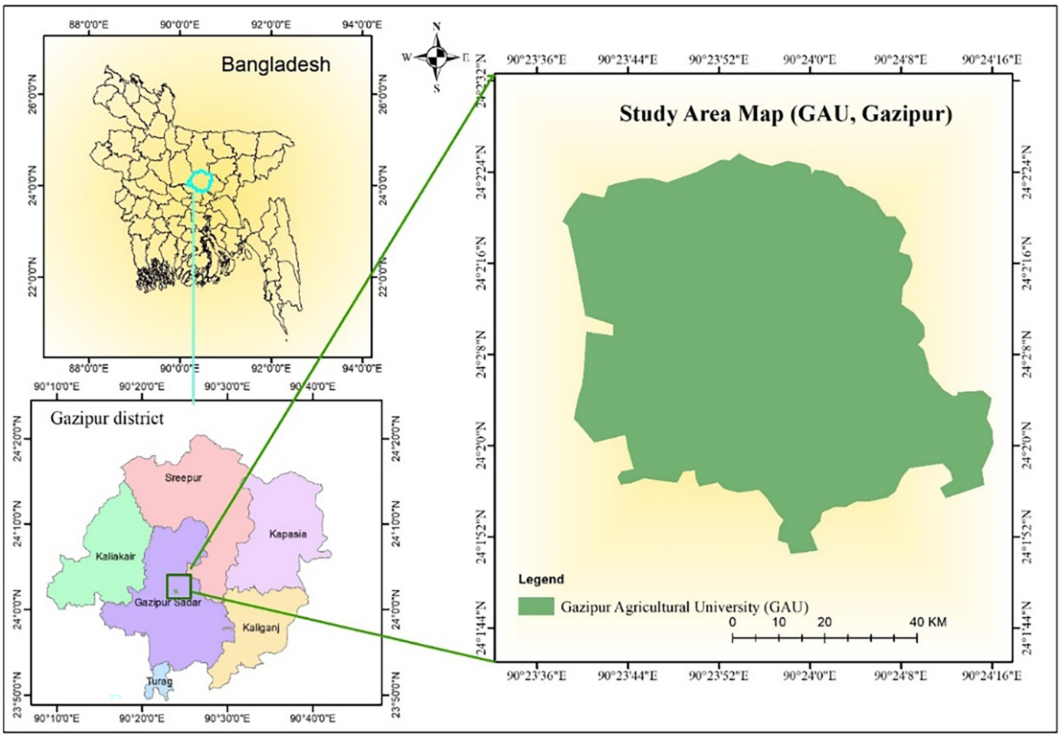

Fig. 1. Location of the study area.

Factor A: agroforestry systems, that is, T_1, Aonla + lemon + Indian spinach; T_2, Aonla + Indian spinach; T_3, Sole Indian spinach (control). Factor B: 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. Therefore, the present experiment consisted with a total of 15 different treatment combinations.

2.4. *Land Preparation, Crop Sowing, and Intercultural Management*

Soil was prepared by plowing and laddering to obtain a quality tilt prior to planting Indian spinach seeds. Plowing, leveling, weeding, stubble removal, and other land preparation tasks were appropriately completed. Seeds of Indian spinach were sown in well-prepared land with 30 × 20 cm spacing. The recommended doses of fertilizers were applied at a rate of 10 t ha^{-1} cowdung, 165 kg ha^{-1} urea, 110 kg ha^{-1} TSP, 110 kg ha^{-1} MOP, and 40 kg ha^{-1} gypsum to ensure proper growth and establishment of Indian spinach [25]. Irrigation, weeding, and thinning were performed according to the requirements. Dithane M-45 at a rate of 2 g/L water was sprayed as needed to control the infestation of leaf spot disease.

2.5. *Data Recording*

Indian spinach was harvested three times at 20-day intervals: 45, 65, and 85 days after sowing (DAS). Vine samples were collected for data collection following harvest. Vine length, base girth, leaf per vine, leaf fresh weight, leaf dry weight, stalk weight, leaf/stem ratio, and yield of Indian spinach were measured at every harvest time. To calculate leaf dry weight, 50 g of leaf was oven-dried for 12 hours at 70°C. The leaf dry weight was calculated using the following formula:

$$Leaf\ dry\ weight = \frac{Subsample\ oven\ dried\ weight}{Subsample\ fresh\ weight} \times Total\ fresh\ weight\ of\ leaves$$

2.6. *Light Measurements*

To measure shade over understory crops, photosynthetically active radiation (PAR) was estimated every two weeks using a Sunfleck Ceptometer (LP-80 AccuPAR).

2.7. *Economic and Land Use Performances*

The benefit–cost ratio (BCR) is used in agroforestry to determine a system's relative profitability in comparison to other traditional systems. BCR was estimated using the following formula [26]:

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

Land equivalent ratio (LER) shows how much land an intercrop needs compared to a species' monocrop:

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

where Ci is the yield of crops as an intercrop, Cs is the yield of crops as the sole crop, Ti is the yield of trees in the intercrop, and Ts is the yield of trees from sole trees [27].

2.8. *Statistical Analysis*

The "Analysis of Variance" (ANOVA) approach was used to statistically examine the experimental data in order to see how different treatments affected the outcomes. The significance of the differences between treatment means was assessed at a 5% level of probability using the least significant difference (LSD) test to interpret the data.

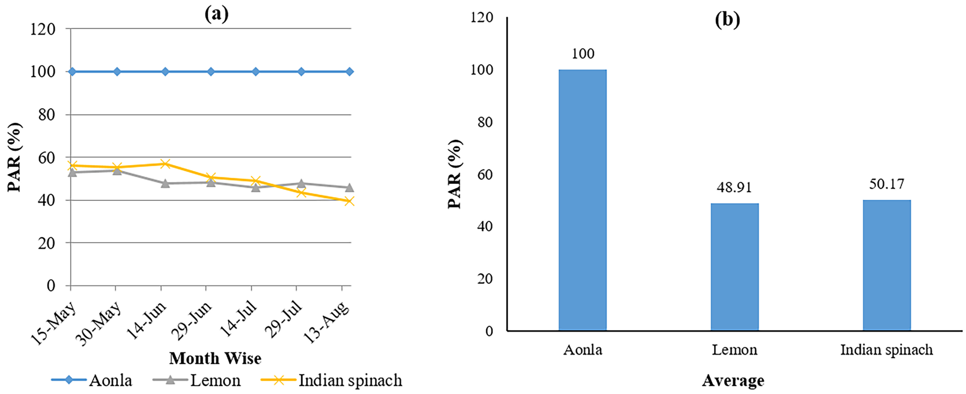

Fig. 2. Availability of Photosynthetically active radiation (PAR) at different strata of aonla + lemon + Indian spinach-based agroforestry system during Indian spinach growing season: (a) month wise and (b) average.

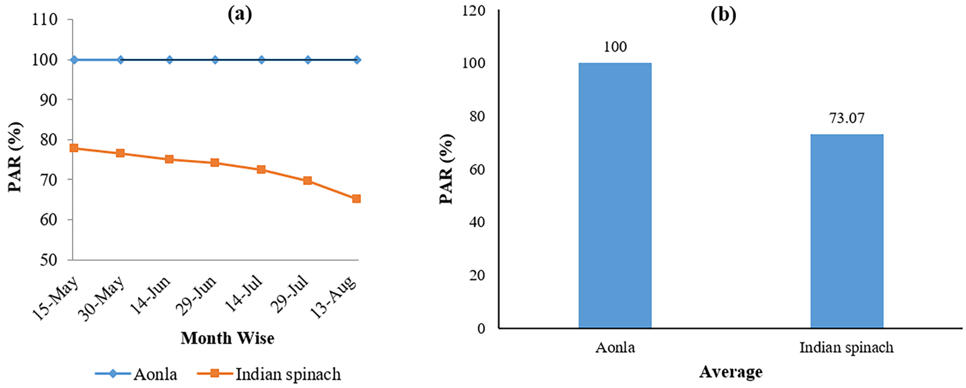

Fig. 3. Availability of Photosynthetically active radiation (PAR) at different strata of aonla + Indian spinach-based agroforestry system during Indian spinach growing season: (a) month wise and (b) average.

3. Results and Discussion

3.1. *Availability of Photosynthetically Active Radiation*

Undoubtedly, one of the most significant resources contributing to yield is light. The various strata of multistory agroforestry have varying PAR accessibility. Compared to the PAR above the aonla tree, the PAR above the lowerstory Indian spinach and lemon was 48.91% and 50.17%, respectively, in an agroforestry system based on aonla + lemon + Indian spinach (Figs. 2a and 2b). Accordingly, the lower-storied Indian spinach received 73.07% PAR compared to aonla in an aonla + Indian spinach-based system throughout the Indian spinach growing season (Figs. 3a and 3b). Aonla, as an upper-storied component, might exert some negative effects on the understory crop as well as reduce the most important yield-supporting attributes, such as PAR. The upper canopy coverage limited the PAR over the lower-storied crops; hence, the lower-storied crops received less intensity of PAR because of partial shading, which might have minimized photosynthesis, dry matter production, and crop yield. Similar results were reported by Ferdous *et al*. [8] and Pingki *et al*. [10], who reported that light is the most important factor for the growth and yield of crops.

3.2. *Crop Productivity*

3.2.1. *Effect of Agroforestry Systems*

The vine length, base girth, leaf per vine, and SPAD values were significantly associated with the studied agroforestry systems (Fig. 4). The highest vine length (47.2 cm) and SPAD value (39) were recorded in the T_1 (aonla + lemon + Indian spinach) treatment, while the lowest vine length (37.2 cm) and SPAD value (35.5) were found in the T_3 (sole Indian spinach) treatment (Figs. 4a and 4d). The highest base girth (2.5 cm) and leaf per vine (78) were recorded in the T_3 treatment, whereas T_1 provided the lowest base girth and leaf per vine of Indian spinach (Figs. 4b, 4c). Similarly, the agroforestry practices studied had a significant impact on leaf fresh weight, leaf dry weight, stalk weight, leaf-stem ratio, and yield of Indian spinach (Figs. 5 and 6). Significantly the highest leaf fresh weight (220 gm), leaf dry weight (14.5 gm), stalk weight (158 gm), leaf-stem ratio (1.45), and yield (21.27 ton hac^{-1}) were found in T_3 treatment (sole Indian spinach), while T_1 treatment provided their lowest values (Figs. 5 and 6). In comparison to the sole Indian spinach (T_3), T_1 and T_2 treatments resulted in a reduction in base girth (by 13.73% and 12%), leaf per vine (by 23% and 15%), leaf fresh weight (by 17.6% and 10%), leaf dry weight (by 22% and 13%), stalk weight (by 8.65% and 4%), leaf stem ratio (by 12.57% and 7%), and yield (by 13.88% and 7.48%), respectively (Figs. 4–6). In contrast, vine length increased by 27% and 11.25%, whereas the SPAD value increased by 2.5% and 0.43%, respectively. Competition between two or more elements for scarce resources, particularly nutrients, water, and light, might have affected the productivity of Indian spinach and reduced the yield in agroforestry practices [28]. A decrease in PAR is closely related to a decrease in yield; however, Indian spinach in the T_1 treatment received

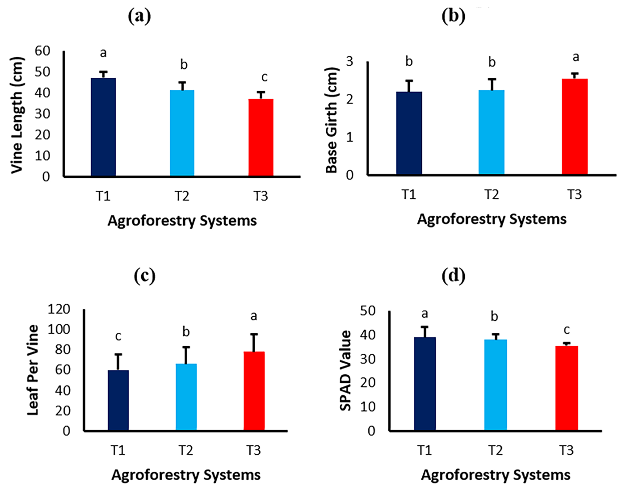

Fig. 4. Vine length (a), base girth (b), leaf per vine (c), and SPAD (d) value of Indian spinach grown under different agroforestry systems. Different alphabetical letters of the bar showed the significant differences ($P < 0.05$) among the treatments.

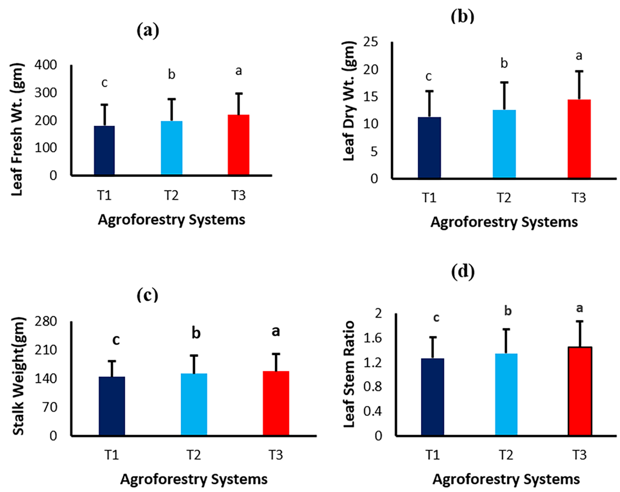

Fig. 5. Leaf fresh weight (a), leaf dry weight (b), stalk weight (c), and leaf-stem (c) ratio of Indian spinach grown under different agroforestry systems. Different alphabetical letters of the bar showed the significant differences ($P < 0.05$) among the treatments.

less PAR than in T_2, and consequently, the yield reduction was larger in the T_1 treatment than in T_2. T_3 (sole Indian spinach) treatment under full sunlight may ensure maximum photosynthesis and growth indicators, resulting in maximum yield. In contrast, shading reduced % PAR in T_1 and T_2 treatments, resulting in lower carbon fixation and less leaf per vine, lower leaf fresh weight, and lower stalk weight, which finally decreased the yield. Moreover, the root system of perennial trees might have suppressed the lower storied annual crops from obtaining water and nutrients, which ultimately resulted in lower crop yields. Our findings are corroborated by Rita *et al*. [18] and other researchers [29]–[31], who also observed that crop yields were reduced owing to the presence of trees in agroforestry systems.

3.2.2. Effect of Varieties

Base girth, leaf per vine, and SPAD values varied significantly among the different varieties of Indian spinach, whereas vine length was insignificant (Fig. 7). V_5 produced

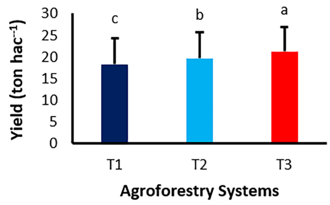

Fig. 6. Yield of Indian spinach grown under different agroforestry systems. Different alphabetical letters of the bar showed the significant differences ($P < 0.05$) among the treatments.

the longest vine length (45 cm) of the Indian spinach (Fig. 7a). The highest base girth (2.52 cm) was found in V_2 which was statistically identical to V_1 and V_3, whereas V_2 produced the highest (86) leaf per vine. In contrast, V_5 had the lowest base girth (2.06 cm) and leaf per vine (41) (Figs. 7b and 7c). The highest SPAD value (39.07), which was not significant for V_2 (38.28), V_3 (38.12), and V_4 (38.3), was recorded in V_1 whereas V_5 produced the lowest (33.9) SPAD value (Fig. 7d). The studied varieties of Indian spinach showed significant variation in terms of leaf fresh weight, leaf dry weight, stalk weight, and leaf-stem ratio. The variety V_2 (BARI Puishak 2) produced the significantly highest leaf fresh weight (299 g plant^{-1}), leaf dry weight (19.2 g plant^{-1}), stalk weight (191 g plant^{-1}), and leaf-stem ratio of 1.55 (Figs. 8a–8d). In contrast, the lowest leaf fresh weight (103.7 g plant^{-1}), leaf dry weight (6.64 g plant^{-1}), and leaf-stem ratio (0.6) were produced by V_5, while V_4 provided the significantly lowest stalk weight (96 g plant^{-1}) of Indian spinach. The yield of Indian spinach varied significantly among the varieties. The highest yield (27.6 ton hac^{-1}) was obtained from variety V_2 (BARI Puishak 2), while V4 (Genotype-10451) provided the lowest yield (14.07 ton hac^{-1}) of Indian spinach (Fig. 9).

The findings demonstrated that different genotypes of Indian spinach had significant differences among themselves and performed differently under shaded conditions. Variety V_5 had more apical dominance, so vine length was the highest, but base girth and leaf per vine were much less than the other varieties. However, V_2 proved superior in leaf vine^{-1}, girth of base, leaf fresh weight, leaf dry weight, stalk weight, and yield over the other varieties, which might be due to its genetic potential to grow under partial shade conditions.

3.2.3. Interaction between Agroforestry Systems and Indian Spinach Varieties

The interactions of agroforestry systems and Indian spinach cultivars with various growth- and yield-contributing traits showed notable variation across different treatment combinations (Table I). The results demonstrated that, the variety V_2 (BARI Puishak 2) produced the highest base girth (2.69 cm), leaf per vine (97), leaf fresh weight (328 gm), leaf dry weight (22 gm), and highest yield (29.3 ton hac^{-1}) in sole Indian spinach system (T_3V_2), while V_5 (Genotype-10452) produced the lowest base girth (1.8 cm), leaf per vine (33), leaf fresh weight (86.1 gm) and leaf dry weight (5.35 gm) in aonla + lemon + Indian spinach (T_1V_5) system. The lowest yield (12.83 ton hac^{-1}) of Indian spinach was produced

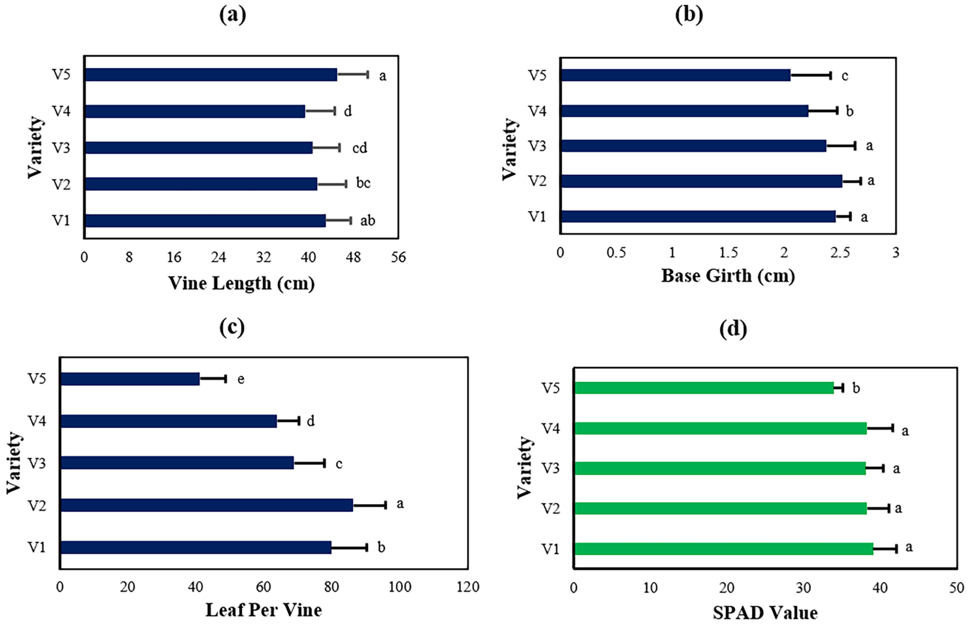

Fig. 7. Response of (a) vine length, (b) base girth, (c) leaf per vine, and (d) SPAD value to the different varieties of Indian spinach. Different alphabetical letters of the bar showed the significant differences ($P < 0.05$) among the treatments.

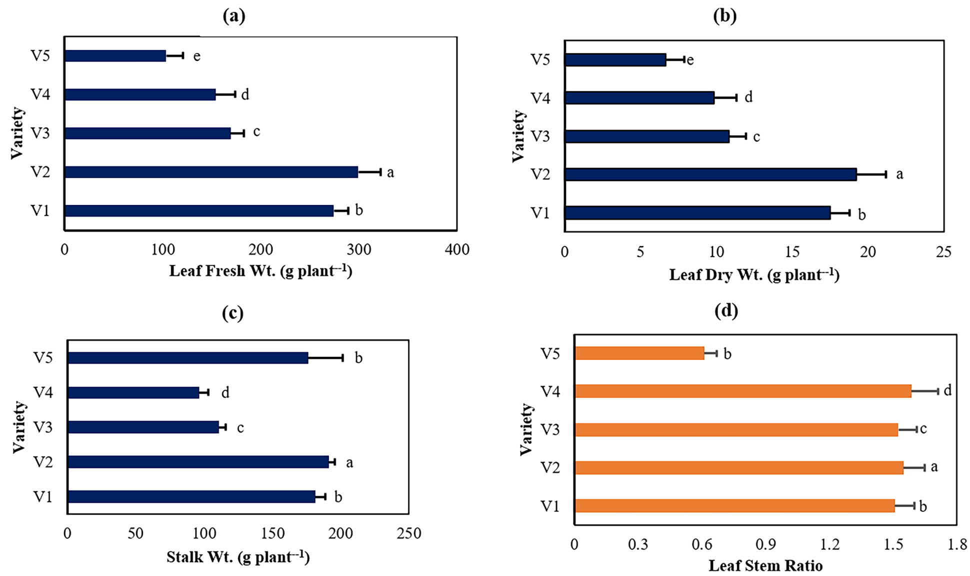

Fig. 8. Response of (a) leaf fresh weight, (b) leaf dry weight, (c) stalk weight, and (d) leaf-stem ratio to the different varieties of Indian spinach. Different alphabetical letters of the bar showed the significant differences ($P < 0.05$) among the treatments.

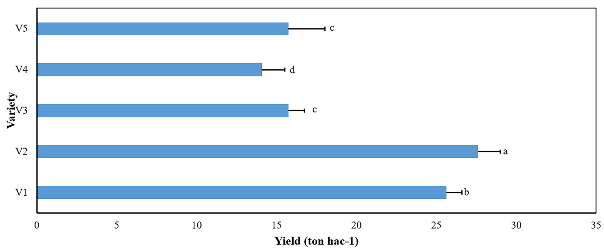

Fig. 9. Response of yield to the different varieties of Indian spinach. Different alphabetical letters of the bar showed the significant differences ($P < 0.05$) among the treatments.

by the variety V_4 (Genotype-10451) under the aonla + lemon + Indian spinach (T_1V_4) system (Table I). It was also observed that, the highest vine length (50.9 cm), SPAD value (41.9), stalk weight (201.7 gm), and leaf-stem ratio (1.71) were recorded in T_1V_5, T_1V_1, T_3V_5, and T_3V_4 treatment combinations, respectively; while, the lowest vine length (34.9 cm), SPAD value (32.9), stalk weight (92.25 gm), and leaf-stem ratio (0.62) were recorded in T_3V_4, T_1V_5, T_2V_4, and T_1V_5 treatment combinations, respectively (Table I).

In comparison to sole cropping (T_3), different Indian spinach varieties V_1, V_2, V_3, V_4 and V_5 cultivated in agro-forestry systems showed an increase in vine length at T_1 by 31.94% highest in V_5 and by 18.27% lowest in V_1 and also in T_2 treatment by 18.64% highest in V_5 and 4.41% lowest in V_1 (Table I). This type of highest and lowest increment was also found for stalk weight and leaf to stem ratio parameters. In the case of leaf per vine, abatement in the T_1 treatment by 33.19% in V_5 was the highest and 16.28% in V_4 was the lowest among all other varieties, whereas in the T_2 treatment, the highest was also noted in V_5 by 19.42%, but the lowest was in V_2 by 11.11%. This trend of decline

TABLE I: Interaction between Agroforestry Systems and Varieties and their Combined Effects on Indian Spinach Yield and Yield-Contributing Characteristics

Treatment combinations	Vine length (cm)	Base girth (cm)	Leaf per vine	SPAD value	Leaf fresh weight. (gm)	Leaf dry weight. (gm)	Stalk weight.(gm)	Leaf stem ratio	Yield (ton hac^{-1})
T_1V_1	47.25 ± 0.71^{ab}	2.38 ± 0.03^{cde}	70.86 ± 0.74^{e}	41.94 ± 0.4^{a}	255.42 ± 0.6^{e}	15.96 ± 0.04^{e}	179.44 ± 3.91^{cd}	1.41 ± 0.01^{e}	24.46 ± 0.08^{d}
T_1V_2	47.16 ± 0.61^{b}	2.41 ± 0.03^{bcd}	76.77 ± 1.14^{cd}	40.52 ± 0.74^{ab}	275.45 ± 0.53^{d}	17.12 ± 0.03^{d}	189.49 ± 2.26^{b}	1.45 ± 0.01^{de}	26.15 ± 0.05^{c}
T_1V_3	45.18 ± 0.53^{bc}	2.31 ± 0.05^{cdef}	58.71 ± 0.6^{f}	39.14 ± 0.62^{b}	155.84 ± 0.58^{i}	9.67 ± 0.04^{i}	109.76 ± 1.83^{fg}	1.43 ± 0.02^{de}	14.94 ± 0.05^{h}
T_1V_4	45.54 ± 0.36^{b}	2.05 ± 0.05^{fgh}	60.25 ± 0.48^{f}	40.89 ± 0.88^{ab}	134.45 ± 1.3^{j}	8.37 ± 0.08^{j}	93.66 ± 4.7^{hi}	1.43 ± 0.02^{de}	12.83 ± 0.13^{i}
T_1V_5	50.89 ± 0.35^{a}	1.81 ± 0.06^{h}	33.40 ± 0.48^{i}	32.92 ± 0.14^{e}	86.11 ± 0.89^{m}	5.35 ± 0.06^{l}	148.58 ± 12.3^{e}	0.62 ± 0.09^{f}	13.2 ± 0.14^{i}
T_2V_1	41.71 ± 0.87^{cd}	2.49 ± 0.04^{abc}	76.11 ± 0.97^{cd}	39.68 ± 0.3^{ab}	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}	2.45 ± 0.03^{abc}	85.80 ± 0.85^{b}	38.67 ± 0.3^{b}	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}	2.17 ± 0.03^{defg}	69.36 ± 0.28^{e}	39.07 ± 0.33^{b}	165.33 ± 0.82^{h}	10.51 ± 0.05^{h}	108.55 ± 4.98^{fg}	1.53 ± 0.03^{c}	15.41 ± 0.1^{gh}
T_2V_4	37.60 ± 0.45^{ef}	2.13 ± 0.05^{efg}	59.77 ± 0.2^{f}	38.49 ± 0.41^{bc}	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}	1.93 ± 0.07^{gh}	40.28 ± 0.68^{h}	33.97 ± 0.3^{de}	102.31 ± 1.47^{l}	6.51 ± 0.09^{k}	178.36 ± 14.1^{d}	0.59 ± 0.05^{f}	15.79 ± 0.2^{gh}
T_3V_1	39.95 ± 0.72^{de}	2.5 ± 0.01^{abc}	92.58 ± 1.28^{a}	35.58 ± 0.24^{d}	287.02 ± 0.93^{c}	18.77 ± 0.06^{b}	176.08 ± 6.7^{d}	1.62 ± 0.04^{b}	26.05 ± 0.13^{c}
T_3V_2	37.03 ± 0.7^{ef}	2.69 ± 0.02^{a}	96.52 ± 1.25^{a}	35.64 ± 0.13^{d}	327.62 ± 0.58^{a}	21.71 ± 0.04^{a}	193.94 ± 1.59^{ab}	1.66 ± 0.02^{ab}	29.34 ± 0.04^{a}
T_3V_3	35.50 ± 0.42^{f}	2.65 ± 0.02^{ab}	78.69 ± 0.92^{c}	36.13 ± 0.31^{cd}	186.07 ± 1.56^{f}	12.25 ± 0.1^{f}	114.14 ± 6.17^{f}	1.62 ± 0.03^{b}	16.89 ± 0.17^{f}
T_3V_4	34.91 ± 0.77^{f}	2.44 ± 0.03^{abc}	$71.97 \pm 0.76d^{e}$	35.49 ± 0.21^{d}	178.18 ± 1.43^{g}	11.66 ± 0.09^{g}	103.4 ± 5.14^{gh}	1.71 ± 0.04^{a}	15.84 ± 0.14^{g}
T_3V_5	38.57 ± 0.31^{def}	2.44 ± 0.03^{abc}	49.99 ± 0.63^{g}	34.81 ± 0.24^{de}	122.61 ± 2.1^{k}	8.06 ± 0.14^{j}	201.71 ± 8.02^{a}	0.63 ± 0.02^{f}	18.24 ± 0.2^{e}

Note: Values (mean ± SE) for the agroforestry system × Indian spinach variety combinations were obtained from three replicates (n = 3). The letters within each column indicate significant differences ($P < 0.05$) among the treatment combinations.

was also noted for the base girth, leaf fresh weight, leaf dry weight, stalk weight, and yield of Indian spinach (Table I). The yield of Indian spinach was reduced as a result of the strong effects of middle-story lemons and upper-story aonla on the growth characteristics of lower-story Indian spinach. This result may be due to lower photosynthesis under partially shaded conditions and competition with perennial trees. It is evident that perennial trees have more developed root systems than annual crops, and in the root zone locations, the tree outcompeted Indian spinach, ultimately resulting in lower base girth, leaf weight, stalk weight, and lower yields. However, higher apical dominance under shaded conditions influenced vine length. Our findings also corroborated the outcomes of other studies [8], [18], [32], [33] on radish, stem amaranth, and aroid under fruit tree-based agroforestry systems.

3.3. Economic and Land Use Performances

Several tools are used to determine the economic and land use performance, and we used the benefit cost ratio (BCR) and land equivalent ratio (LER) in our study. The economic and land use performances demonstrated that agroforestry practices provided higher economic returns and profitable land use than sole cropping of Indian spinach (Table II). Compared to T_3 (single cropping), the gross return of Indian spinach was higher in both T_1 and T_2 agroforestry systems, while it was highest in T_1V_2 (222,768 Tk ha^{-1}) and lowest in T_3V_4 (95,034 Tk ha^{-1}). Similarly, net return was highest in T_1V_2 (162,268 Tk ha^{-1}) and lowest in T_3V_4 (34,534 Tk ha^{-1}). In compare to T_3 (sole cropping), higher BCR was exhibited by T_1 (aonla + lemon + Indian spinach) system followed by T_2 (aonla + Indian spinach) system. The highest BCR (3.68) was found in the T_1V_2 treatment combination and the lowest (1.57) in the T_3V_4 treatment combination. The T_1 agroforestry system was later discovered to have a greater LER than the T_2 agroforestry system. Surprisingly, the T_1V_2 system had the highest LER (3.56), while the lowest (2.17) was in the T_2V_4 treatment combination (Table II). In terms of land use, the benefit of intercropping over a single crop is indicated by a land equivalent ratio (LER) value greater than 1 [34]. According to our experiment, the T_1V_2 treatment combination had the greatest LER value (3.56), indicating that intercropping has a 3.56-fold greater advantage than solitary cropping and that a 3.56 times in area would be required to provide a comparable yield under the sole crop.

Agroforestry systems can yield higher economic returns for several reasons. For example, middle-storied lemons and upper-storied aonla produced better yields without any additional inputs (water and fertilizer) than their sole farming. Moreover, crop production benefits from trees in fields, including the addition of mulch, organic matter, and nutrient-rich soils [35]. The income table is further enhanced by additional tree resources, including fruit,

TABLE II: Economic and Land Use Performances of Indian Spinach Associated Different Treatment Combinations

Treatment combinations	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	–

Note: BCR: Benefit cost ratio; LER: Land equivalent ratio.

firewood, timber, and non-timber products. Aonla and lemon, two fruits with greater market demand, and Indian spinach, a leafy vegetable that is popular in Bangladesh year-round, were the primary contributors to the better economic return (BCR) in the agroforestry system (T_1) over T_2 (aonla with Indian spinach) and T_3 (aonla only). These findings are best endorsed by Al Riyadh *et al*. [7], Rita *et al*. [18], Riyadh *et al*. [32], and Das *et al*. [36] under different agroforestry practices.

4. Conclusions

Considering the economic and land use performances, it can be stated that Indian spinach cultivation in underutilized spaces in association with fruit trees has the potential to uplift the system's overall productivity and economic profitability. Although the accessibility of Photosynthetically active radiation (PAR) decreased which ultimately declined the yield of Indian spinach in agroforestry systems compared to sole cropping; however, the overall output remained the highest because of the combined output of the agroforestry systems. The results showed that incorporating Indian spinach into the underused spaces of this aonla-based multistory agroforestry can increase its economic turnover. In particular, BARI Puishak 2 has demonstrated superiority over other varieties in terms of yield, BCR, and LER. Therefore, cultivating Indian spinach in aonla-based multistoried agroforestry systems might be a suitable productive and profitable option to help resource-limited farmers. However, multilocation field trials should be conducted to improve the practicality of the system.

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Author Contributions

All authors worked together to complete this research, and the final manuscript was reviewed and approved by all authors.

Conflict of Interest

No conflicts of interest are disclosed by the authors.

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