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Agroforestry: A Sustainable Land-Use Practice for Enhancing Productivity and Carbon Sequestration in Madhupur Sal Forest, Bangladesh

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Abstract: This paper explores the role of agroforestry in mitigating climate change by sequestering atmospheric carbon in the tropics and subtropics, specifically in the Madhupur Sal forest of Bangladesh. Agroforestry, combining trees with crops on agricultural lands, is recognized for its potential to act as carbon sinks and enhance productivity. The study assesses various agroforestry practices, including Acacia-Pineapple-Turmeric-Papaya, Acacia-Pineapple-Zinger-Banana, and Sal-Pineapple-Aroid combinations. The research reveals improved farm productivity in these agroforestry systems, with different tree species sequestering varying amounts of carbon. Acacia species, ranging from 12 to 25ft in height, sequestered an average of 23.35 lbs/year, while Sal species (*Shorea robusta*), with trees 45 to 61ft tall, sequestered 49.80 lbs/year on average. Factors such as tree height, diameter at breast height (DBH), number of leaves, and branches influence carbon sequestration. The paper suggests integrating the carbon trading system of the Clean Development Mechanism (CDM) with Carbon Sequestration (CS) potential to leverage agroforestry for greenhouse gas emission reduction in Bangladesh. By emphasizing the profitability of these practices alongside carbon sequestration, the study encourages the adoption of agroforestry as a sustainable and economically viable strategy for climate change mitigation.

Keywords: agroforestry; carbon sequestration; productivity; madhupur sal forest; sustainable land-use practice

1. Introduction

Agriculture is a vital driver of Bangladesh's economic growth, contributing significantly to GDP, employment, and export revenues [1]. Despite its historical importance, the industry faces challenges such as diminishing arable land, population growth, and declining productivity. The government has implemented diverse agricultural policies to address these issues, especially in the context of climate change impacts, including rising temperatures and extreme weather events [2]. In response to climate change challenges, agroforestry has been recognized as a viable strategy [3]. Trees play a crucial role in mitigating climate change by capturing atmospheric carbon through photosynthesis [4]. The Madhupur Sal forest area in Bangladesh, with prevalent Acacia-Pineapple-based agroforestry practices, serves as a promising site for studying the productivity and carbon sequestration potential of different agroforestry systems [5].

The global rise in carbon dioxide and methane concentrations, mainly due to industrialization, underscores the importance of forests as natural climate change brakes [6]. Madhupur Sal forest, covering a substantial portion of Bangladesh's forested territory, plays a crucial role in sequestering carbon [7]. The estimation of the total carbon stock in Madhupur Sal forest is essential for understanding its pivotal role in mitigating climate change at both national and global levels.

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Bangladesh, being highly vulnerable to climate change, has experienced an increase in CO_2 levels, primarily from fossil fuel burning [8]. Efforts to reduce CO_2 emissions include managing carbon fluxes in agricultural systems and utilizing mechanisms like the Kyoto Protocol's clean development mechanism. Forestry, particularly agroforestry, has gained global recognition as a solution to reduce CO_2 emissions, with tropical deforestation accounting for a significant portion of yearly CO_2 emissions. In Bangladesh the government recognize the importance of restore degraded Sal forest. Government Restore 137,800 ha deforested hill and plain land Sal forest and also 20,000 ha degraded hill and plain land Sal forest [9].

While agroforestry's benefits were initially emphasized at local or regional scales, there is a growing awareness of its global environmental services, including carbon sequestration and biodiversity protection. This research aims to investigate various agroforestry systems in Madhupur Sal forest, evaluating tree and crop productivity. Assessing carbon sequestration potential is crucial for understanding agroforestry's role in climate change mitigation.

2. Materials and Methods

2.1. Study Area

The study was carried out in the Madhupur tract (45,565.2 acres), commonly known as the Madhupur Sal Forest or Madhupur Garh, In Bangladesh, moist deciduous plain land Sal forests distributed over the relatively drier central and north-western parts of the country [10,11]. This area is mainly made up of the districts of Tangail, Mymensingh, Gazipur, and Dhaka; of the above, it is in the Madhupur Sal forest (under Tangail and Mymensingh districts) particularly that the majority of the Sal forests exist. The Madhupur Sal forest is located in the northeastern part of the Tangail Forest Division with a small portion running along the boundary with the Mymensingh Forest Division [12,13].

The climate of the Madhupur Garh varies slightly from north to south, the northern reaches being much cooler in winter. Average temperatures vary from 29.3°C to 21.1°C in summer, falling to 20°C in winter, with extreme lows of 10°C. Rainfall ranges between 1,500 mm to 2,100 mm annually and the average is 2011.6 mm. Mean annual Relative Humidity (RH) and total evaporation are 84.8% and 1050 mm, respectively [14]. The Madhupur Sal tract belongs to the Bio-ecological Zone No. 3 and the 28th AEZ (Agro-Ecological Zone) of Bangladesh [15].

The study selected six important villages (Dhokola, Auronkhola, Madhupur National Park, Gaira, Beribaith, and Makontinagar) under three unions of the study area where ethnic people are practicing agroforestry for data collection. Three different agroforestry practices (Acacia-Pineapple-Turmeric-Papaya, Acacia-Pineapple-Zinger-Banana, and Sal-Pineapple-Aroid based) were selected to quantify the productivity and sequestration status of carbon as a whole in Madhupur Sal forest of Bangladesh.

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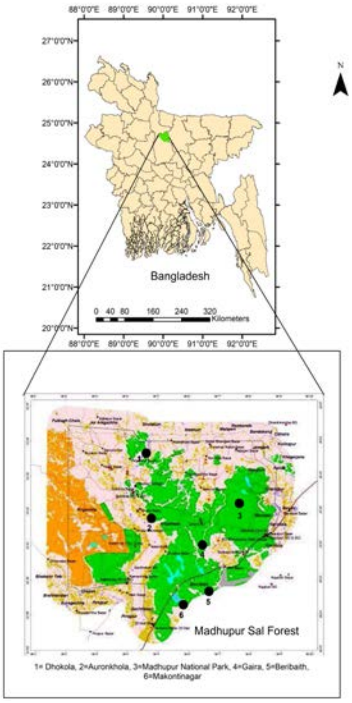

Figure 1. A map of Madhupur Sal forest showing the study area.

2.2. Data Collection

The study used questionnaire survey techniques for collecting the economic aspects of agroforestry practices in Madhupur Sal forest area. In this process, the study randomly selected agroforestry farmers for questionnaire interviews. On the contrary, for the carbon sequestration of agroforestry practices, the study used quadrates (10 m×10 m) techniques for collecting ecological data. A 20-sample plot (10 m×10 m) was chosen at random from six different villages in the agroforestry field. For calculating carbon sequestration, tree height, DBH, and age of trees data were collected.

2.3. Calculation of Net Present Value (NPV)

The difference between the present value of all future projected cash inflows and the present value of all future expected cash outflows is the net present value. For calculating Net Present Value, at first, we identified the future benefits and then showed out the present and future costs. Then the present value of future costs and benefits were calculated. The present value factor is,

$$1 / (1+r)^n \quad (1)$$

Here,
r = Discounting rate;
n = Number of years
The formula for calculating the present value is:
Present Value of Future Benefits = Future Benefits × Present Value Factor.

$$\text{Present Value of Future Costs} = \text{Future Costs} \times \text{Present Value Factor} \quad (2)$$

Calculation Net Present Value using this formula:

$$\text{NPV} = \sum \text{Present Value of Future Benefits} - \sum \text{Present Value of Future Costs} \quad (3)$$

If the Net Present Value (NPV) is positive, the research should be undertaken. If the NPV is negative, the research should not be undertaken [16].

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2.4. Calculation of Benefit-Cost Ratio (BCR)

The benefit-cost ratio (BCR) is a monetary or qualitative statistic that shows the link between the relative costs and benefits of a proposed project. Cost-benefit analysis formula helps firms compare and calculate which research or task would offer maximum profits with minimum costs involved.

$$\text{Benefit-Cost Ratio (BCR)} = \frac{\sum_{t=0}^{n} \frac{Bt}{(1+r)}}{\sum_{t=0}^{n} \frac{Ct}{(1+r)}} \tag{4}$$

where,

Bt= Gross benefit in the nth year

Ct= Total cost in the nth year

t = Number of years (1, 2, 3………n)

r = Interest (discount) rate

If the benefit-cost ratio is greater than 1, go ahead with the research project. If the benefit-cost ratio is less than 1, should not go ahead with the research project [17].

2.5. Calculation of Carbon Sequestration

The growth features of the tree species, the local growth circumstances where the tree is placed, and the density of the tree's wood all affect how quickly carbon gets sequestered. Even so, I can roughly estimate the quantity of CO_2 a specific tree sequesters and get the annual sequestration rate by dividing it by the age of the tree. This process is:

- Determination of the total (green) weight of the tree.
- Determination of the dry weight of the tree.
- Determination of the weight of Carbon in the tree.
- Determination of the weight of carbon dioxide sequestered in the tree.
- Determination of the weight of CO_2 sequestered in the tree per year [18].

2.6. Determination of the Total (Green) Weight of the Tree

The process was used to determine the weight of a tree based on its species

W = Above-ground weight of the tree in pounds

D = Diameter of the trunk in inches

H = Height of the tree in feet

$$\text{For trees with } D < 11: \quad W = 0.25\, D^2H \tag{5}$$

$$\text{For trees with } D >= 11: \quad W = 0.15\, D^2H \tag{6}$$

The variables D2 and H were extended to exponents above or below 1 depending on the species of tree and the coefficient (for example, 0.25) which was altered. The weight of a tree's root system typically equals 20% of its above-ground weight. To calculate the tree's total green weight, the above-ground weight of the tree was multiplied by 120% [18].

2.7. Determination of the Dry Weight of the Tree

A suggested table was used to calculate the tree's dry weight. The average weight of a cord of wood for several tree species is listed in the table. The average tree was predicted to have 72.5% dry matter and 27.5% moisture when all tree species in the table were taken into consideration. To get the tree's dry weight, the weight of the tree was multiplied by 72.5% [18].

2.8. Determination of the Weight of Carbon in the Tree

The average carbon content is typically 50% of the tree’s total volume. Therefore, increase the tree's dry weight by 50% to get the amount of carbon it contains [18].

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2.9. Determination of the Weight of CO_2 Sequestered in the Tree

CO_2 is composed of one molecule of C and two molecules of oxygen.
The atomic weight of Carbon is 12.001115
The atomic weight of Oxygen is 15.9994
The weight of CO_2 is C+2*O = 43.999915
The ratio of CO_2 to C is 43.999915/12.001115 = 3.6663
Therefore, to determine the weight of CO_2 sequestered in the tree, multiply the weight of carbon in the tree by 3.6663 [18].

2.10. Determination of the Weight of CO_2 Sequestered in the Tree per Year

Finally, the weight of CO2 sequestered in the tree was divided by the age of the tree to determine the weight of CO2 sequestered per year per tree. The simple equation is:

Weight of CO_2 sequestered per year = weight of CO_2 sequestered per tree/tree age …..(7)[18].

2.11. Data Analysis

After compilation and tabulation, the data was analyzed statistically following the selected objective. When necessary, qualitative data are translated into quantitative data using appropriate grading. The data is then evaluated using Microsoft Office Excel and R studio software. The obtained data is analyzed using descriptive statistics. Percentage of tables, column charts, and pie charts were used to depict the connection between agroforestry adoptions.

3. Results

3.1. Demographic Features of the Respondents

Farmers from various age classes ranging from 20 to 85 years were involved in practicing agroforestry in Madhupur Sal forest and were again gender categorized into male (74.36%) and female (25.64%). Mostly, middle-aged farmers were growing trees with crops as they could easily indulge in labor-intensive activities for diversified cultivation. Very few farmers from the elderly, aged more than 50 years, and farmers aged below 35 years were reluctant to agroforestry. Illiteracy in the rural community has been eradicated since the mandatory literacy programs run by the Government of Bangladesh to educate society were initiated throughout the country. The literacy of most of the farmers in the area was classified among different levels that determined their willingness to practice agroforestry. As the family is the oldest social unit, the status of society is largely influenced by various dimensions of family. The majority of the farmers have medium (71.79%) in size followed by large and small families. The size of the families of the farmers does not influence their livelihood choices because most people rely on agroforestry methods for a living, regardless of how large or small their family is. Depending on the demand for the families, the area of the farms was classified which indicated that most of the farmers (64.1%) hold small-sized farms up to 1 hectare, whereas 30.77% of farmers practice agroforestry (tree planting, sowing crops, and maintenance activities, fruit-based agroforestry, homestead agroforestry, etc.) in their medium-sized farmlands. Sustainability is key to the notion of agricultural development, and a better understanding of sustainable agriculture awareness among farmers is of particular importance to researchers. The study revealed that the majority of respondents (47.44%) were highly concerned about the importance of applying sustainable agricultural practices, while 43.59% had intermediate/moderate knowledge, and only 8.97% of farmers were unaware of the fact of sustainability (Table 1). The concept of different agroforestry practices in the area was prominently accepted by the farmers as most of the farmers (62.82%) classified the practice as profitable and another 32.05% of farmers found agroforestry as highly profitable, 5.13% of farmers defined it as not profitable and no participant told even-break by practicing agroforestry (Figure 2).

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Table 1. Demographic features of the respondent.

Characteristics	Categories	Percentage (%)
Gender	Male	74.36
	Female	25.64
Age (Year)	Young (≤35)	17.95
	Middle (36-50)	58.97
	Old (>50)	23.08
Level of education	Can sign only	11.52
	Primary	21.79
	Secondary	41.03
	Higher Secondary	15.38
	Tertiary	10.26
Family size	Small (up to 4)	12.82
	Medium (5-8)	71.79
	Large (>8)	15.38
Farm size	Small (0.21-1 ha)	64.1
	Medium (1-3 ha)	30.77
	Large (>3 ha)	5.13
Knowledge level of sustainable agriculture	Poor	8.97
	Moderate	43.59
	High	47.44

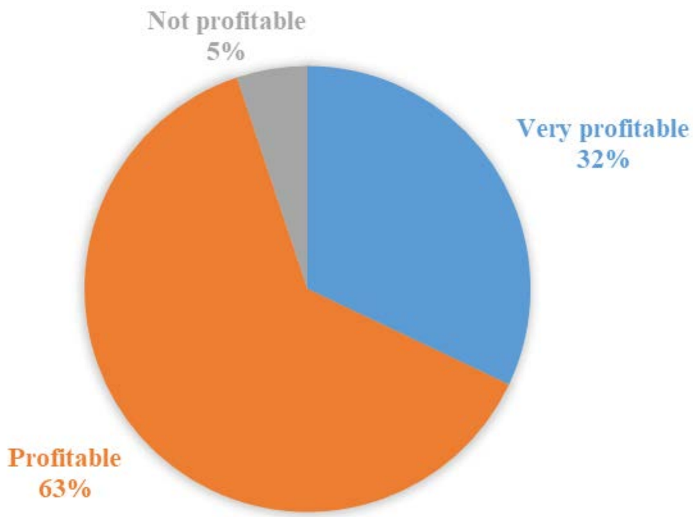

Figure 2. Profitability rate of agroforestry practices in Madhupur Sal forest.

3.2. Economic Perspective of Agroforestry Practices

The growth and maintenance of tree crop-based agroforestry practices are shaped by different aspects of economic features for the rural farmers of Bangladesh. According to the analysis of agroforestry experts on different popular agroforestry models in the study area, this study focused on the three most prominent agroforestry practices in Madhupur Sal forest of Bangladesh.

3.3. Productivity Analysis of Acacia-Pineapple-Turmeric-Papaya-Based Agroforestry

According to the economic perspective, this agroforestry system required intense agricultural labor, which was the primary input cost of the agroforestry systems that was comparatively lower for the establishment (Table 3). However, the Acacia tree requires high-quality seedlings to build agroforestry systems, the initial sapling and tree installation expenses were higher. The total input cost of production was 2141.45 USD/hectare and the total profit was 6212.95 USD/hectare. The Net

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Present Value (NPV) of this agroforestry system was 1833.55 USD/hectare and the Benefit-Cost Ratio was 1.90 (Table 3). This agroforestry system is more profitable than the general agricultural system.

Table 2. Financial cash flow of Akashmoni-Pineapple-Turmeric-Papaya based agroforestry practices (* 1 USD = 109.65 BDT).

Inputs	Cost/Returns (USD/ha)
Tree seedlings/saplings costs	53.63
Land preparation costs	151.39
Planting and establishment of tree saplings costs	41.31
Tree pruning, training, and other management costs	29.09
Pineapple cultivation costs	582.31
Papaya cultivation costs	117.56
Turmeric cultivation costs	149.57
Agricultural labor costs	469.68
Manure and fertilizer costs	109.35
Insecticide and pesticide costs	42.59
Weeding and irrigation costs	82.99
Mulching cost	20.98
Harvesting costs of crops	193.89
Firewood and timber harvesting costs	47.88
Non-timber product harvesting costs	26.90
Miscellaneous cost	22.34
Total production costs	2141.45
Output	
Income from firewood	342.91
Income from non-timber products	176.93
Income from timber	783.04
Income from pineapple	3972.64
Income from papaya	268.13
Income from turmeric	414.96
Income from crop residues	254.35
Total income/productivity	6212.95
Net income/Profit	4071.50
Net Present Value	1833.55
Benefit–Cost Ratio (BCR)	1.90

3.4. Productivity Analysis of Sal-Pineapple-Aroid Based Agroforestry

As Sal (*Shorea robusta*) is the most prominent species of the forest and Pineapple is widely spread in the area, Sal-Pineapple-Aroid-based agroforestry is one of the major agroforestry practices. Sal can tolerate high temperatures and usually loses its leaves from February to March, with new leaves appearing in April and May. These leaves from Sal are used for mulching so that soil can conserve moisture and leaves decompose to add soil nutrients. In this agroforestry model, the total production cost and profit were 2150.30 USD/hectare and 5745.10 USD/hectare worth a Net Present Value (NPV) of 1372.28 USD/hectare and the Benefit-Cost Ratio was 1.67 (Table 3)

Table 3. Financial cash flow of Sal-Pineapple-Aroid-based agroforestry practices (* 1 USD = 109.65 BDT).

Inputs	Cost/Returns (USD/ha)
Tree seedlings/saplings costs	88.46
Land preparation costs	160.05
Planting and establishment of tree saplings costs	37.85

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Tree pruning, training, and other management costs	35.29
Pineapple cultivation costs	632.01
Aroid cultivation costs	250.80
Agricultural labor costs	400.36
Manure and fertilizer costs	95.76
Insecticide and pesticide costs	43.41
Weeding and irrigation costs	76.61
Mulching cost	0.00
Harvesting costs of crops	228.91
Firewood and timber harvesting costs	45.14
Non-timber product harvesting costs	28.73
Miscellaneous cost	26.90
Total production costs	2150.30
Output	
Income from firewood	289.10
Income from non-timber products	130.41
Income from timber	837.21
Income from pineapple	3938.90
Income from aroid	322.85
Income from crop residues	226.63
Total income/productivity	5745.10
Net income/Profit	3594.80
Net Present Value	1372.28
Benefit–Cost Ratio (BCR)	1.67

3.5. Productivity Analysis of Acacia-Pineapple-Zinger-Banana Based Agroforestry

The study analyzed nine Acacia-Pineapple-turmeric-Papaya-based agroforestry plots for detailed economic analysis and converted the findings to hectares. The total input cost of this agroforestry model was 2150.02 USD/hectare and the net profit was 4434.93 USD/hectare. However, the Net Present Value (NPV) was 2170.66 USD/hectare and the Benefit-Cost Ratio (BCR) was 2.06 (Table 4).

Table 4. Financial cash flow of Acacia-Pineapple-Zinger-Banana-based agroforestry practices (* 1 USD = 109.65 BDT).

Inputs	Cost/Returns (USD/ha)
Tree seedlings/saplings costs	54.54
Land preparation costs	139.53
Planting and establishment of tree saplings costs	42.41
Tree pruning, training, and other management costs	28.18
Pineapple cultivation costs	565.34
Banana cultivation costs	123.58
Zinger cultivation costs	193.80
Agricultural labor costs	416.51
Manure and fertilizer costs	87.00
Insecticide and pesticide costs	39.76
Weeding and irrigation costs	89.83
Mulching cost	19.15
Harvesting costs of crops	269.04
Firewood and timber harvesting costs	32.56
Non-timber product harvesting costs	29.09
Miscellaneous cost	19.70
Total production costs	2150.02

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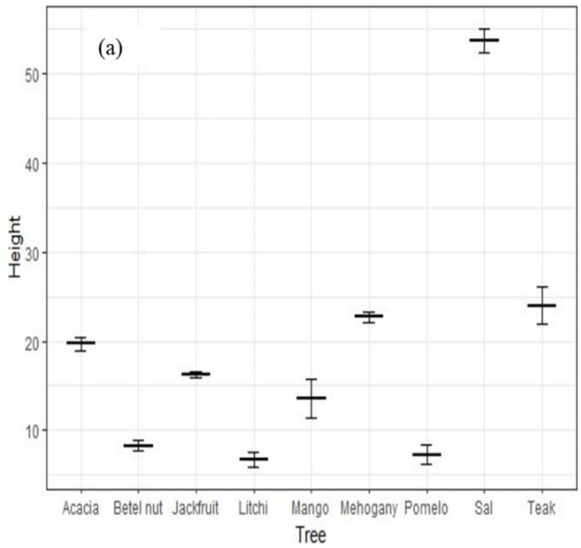
Output	
Income from firewood	327.41
Income from non-timber products	163.70
Income from timber	817.15
Income from pineapple	4248.88
Income from banana	322.85
Income from zinger	507.07
Income from crop residues	197.90
Total income/productivity	6584.95
Net income/Profit	4434.93
Net Present Value	2170.66
Benefit–Cost Ratio (BCR)	2.06

3.6. Ecological Perspective of Selected Agroforestry Practices

3.6.1. Species Composition of Agroforests

A total of 9 tree species that were planted with diverse crops in the agroforestry model were observed, totaling 173 trees in the Madhupur Sal forest. The forest is enriched with Sal (Shorea robusta), where Acacia (Acacia auriculiformis) species were mostly planted in association followed the availability of Teak (Tectona grandis), Litchi (Litchi chinensis), and Jackfruit (Artocarpus heterophyllus). The average height of the tree was 19.7ft, DBH (Diameter Breast Height) 4.1 inches, and age 7 years for Acacia (Acacia auriculiformis). The average height of the tree ranged from 6.5ft to 54ft for Mango (Mangifera indica), Jackfruit (Artocarpus heterophyllus), Teak (Tectona grandis), Mahogany (Swietenia macrophylla), Litchi (Litchi chinensis), Pomelo (Citrus maxima), Betel nut (Areca catechu), Sal (Shorea robusta). The average age of the tree varied from 4.5 years to 36 years for Pomelo (Citrus maxima), Betel nut (Areca catechu), Teak (Tectona grandis), Mango (Mangifera indica), Jackfruit (Artocarpus heterophyllus), Sal (Shorea robusta) whereas average diameter was 1.5 to 13 inches. Different trees showed various carbon sequestration due to trees' height, diameter, and age. Furthermore, particular tree management techniques influence the rate of Carbon Sequestration (CS) by urban trees.



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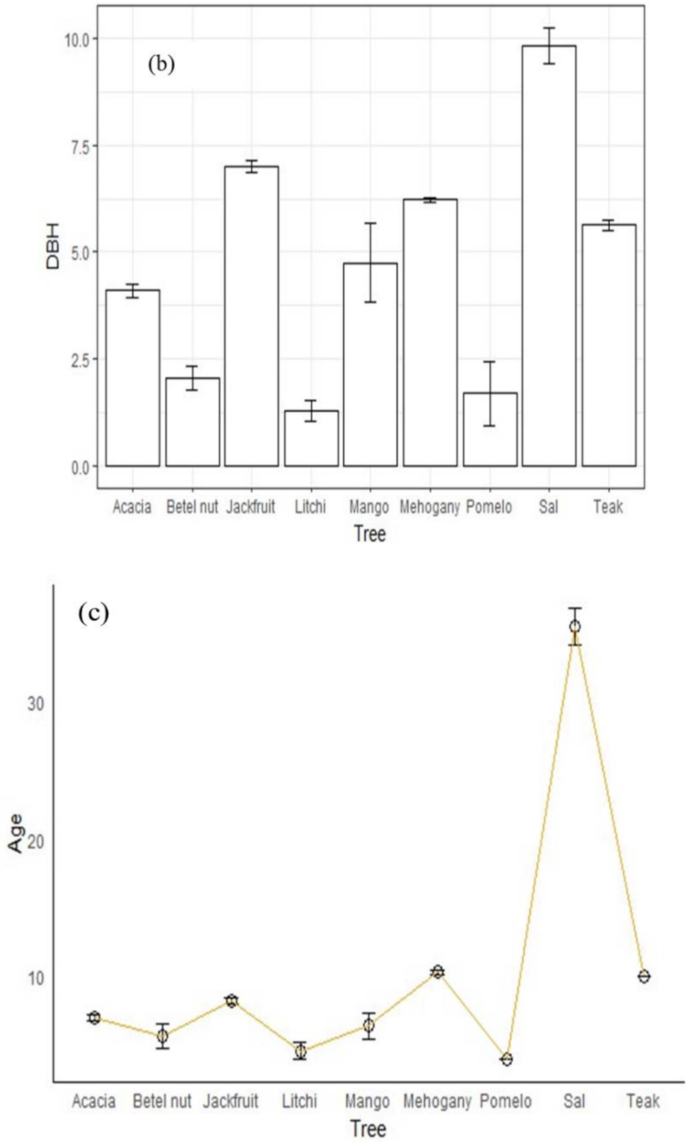

Figure 3. (a) height (ft), (b) DBH (inch), and (c) age (year) of major tree species used in agroforestry practices of Madhupur Sal forest.

3.7. Weight of the Trees

The average green weight of the trees varies from 4.5 lbs for Litchi (*Litchi chinensis*) to 1342 lbs for Sal (*Shorea robusta*) while the average dry weight varies from 3.27 lbs for Litchi (*Litchi chinensis*) to 972.71 lbs for Sal (*Shorea robusta*). The average carbon weighs 1.62 lbs for Litchi (*Litchi chinensis*) to 486.36 lbs for Sal (*Shorea robusta*). The average green weight, dry weight, and carbon weight of Acacia (*Acacia auriculiformis*) were 151.18 lbs, 109.60 lbs, and 54.80 lbs respectively mostly observed in agroforestry practices (Figure 4). The green weights of Mango (*Mangifera indica*), Teak (*Tectona grandis*), and Mahogany (*Swietenia macrophylla*) were 120.42 lbs, 230.48 lbs, and 262.69 lbs respectively. Concerning green weight, dry weight and carbon weight, Litchi (*Litchi chinensis*), Pomelo (*Citrus maxima*), Betel nut (*Areca catechu*) had minimum carbon sequestration and Sal (*Shorea robusta*), Mahogany (*Swietenia macrophylla*), Jackfruit (*Artocarpus heterophyllus*), Acacia (*Acacia auriculiformis*) showed maximum carbon sequestration.

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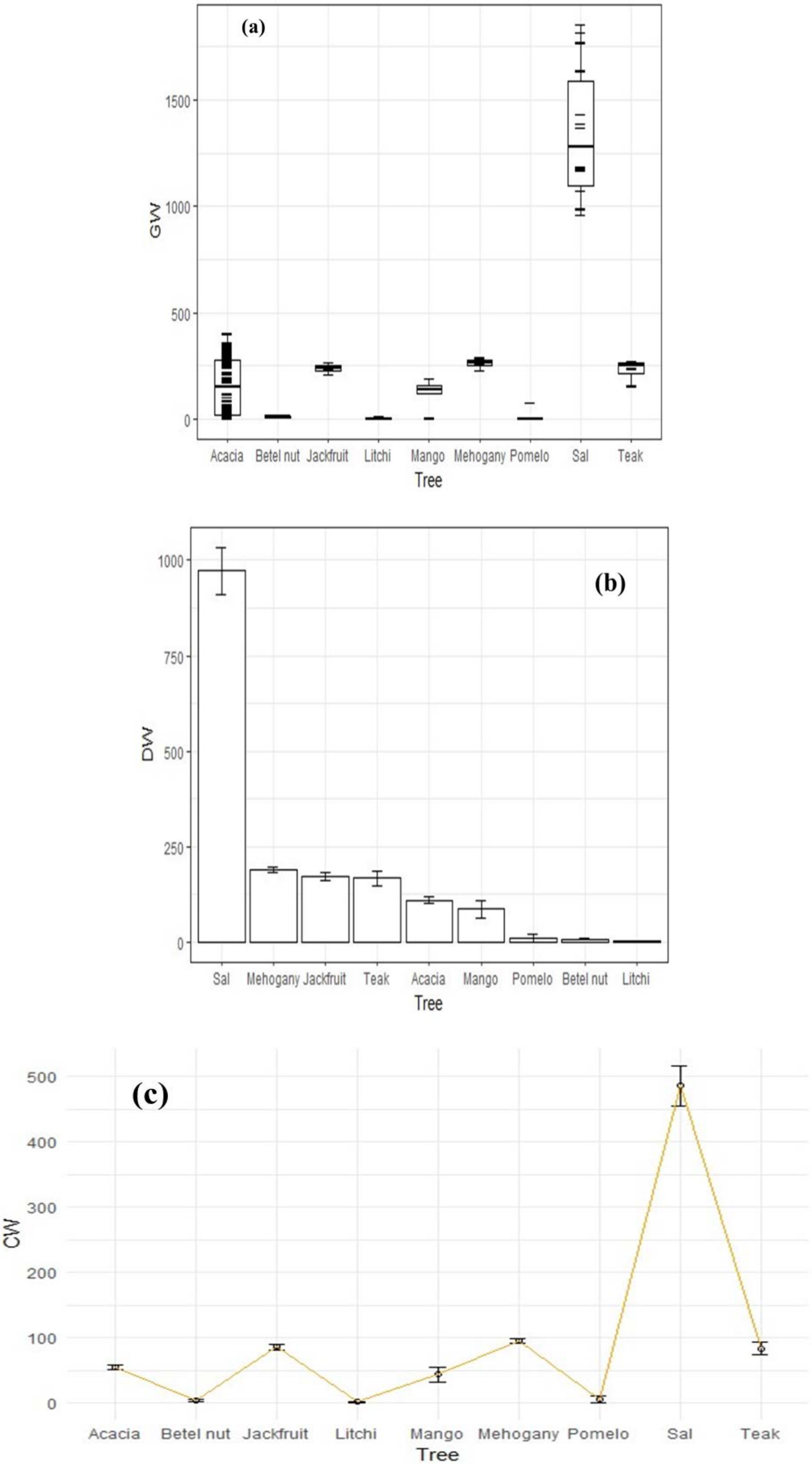

Figure 4. (a) green weight (lbs), (b) dry weight (lbs), and (c) carbon weight (lbs) of major agroforest tree species.

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3.8. Carbon Sequestration of Various Tree Species

The result showed Sal (*Shorea robusta*) is the maximum carbon-sequestrating tree and Betel nut (*Areca catechu*), Litchi (*Litchi chinensis*), and Pomelo (*Citus maxima*) are the minimum CO_2 sequestrating trees (Figure 5). Shorea robusta sequesters average 1783.83 lbs of carbon dioxide, however, *Acacia auriculiformis* 200.92 lbs, *Litchi chinensis* 6 lbs, *Swietenia macrophylla* 349.12 lbs, *Tectona grandis* 306.31 lbs, *Artocarpus heterophyllus* 316.16 lbs, *Mangifera indica* 160.04 lbs of carbon was sequestrated in Madhupur Sal forest (Figure 5). The maximum yearly CO_2 sequestration was 49.80 lbs/year for *Shorea robusta* and 31.84 lbs/ year for *Tectona grandis* and the minimum CO_2 sequestration was 4.43 lbs/year and 1.15 lbs/year for *Citus maxima* and *Litchi chinensis* (Figure 5). Acacia auriculiformis yearly sequestrate 23.35 lbs of CO_2.

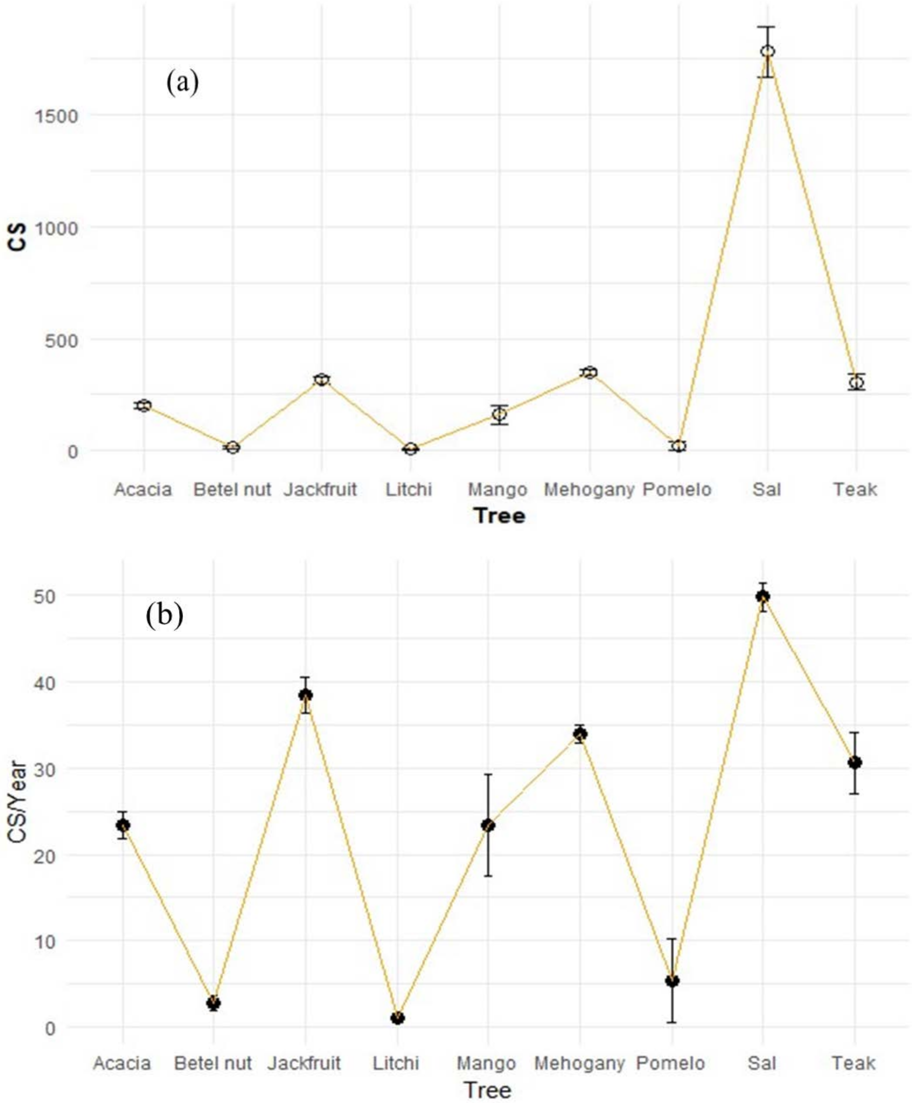

Figure 5. (a) average carbon sequestration (lbs), and (b) average amount of yearly carbon sequestration (lbs) of major tree species used in agroforestry practices.

4. Discussion

It is conceivable to capture approximately 250 to 500 million tons of carbon dioxide annually in the United States, and on a global scale, this figure could reach upwards of 2,000 million tons per year for several decades [19]. According to Toochi (2018), Northeastern maple–beech–birch forests exhibit carbon sequestration rates of 1,760 lbs of CO_2 per acre per year for a 25-year-old forest and 3,909 lbs of CO_2 per acre per year for a 120-year-old forest. Additionally, these forests sequester 2.52 lbs of CO_2 per tree per year for a 25-year-old forest and 5.58 lbs of CO_2 per tree per year for a 120-year-old forest.

In contrast, white and red pine forests sequester 14 lbs of CO_2 per tree per year for a 25-year-old forest and 11.7 lbs of CO_2 per tree per year for a 120-year-old forest [20].

In Bangladesh, roadside plantations demonstrate the highest above-ground carbon sequestration rate at 165.81 Mg C ha^{-1}, surpassing institutional plantations at 150.00 Mg C ha^{-1}. Among natural forests, protected areas accumulate the highest above-ground carbon at 195.8 Mg C ha^{-1}, followed by mangroves at 76.80 Mg C ha^{-1}. The estimated below-ground carbon for fast-growing species is 100.84 Mg C ha^{-1}, compared to above-ground carbon at 110.25 Mg C ha^{-1} [21]. Mangrove forests have a carbon stock of approximately 117 Mg C ha^{-1}, bamboo stands at 52 Mg C ha^{-1}, palm at 22 Mg C ha^{-1}, institutional plantations at 174 Mg C ha^{-1}, fragmented forests at 33 Mg C ha^{-1}, home gardens at 52 Mg C ha^{-1}, and protected areas at 233 Mg C ha^{-1} [22–27].

Two unresolved issues could significantly impact the effectiveness of carbon sequestration in greenhouse gas mitigation programs, with potential counteracting effects. Firstly, the secondary benefits of converting agricultural land to forests might outweigh the costs, making carbon sequestration a no-regrets strategy. On the other hand, if leakage is a serious issue at both national and international levels, governments may invest substantial funds in subsidies or incentives, resulting in little or no net gain in carbon, forests, or secondary benefits [19].

In Denmark, LER values ranged from 1.36 to 2.00, indicating that agroforestry systems were 36–100% more productive compared to monocultures. The agroforestry gross margin in Denmark was lower at €112 ha^{-1} $year^{-1}$ compared to the United Kingdom's €5083 ha^{-1} $year^{-1}$, and the crop component yielded higher returns than the tree component in agroforestry [28]. In Europe, the primary productive advantages of agroforestry systems are associated with improved resource utilization in spatial and temporal scales, leading to enhanced environmental benefits such as reduced nutrient losses, increased carbon sequestration, biodiversity enhancement, soil loss reduction, and fire risk management in specific areas. These advantages can provide significant social benefits at the farm level across different biogeographic regions in Europe, benefiting the general public [29].

Regarding the impact of agroforestry interventions, Castle et al. (2021) found positive or neutral effects on dietary diversity and food intake. While there is limited evidence on the environmental outcomes of agroforestry interventions, available studies suggest that environmental benefits are being achieved to some extent, aligning with the broader literature on agroforestry practices. The evidence base is insufficient to assess the interaction between environmental and social impacts. Studies did consider variable impacts across different population sub-groups, revealing that smallholder farmers typically experience the most positive effects from agroforestry interventions. Impacts on women and poorer groups varied relative to men and richer households, emphasizing the importance of considering these groups in intervention design [30].

5. Conclusions

The multitude of agroforestry systems, whether practiced in the tropics or temperate regions, are firmly based on strong ecological principles and avail to the achievement of many local development goals through the provision of many basic needs and ecosystem services. Due to the favorable economic and ecological effects of Acacia-Pineapple-Turmeric-Papaya, Sal-pineapple-Aroid, and Acacia-Pineapple-Zinger-Banana agroforestry, these agroforestry models should garner more attention at a national and worldwide level in terms of sustainable land-use techniques. For typically resource-poor agroforestry farmers, trading of the sequestered C is a feasible possibility for economic advantage and mitigating greenhouse gases. The findings of this study will encourage both locally and internationally to implement additional legislative changes that will improve the sustainability of agroforestry systems. The management of trees in the Madhupur Sal forest can help reduce emissions of greenhouse gas and sequester carbon, and carbon sequestration by trees may make it possible for a developing country like Bangladesh to engage in carbon trading.

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