

**ASSESSING FARMERS' PERCEPTIONS AND CARBON SEQUESTRATION  
POTENTIAL OF CROPLAND AGROFORESTRY IN THE CONTEXT OF  
CLIMATE CHANGE**



**A THESIS**

**BY**

**MD. FORHAD HOSSEN**

**Registration No. 1701367**

**MS Session: Jan-June 2023**

**Thesis Semester: January June, 2025**

**MASTER OF SCIENCE (M.S.)**

**IN**

**AGROFORESTRY AND ENVIRONMENT**

**DEPARTMENT OF AGROFORESTRY AND ENVIRONMENT**

**HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY**

**UNIVERSITY, DINAJPUR**

**JUNE 2025**

**ASSESSING FARMERS' PERCEPTIONS AND CARBON SEQUESTRATION  
POTENTIAL OF CROPLAND AGROFORESTRY IN THE CONTEXT OF  
CLIMATE CHANGE**



**A THESIS**

**BY**

**MD. FORHAD HOSSEN**

**Registration No. 1701367**

**MS Session: Jan-June 2023**

**Thesis Semester: January June, 2025**

*Submitted to the Department of Agroforestry and Environment, Hajee Mohammad  
Danesh Science and Technology University, Dinajpur in partial fulfillment of the  
requirements of the degree of*

**MASTER OF SCIENCE (M.S.)**

**IN**

**AGROFORESTRY AND ENVIRONMENT**

**DEPARTMENT OF AGROFORESTRY AND ENVIRONMENT  
HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY  
UNIVERSITY, DINAJPUR**

**JUNE 2025**

**ASSESSING FARMERS' PERCEPTIONS AND CARBON SEQUESTRATION  
POTENTIAL OF CROPLAND AGROFORESTRY IN THE CONTEXT OF  
CLIMATE CHANGE**



**A THESIS**

**BY**

**MD. FORHAD HOSSEN**

**Registration No. 1701367**

**MS Session: Jan-June 2023**

**Thesis Semester: January June, 2025**

Approved as to style and contents by

---

**(Prof. Dr. Md. Shoaibur Rahman)**

Supervisor

---

**(Prof. Dr. Md. Abu Hanif)**

Co-Supervisor

---

**(Prof. Dr. Md. Shoaibur Rahman)**

Chairman of Examination Committee

and

Chairman, Department of Agroforestry and Environment

Hajee Mohammad Danesh Science and Technology University, Dinajpur.

**JUNE 2025**

**Dedicated**

**To**

**My Beloved Parents and**

**Honorable Teachers**

## **DECLARATION**

I hereby declare that the work presented in this thesis titled “**ASSESSING FARMERS’ PERCEPTIONS AND CARBON SEQUESTRATION POTENTIAL OF CROPLAND AGROFORESTRY IN THE CONTEXT OF CLIMATE CHANGE**” has been carried out by myself and that it has not been submitted for any previous degree. All quotations have been distinguished by quotation marks and all sources of information specifically acknowledged by references to the author.

Examination Roll No. **1701367**

Department of Agroforestry and Environment

Hajee Mohammad Danesh Science and Technology University,

Dinajpur-5200,

Bangladesh

## ACKNOWLEDGEMENT

*All praises are due to the Almighty Allah, the great, the gracious, merciful and supreme ruler of the universe to complete the research work and thesis successfully.*

*The author expresses the deepest sense of gratitude, sincere appreciation and heartfelt indebtedness to his reverend research supervisor, **Prof. Dr. Md. Shoaibur Rahaman**, Department of Agroforestry & Environment, Hajee Mohammad Danesh Science and Technology University, Dinajpur for his scholastic guidance, innovative suggestion, constant supervision and inspiration, valuable advice and helpful criticism in carrying out the research work and preparation of this manuscript.*

*The author deems it a proud privilege to acknowledge his gratefulness, boundless gratitude and best regards to his respectable co-supervisor **Prof. Dr. Md. Abu Hanif**, Department of Agroforestry & Environment, Hajee Mohammad Danesh Science and Technology University, Dinajpur for his valuable advice, constructive criticism and factual comments in upgrading the research work.*

*Special appreciation and warmest gratitude are extended to his other esteemed teachers Department of Agroforestry & Environment, Hajee Mohammad Danesh Science and Technology University, Dinajpur who provided teaching, creative suggestions, guidance and constant inspiration from the beginning to the completion of the course and research work. Their contribution, love and affection would persist in his memory for countless days.*

*The author expresses his heartiest thanks to his dearest friends of Hajee Mohammad Danesh Science and Technology University, Dinajpur for their endless and active co-operation during the entire period of the research.*

*Finally, the author expresses his unfathomable tributes, sincere gratitude and heartfelt indebtedness from his core of heart to his parents, whose blessings, inspiration, sacrifices, and moral support opened the gate and paved the way of his higher study. The authoress also expresses his indebtedness to his brothers and sisters for their love and well-wishing for him.*

**The Author**

**JUNE 2025**

# ASSESSING FARMERS' PERCEPTIONS AND CARBON SEQUESTRATION POTENTIAL OF CROPLAND AGROFORESTRY IN THE CONTEXT OF CLIMATE CHANGE

## ABSTRACT

Agroforestry serves as a vital strategy for enhancing climate resilience, conserving biodiversity, and sustaining rural livelihoods in northern Bangladesh. This study aimed to evaluate farmers' perceptions of climate change, the role of agroforestry practices in mitigating its impacts, and the contribution of cropland agroforestry to carbon sequestration. The research was conducted from February to May 2025 in five villages of Sundorpur Union under Kaharole Upazila, Dinajpur district. A total of 63 cropland agroforestry farms covering 2.52 hectares were randomly selected. Semi-structured interviews captured demographic and socioeconomic data, while biophysical data were collected from 20 m × 20 m quadrats. Findings revealed that farmers were experiencing climate-related stresses such as drought, rising temperatures, and irregular rainfall. Consequently, 71.43% reported increased irrigation demand, 52.4% cited rising input costs, and 30.16% experienced reduced crop yields due to climate change. Biophysical assessments recorded 13 woody perennial species comprising 715 individual trees. *Areca catechu* showed the highest Importance Value Index (IVI) at 69.08%, followed by *Eucalyptus camaldulensis* (56.12%) and *Swietenia macrophylla* (50.79%). Biodiversity indices indicated moderate diversity, with a Shannon–Wiener index of 1.84 and Margalef's richness index of 1.521. *Swietenia macrophylla* had the highest basal area (10.6 m<sup>2</sup>/ha), while *Areca catechu* had the highest stand density (104.37 individuals/ha). *Eucalyptus camaldulensis* contributed most to above-ground biomass (52.27 Mg ha<sup>-1</sup>), followed by *Swietenia macrophylla* (23.89 Mg ha<sup>-1</sup>). The total woody biomass was estimated at 133.00 Mg ha<sup>-1</sup>, with a total carbon stock of 66.50 Mg C ha<sup>-1</sup>. Despite these benefits, adoption of cropland agroforestry is limited by inadequate training, weak institutional support, and resource competition. Nevertheless, farmers recognized its potential in climate adaptation and ecosystem enhancement, highlighting the need for targeted policy support, capacity building, and continued research to strengthen its adoption under changing climatic conditions.

**Keywords:** Agroforestry, cropland agroforestry, farmers' perceptions, biodiversity, IVI, carbon stock, climate change, Dinajpur.

## CONTENTS

CHAPTER	TITLE	PAGE NO
	<b>DECLARATION</b>	<b>i</b>
	<b>ACKNOWLEDGEMENT</b>	<b>ii</b>
	<b>ABSTRACT</b>	<b>iii</b>
	<b>CONTENTS</b>	<b>iv</b>
	<b>LIST OF TABLES</b>	<b>viii</b>
	<b>LIST OF FIGURES</b>	<b>ix</b>
	<b>LIST OF APPENDICES</b>	<b>x</b>
<b>CHAPTER 1</b>	<b>INTRODUCTION</b>	<b>1-4</b>
<b>CHAPTER 2</b>	<b>REVIEW OF LITERATURE</b>	<b>5-20</b>
	2.1 Concepts and Importance of Agroforestry	5
	2.2 Agroforestry in the Context of Climate Change	6
	2.3 Types of Agroforestry Systems in Bangladesh	9
	2.4 Cropland Agroforestry Practices in Bangladesh	10
	2.5 Climate Change Impacts on Agriculture in Northern Bangladesh	12
	2.6 Carbon Sequestration Potential of Agroforestry	14
	2.7 Agroforestry for Sustainable Land Management	17
	2.8 Socio-Economic Benefits of Agroforestry	18
	2.9 Biodiversity Conservation through Agroforestry	18
	2.10 Challenges to Agroforestry Adoption in Bangladesh	20
<b>CHAPTER 3</b>	<b>MATERIALS AND METHODS</b>	<b>22-35</b>
	3.1 Brief Description of the Study Area	22
	3.1.1 Overview of the Study Area	22
	3.1.2 Land types	23
	3.1.3 Climatic scenario of the study area	23
	3.2 Sampling strategy and data collection techniques	23
	3.2.1 Sampling design	23
	3.2.2 Preparation of interview schedule	24

## CONTENTS (Contd.)

CHAPTER	TITLE	PAGE NO
	3.2.3 Field Surveys	24
	3.2.4 Measurement of independent variables	25
3.3	Measuring biodiversity index and estimation of Carbon sequestration	29
	3.3.1 Diameter at Breast Height (DBH)	29
	3.3.2 Stand Density (D)	30
	3.3.3 Basal area (m <sup>2</sup> /ha)	30
	3.3.4 Relative Density (RD%)	30
	3.3.5 Frequency (F%)	31
	3.3.6 Relative Frequency (RF%)	31
	3.3.7 Relative Dominance (RD <sub>0</sub> %)	32
	3.3.8 Importance Value Index (IVI)	32
	3.3.9 Diversity Indices	33
	3.3.10 Above-Ground Biomass (AGB)	34
	3.3.11 Below-Ground Biomass (BGB)	34
	3.3.12 Total Biomass and Tree Carbon Stock	34
3.4	Statistical analysis	35
<b>CHAPTER 4</b>	<b>RESULTS AND DISCUSSION</b>	<b>36-58</b>
4.1	Demographic characteristics of the respondents	36
	4.1.1 Age	36
	4.1.2 Family size	36
	4.1.3 Education	36
	4.1.4 Farm size	36
	4.1.5 Cropland Agroforestry Field Size	37
4.2	Farming experience of the respondents	38
	4.2.1 Farming experience	38
	4.2.2 Agroforestry (AGF) farming experience	39

## CONTENTS (Contd.)

CHAPTER	TITLE	PAGE NO
4.3	Planting System in Agroforestry field	39
4.4	Intention of planting trees in cropland	40
4.5	Change in Productivity Since Adopting Agroforestry	41
4.6	Perceived effects of climate change and benefits of agroforestry in relation to climate change	42
4.6.1	Observed climatic changes	42
4.6.2	Affects of climate change in farming practices	43
4.6.3	Benefits of Cropland Agroforestry in relation to Climate change	44
4.7	Barriers and Challenges faced by respondents to Adopt Agroforestry	45
4.8	Policy Support Received by Agroforestry Farmers & Their Suggestion	47
4.8.1	Policy Support Received by Respondents	47
4.8.2	Policy change Suggestions to promote agroforestry	48
4.9	Stand structure, composition and diversity of woody perennials	48
4.9.1	Importance Value Index (IVI) of identified woody perennials of cropland agroforestry	48
4.9.2	Shannon–Wiener Diversity Index (H') and Margalef's Index (R) of Woody Perennials	50
4.9.3	Height and DBH of Woody Perennials in Cropland Agroforestry	51
4.9.4	Stand density and basal area of woody perennials in Cropland Agroforestry	52

## CONTENTS (Contd.)

CHAPTER	TITLE	PAGE NO
4.10	Total biomass carbon stocks of cropland agroforestry practices	53
4.10.1	Above Ground Biomass (AGB) per individual tree of a species	53
4.10.2	Woody Biomass and Carbon Stock in Cropland Agroforestry Systems	54
4.10.3	Influence of DBH, Height, Basal Area, and Stand Density on Carbon Sequestration in Cropland Agroforestry	56
<b>CHAPTER 5</b>	<b>SUMMARY AND CONCLUSION</b>	<b>59-62</b>
5.1	Summary	59
5.2	Conclusion	61
5.3	Recommendations	62
	<b>REFERENCES</b>	<b>63-74</b>
	<b>APPENDIX</b>	<b>75-88</b>

## LIST OF TABLES

TABLE NO.	TITLE	PAGE NO
4.1	Descriptive statistics showing the demographic characters of respondents	37
4.2	Perceived Benefits of Agroforestry in Relation to Climate Change by Respondents	44
4.3	Perceived Barriers and Challenges in Practicing Agroforestry by Respondents	45
4.4	Extent of Policy Support Received by Agroforestry Farmers	47
4.5	Relative Density (RD%), Relative Frequency (RF%), Relative Dominance (RD0%), and Importance Value Index (IVI %) of Woody Perennial Species in Cropland Agroforestry Systems	49
4.6	Shannon–Wiener Diversity Index (H') of most abundant Woody Perennials in Cropland Agroforestry	50
4.7	Total Biomass (Mg ha <sup>-1</sup> ) and Carbon Stock Estimation (Mg C ha <sup>-1</sup> ) of Woody Perennials in Cropland Agroforestry Systems	55

## LIST OF FIGURES

FIGURE NO.	TITLE	PAGE NO
3.1	Map of Kaharole Upazila of Dianjpur District, Bangladesh (source: Banglapedia)	22
4.1	Farm size and Cropland AGF size of the respondents in the study area	38
4.2	Farming experience of the respondents in the study area	38
4.3	Planting System of trees in crop field	39
4.4	Distribution of Farmers' Intentions for Planting Trees in Cropland Agroforestry Systems	40
4.5	Changes in productivity since adopting Agroforestry	41
4.6	Perceived Climatic Changes Experienced by Respondents in the Study Area	42
4.7	Perceived Affects of Climate Change on Farming Practices by Respondents	43
4.8	Ranking of Barriers to Agroforestry Adoption Using Problem Finding Index (PFI)	46
4.9	Bar graphs showing (a) DBH (cm) and (b) height (m) of woody perennials of cropland agroforestry practices in the study area.	51
4.10	Bar chart graph showing both stand density and basal area of abundantly found woody species in Cropland agroforestry practices	52
4.11	Above-ground biomass (AGB) for most abundant woody perennials in the cropland agroforestry	54
4.12	Relationship Between Tree Structural Attributes and Carbon Stock in Cropland Agroforestry Systems	57

## LIST OF APPENDICES

APPENDIX NO	TITLE	PAGE NO
I	Table showing Farming experience of the respondents in the study area	75
II	Pivot table for multiple response analysis: Observed climatic changes by respondents	75
III	Pivot table for multiple response analysis: Intension of Planting trees in Crop field	76
IV	Perceived affects of climate change in farming practices	76
V	Problem Finding Index (PFI) for ranking Barriers / Challenges to adopt agroforestry practices	77
VI	Policy change suggestion to promote agroforestry	77
VII	Total number of woody perennial individuals in cropland agroforestry practices and their IVI	78
VIII	Mean DBH & Height of Woody Perennial Species	79
IX	Basal Area and Stand Density of Woody Perennials of cropland agroforestry in the study area	80
X	Wood specific gravity ( $\text{g cm}^{-3}$ ) of woody perennials of cropland agroforestry in the study area (Source: Global wood density database)	80
XI	Mean Above Ground Biomass (AGB) of Woody perennials of Cropland Agroforestry practices in the study area	81
XII	ANOVA: Regression of DBH, Height, Basal Area, and Stand Density on Carbon Sequestration in Cropland Agroforestry	81
XIII	An interview schedule on “Farmers perception on Cropland Agroforestry practices and its role to mitigate climate change impact”	83
XIV	Photographs of the study area	86

# CHAPTER 1

## INTRODUCTION

Agroforestry is a land-use management system that integrates trees and shrubs into agricultural landscapes for ecological, economic, and social benefits (Plieninger et al., 2020). Unlike conventional monoculture systems, agroforestry harmonizes perennial vegetation with annual crops or livestock, creating multifunctional landscapes that increase resource use efficiency and enhance sustainability (Nair et al., 2021). This intentional interaction between woody perennials and crops or animals results in ecological synergy, where trees contribute to soil fertility, nutrient cycling, microclimate regulation, and biodiversity conservation (Atangana et al., 2014a; Udawatta et al., 2021). Historically, agroforestry has been practiced for centuries across diverse agroecological zones, particularly in tropical and subtropical regions, where smallholder farmers depend on multifunctional landscapes for subsistence and income generation (Ashiagbor et al., 2020; Desmiwati et al., 2021). Today, it is recognized not only as a traditional practice but also as a modern approach to achieving sustainable agriculture, ecosystem restoration, and climate-smart land use (Awazi & Tchamba, 2019; Dagar & Tewari, 2018).

The importance of agroforestry lies in its ability to provide a wide array of ecosystem services. It contributes to food and nutritional security, enhances biodiversity, controls soil erosion, enriches soil organic matter, and stabilizes hydrological cycles (Chowdhury et al., 2022). Economically, it diversifies farm income and reduces dependence on external inputs, making farming systems more resilient to price and climate shocks (Ashiagbor et al., 2020). Moreover, agroforestry helps to mitigate land degradation, which is a pressing issue in many parts of South Asia, including Bangladesh (Akter et al., 2022). It is especially beneficial for smallholders, who can utilize limited land resources more efficiently through integrated systems that yield food, fodder, fuel, and timber (Jahan et al., 2022; Rahman et al., 2020). As an environmentally sustainable and socially inclusive practice, agroforestry aligns with several global development frameworks, including the Sustainable Development Goals (SDGs), the UN Decade on Ecosystem Restoration, and the Convention on Biological Diversity (Awazi, 2024; Telwala, 2023).

Agroforestry is widely recognized as a climate change mitigation and adaptation strategy. The Intergovernmental Panel on Climate Change identifies agroforestry as a key land-based mitigation option due to its capacity for carbon sequestration, emission reduction, and

microclimate regulation (Karim et al., 2020; Yirga, 2019). Trees act as carbon sinks by capturing atmospheric CO<sub>2</sub> and storing it in biomass and soil, thereby reducing greenhouse gas (GHG) concentrations in the atmosphere (Islam et al., 2015). Globally, studies have estimated that agroforestry systems can sequester between 0.29–15.21 Mg C ha<sup>-1</sup> yr<sup>-1</sup> depending on the system type, species composition, and climate zone (Nair et al., 2009). Research in Africa, Latin America, and Southeast Asia has confirmed the potential of various agroforestry systems—such as alley cropping, silvopasture, and parkland systems—to store large amounts of biomass carbon (Chavan et al., 2014; Jinger et al., 2022).

In Bangladesh, where agriculture is extremely vulnerable to climate change, agroforestry is promoted as a climate-resilient farming system (Islam et al., 2011; Jahan et al., 2022). Several studies have demonstrated the ecological and economic benefits of agroforestry in mitigating climate-related risks such as drought, salinity, and erratic rainfall (Datta & Behera, 2023; Hanif et al., 2015). For instance, Ruba & Talucder (2023) reported that homestead and cropland agroforestry practices in coastal Bangladesh improve resilience and carbon storage potential under changing climate conditions. Agroforestry plays a critical role in terrestrial carbon sequestration by storing carbon in above-ground biomass, root systems, and soil organic matter (Abbas et al., 2017; Reppin et al., 2020). The biomass of trees contributes significantly to the total carbon pool, while root turnover and litter deposition enhance soil carbon stocks (Toppo & Raj, 2018). Different agroforestry practices show varying carbon sequestration capacities, influenced by tree species, management intensity, and ecological conditions.

For example, silvopastoral systems in Latin America have been found to sequester up to 63 Mg C ha<sup>-1</sup> in total biomass (Picasso & Pizarro, 2024), while alley cropping systems in India and Africa contribute between 15–45 Mg C ha<sup>-1</sup> (Cardinael et al., 2015). In South Asia, tree-crop combinations such as *Populus deltoids* with wheat have shown promising carbon accumulation rates (Kumar et al., 2020). In Bangladesh, studies by Alam (2012) and (Baul et al., 2021) have quantified carbon stocks in homestead forests and roadside plantations, reporting values ranging from 30 to over 80 Mg C ha<sup>-1</sup> depending on stand age and species composition. However, there is limited data on the carbon sequestration potential of cropland-based agroforestry systems, which highlights the need for more focused research. Agroforestry systems such as homegardens, boundary plantations, and cropland agroforestry vary in their structural complexity and carbon storage capacity. Homegardens, characterized by multilayered vegetation and species diversity, have been found to store up to 69.15 Mg C

ha<sup>-1</sup> in some regions of Bangladesh (Jaman et al., 2016). Boundary plantations with species like *Eucalyptus*, *Swietenia*, and *Acacia* also contribute significantly to carbon stocks, particularly in linear arrangements around croplands (Hasan et al., 2025).

Cropland agroforestry, where trees are interspersed with crops such as rice, maize, or wheat, provides a balanced approach to production and carbon storage. Fast-growing species like *Eucalyptus camaldulensis* and *Areca catechu* have shown high biomass production, contributing substantially to above-ground carbon pools (Ali et al., 2024). In Bangladesh, species like *Swietenia macrophylla* and *Moringa oleifera* have been successfully integrated with crops, offering both livelihood benefits and climate mitigation potential (Hasan et al., 2024). Cropland agroforestry systems are increasingly promoted as a strategy to address the dual challenges of food insecurity and climate vulnerability. Globally, research by Agevi et al., (2017) and Alías et al. (2022) emphasizes the capacity of agroforestry to provide climate-resilient livelihoods while sequestering carbon in smallholder landscapes. These systems stabilize crop yields, enhance soil fertility, and increase resilience against extreme weather events. In Bangladesh, cropland agroforestry remains underutilized despite its potential. Farmers often integrate tree species along field boundaries or within crop fields, but these practices are rarely optimized for maximum ecological or carbon benefits. Moreover, institutional, technical, and social barriers limit the widespread adoption of cropland agroforestry (Islam et al., 2023a).

Bangladesh is characterized by intensive cropping systems and increasing environmental stress due to climate change. The region frequently experiences erratic rainfall, rising temperatures, and periodic droughts, which threaten food production and rural livelihoods (Dastagir, 2015; Kreft et al., 2016; Sikder & Xiaoying, 2014). Despite having suitable land and a strong tradition of agroforestry, cropland agroforestry in this region remains poorly documented and underdeveloped. Given these challenges and opportunities, there was a critical need to assess the current status, performance, and constraints of cropland agroforestry systems in northern Bangladesh. Understanding how these systems contribute to carbon sequestration and climate resilience can inform targeted policy interventions and improve adoption rates. This study aimed to fill that research gap by evaluating farmers' perceptions of climate change, measuring carbon stocks in cropland agroforestry systems, and identifying key barriers to their expansion in the context of climate change adaptation and mitigation.

This research was designed to explore the perception of farmers on agroforestry practices as a climate change mitigation strategy and contribution of cropland agroforestry practices for atmospheric carbon sequestration in northern part (Dinajpur district) of Bangladesh.

Therefore, this study is designed to explore the following objectives-

- 1.To assess farmers' view on agroforestry practices in the context of climate change
- 2.To find out the diversity of tree species on cropland agroforestry system
- 3.To quantify woody biomass carbon stock in cropland agroforestry system

This study might offer practical insights for building climate-resilient agricultural systems and support the scaling up of agroforestry in Bangladesh.

## CHAPTER 2

### REVIEW OF LITERATURE

An extensive review of relevant scientific literature, policy documents, and reports was conducted to establish a solid theoretical foundation for this research. The review focused on agroforestry practices, climate change adaptation and mitigation strategies, and their relevance to the context of Bangladesh. This involved identifying the latest trends, challenges, and gaps in knowledge, particularly in relation to cropland agroforestry's role in addressing climate change in Northern Bangladesh.

#### 2.1 Concepts and Importance of Agroforestry

Nair *et al.* (2021) stated that the term agroforestry was coined in 1977 as part of the early international efforts to initiate research on integrated production systems involving crops and trees. Numerous discussions and arguments were held during those early days to define and characterize agroforestry, and several definitions were proposed. The basic concept that is common to all diverse agroforestry practices is the purposeful growing or deliberate retention of trees with crops and/or animals in interacting combinations for multiple products or benefits from the same management unit. Today, agroforestry represents the modern, science-based approach to harnessing the sustainability attributes and production benefits of time-tested practices of integrating trees in agricultural systems for a variety of objectives.

Agroforestry (AF) is a dynamic, ecologically based, natural resources management system that, by integrating trees on farms, ranches, and in other landscapes, diversifies and increases production and promotes social, economic, and environmental benefits for land users (Dagar & Tewari, 2018).

According to Atangana *et al.*, (2014), Several definitions have been proposed to agroforestry, of which the most commonly used are those of Lundgreen and Raintree (Agricultural research for development: potentials and challenges in Asia, 1982, pp 37–49) and Leakey (Agroforest Today 8:1, 1996). Agroforestry is any land-use system, practice or technology, where woody perennials are integrated with agricultural crops and/or animals in the same land management unit, in some form of spatial arrangement or temporal sequence. Agroforestry is also a dynamic and ecologically -based natural resource management system.

Agroforestry refers to the deliberate introduction or retention of trees on farms to increase, diversify, and sustain production for increased social, economic, and environmental benefits.

According to Torquebiau (2000), Agroforestry is the association of trees with farming practices, is progressively becoming a recognized land-use discipline. Based on field experience from several countries, a structural classification of agroforestry into six simple categories is proposed: crops under tree cover, agroforests, agroforestry in a linear arrangement, animal agroforestry, sequential agroforestry and minor agroforestry techniques. The history of agroforestry is peculiar. It was born several thousand years ago as an agricultural practice, when man started to practice slash and burn (shifting) cultivation, or the art of utilizing trees to restore soil fertility during a fallow period.

Amonum *et al.*, (2009) highlighted that Agroforestry can be viewed as a societal response, primarily born out of a need to fulfill immediate basic human needs of food, fuel, fodder, shelter, protection etc. Effort to define Agroforestry began in the mid-1970s and evolved rapidly as studies began on the diversity and scope of Agroforestry practices. There are three basic types of Agroforestry systems viz: Agrisilviculture (Crops + trees), silvopastoral (Pasture/animal + trees); and Agrosilvopastoral (crops + pasture + trees). Other specified Agroforestry can also be defined e.g. apiculture (bees with trees), aquaculture (fishes with trees and shrubs) and multipurpose tree lots). Agroforestry is becoming recognized as a land use system which is capable of yielding both wood and food while at the same time conserving and rehabilitating ecosystems.

Garrett *et al.*, (2022) said that agroforestry is based on the expected role of on-farm and off-farm tree production in supporting sustainable land-use and natural-resource management. While the aboveground and belowground diversity provides more stability and resilience for the system at the site level, the system provides connectivity with forests and other landscape features at the landscape and watershed levels.

## **2.2 Agroforestry in the Context of Climate Change**

According to van Noordwijk *et al.*, (2021), agroforestry can contribute to climate change adaptation in four ways: (1) Reversal of negative trends in diverse tree cover as generic portfolio risk management strategy; (2) targeted, strategic, shift in resource capture (e.g. light, water) to adjust to changing conditions (e.g. lower or more variable rainfall, higher temperatures); (3) vegetation-based influences on rainfall patterns; and/or (4) adaptive,

tactical, management of tree-crop interactions based on weather forecasts for the (next) growing season. Evidence for the generic risk reduction by increase of buffer functions and diversity is strong; examples of specific adaptations to confirmed trends in local climate are still sparse, but start to emerge, especially with respect to hydroclimatic change.

A study conducted by Nath et al., (2021) in India demonstrated that Agroforestry holds a great potential for creating carbon (C) sinks and mitigating emissions from agriculture, while also increasing adaptive capacity. They found biomass C stocks were higher in agrosilvopastoral (73.4 Mg C ha<sup>-1</sup>) than in agrisilvicultural (42.6 Mg C ha<sup>-1</sup>) and silvopastoral systems (42.7 Mg C ha<sup>-1</sup>). Similarly, SOC stocks were higher in agrosilvopastoral (53.0 Mg C ha<sup>-1</sup>) than in agrisilvicultural (44.1 Mg C ha<sup>-1</sup>) and silvopastoral systems (33.5 Mg C ha<sup>-1</sup>). Agroforestry systems in humid zones had significantly higher total biomass C stocks (97.9 Mg C ha<sup>-1</sup>) and SOC stocks (51.8 Mg C ha<sup>-1</sup>). SOC stocks were significantly higher under agroforestry in medium (51.2 Mg C ha<sup>-1</sup>) than in high (46.7 Mg C ha<sup>-1</sup>) and low (32.7 Mg C ha<sup>-1</sup>) altitudes. Assuming no significant change in area under agrisilvicultural, agrosilvopastoral and silvopastoral systems, the total C sequestered by 2050 was projected to be 4.2, 4.5 and 1.5 Pg CO<sub>2</sub> eq, respectively. With an increase in 5% of current area at 5-years intervals, the total CO<sub>2</sub> eq sequestered by 2050 was estimated at 5.4 Pg in agrisilvicultural, 5.8 Pg in agrosilvopastoral and 1.9 Pg in silvopastoral systems. The results concluded that expansion of the area under agroforestry by a mere 30% has the potential to offset significant proportions of India's total emissions by 2050. Therefore, they recommend the inclusion of agroforestry in the Nationally Determined Contribution of India.

According to Sapkota *et al.* (2019), many agricultural practices like agroforestry can potentially mitigate GHG emissions without compromising food production. Long-term changes in average temperatures, precipitation, and climate variability threaten agricultural production, food security, and the livelihoods of farming communities globally. Whilst adaptation to climate change is necessary to ensure food security and protect livelihoods of poor farmers, mitigation of greenhouse gas (GHG) emissions can lessen the extent of climate change and future needs for adaptation.

Datta & Behera, (2023) explored farmers' perceptions of climate change and the functions of agroforestry in coping with climate risks and, ultimately, employs binary logistic regression to examine household-level factors that influence agroforestry adoption in the Indian Eastern

Himalayan foothills. The results show the following: (i) a substantial majority of farmers perceived climate change; (ii) about 47% of farming households adopted agroforestry, stating trees offer them an alternate income stream in the case of crop failure due to uncertain rains. Moreover, farmers reported that trees are more resistant to flooding, less water-intensive, and less prone to pest attacks; and (iii) the likelihood of adopting agroforestry is significantly influenced by ethnicity, remittances, landholding size, and the educational attainment of the household head. However, farmers with secure land tenure and access to extension service agents are less likely to choose agroforestry over conventional farming of cereals.

Jhariya *et al.*, (2019) studied Agroforestry in the Context of Climate Change and concluded that the present situation to combat climatic elements agroforestry appears as one potential practice under sustainable agriculture system to boost up agricultural productivity as well as a strategy for combating climate change. Such land-use practices promote elevated carbon (C) sink. Under these circumstances, agroforestry seems to have very high potential to combat climate change. The major strategies throughout the country are to develop a uniform agroforestry policy having relaxations in the existing rules and regulations needs to be formulated, and the various agroforestry schemes under varied agro-ecological conditions should be implemented by framing some government bodies which also promotes research and development (R&D) activities in agroforestry.

Van Noordwijk (2018) estimated that three concepts of agroforestry interact with three aspects of climate change, linking local to global scales. Scientific knowledge can contribute to public policy development in four distinct phases: grasp, commit, operationalize and innovate. This contribution highlights three ways agroforestry can be part of a climate change response: adapt to increased risks and uncertainties, facilitate an energy transition (while capturing and storing carbon), and restoring landscape multifunctionality to allow current human resource appropriation to become sustainable, fitting sustainable development goals within planetary boundaries.

Mbow *et al.*, (2014) found contribution of agroforestry to food security in Africa in the face of climate variability and change. They also provide environmental and social benefits as part of farming livelihoods. Varied ecological and socio-economic conditions have given rise to specific forms of agroforestry in different parts of Africa. More explicit inclusion of agroforestry and the integration of agriculture and forestry agendas in global initiatives on climate change adaptation and mitigation can increase their effectiveness.

According to Matocha *et al.*, (2012), Agroforestry and ecosystem conservation are key approaches in the integration of climate change adaptation and mitigation objectives, often generating significant co-benefits for local ecosystems and biodiversity. Synergies between climate change adaptation and mitigation actions are particularly likely in projects involving income diversification with tree and forest products, reduction of the susceptibility of land-use systems to extreme weather events, improvement of soil fertility, fire management, wind breaks, and the conservation and restoration of forest and riparian corridors, wetlands, and mangroves. On the other hand, trade-offs between adaptation and mitigation are possible when fast-growing tree monocultures for mitigation conflict with local tree and forest uses, making livelihoods more vulnerable, when trees are planted in water-scarce areas conflicting with local water uses, and in some cases when “climate-smart” agroforestry practices conflict with the need for agricultural intensification to produce increasing amounts of food for a growing population.

Nair *et al.*, (2010) showed that Agroforestry systems have a higher potential to sequester C because of their perceived ability for greater capture and utilization of growth resources (light, nutrients, and water) than in single-species crop or pasture systems. The estimates of C stored in AFS range from 0.29 to 15.21 Mg ha<sup>-1</sup> yr<sup>-1</sup> aboveground and 30 to 300 Mg C ha<sup>-1</sup> up to 1 m depth in the soil. Recent studies under various AFS in diverse ecological conditions showed that tree-based agricultural systems, compared to treeless systems, stored more C in deeper soil layers near the tree than away from the tree, and higher soil organic C content was associated with higher species richness and tree density.

Howlett *et al.*, (2011) showed that silvopasture has an important role in C sequestration and climate change mitigation deal with the importance of soil particle size and land management practices on C storage in soils.

### **2.3 Types of Agroforestry Systems in Bangladesh**

Akter *et al.*, (2022) investigated that 150 tribal farmers practicing different types of agroforestry systems in Madhupur Sal forest, using a mixed-method strategy that included a survey, focus group discussion, key informant interviews, and direct observation. According to the results, tribal farmers used a total of 22 trees and 33 crop species in their existing agroforestry systems, indicating a rich composition and high diversity. *Acacia auriculiformis* was the most common tree species (with 82% of farmers possessing this species), followed by *Mangifera indica* (75%), *Acacia sp.* (73%), and *Gmelina arborea* (54%). Interviews

revealed that agroforestry systems have provided numerous benefits and greatly enhanced farmers' livelihoods through better access to food, timber, fodder, and fuelwood and greater access to livelihood capitals (except social capital).

Nair, Kumar, & Nair (2021) developed a classification scheme based on the system's structure (nature and arrangement of components) as the primary criterion, and three major categories of AFS were identified: agrisilvicultural, silvopastoral, and agrosilvopastoral systems. Other criteria such as the system's function (major role or output), ecological distribution (rainfall, elevation), and socioeconomic characteristics (subsistence, commercial) were then used to group the systems in a purpose-oriented manner: for example, a silvopastoral system in tropical savannas, an agrisilvicultural system for soil conservation, and so on. In situations where such a detailed classification is not relevant or needed as in the temperate regions, classification has been limited to the identification of the major practices. Thus, during the late 1990s to early 2000s, alley cropping, silvopasture, forest farming, riparian buffer, and windbreaks were recognized as the major agroforestry practices.

According to Nair (1985), Several criteria can be used to classify and group AF systems (and practices). The most commonly used ones are the system's structure (composition and arrangement of components), its function, its socio-economic scale and level of management, and its ecological spread. Structurally, the system can be grouped as agrisilviculture (crops — including tree/shrub crops — and trees), silvopastoral (pasture/animals + trees), and agrosilvopastoral (crops + pasture/animals + trees). Other specialized AF systems such as apiculture with trees, aquaculture in mangrove areas, multipurpose tree lots, and so on, can also be specified. Arrangement of components can be in time (temporal) or space (spatial) and several terms are used to denote the various arrangements. Functional basis refers to the main output and role of components, especially the woody ones. These can be productive functions (production of 'basic needs' such as food, fodder, fuelwood, other products, etc.) and protective roles (soilconservation, soil fertility improvement, protection offered by windbreaks and shelterbelts, and so on).

## **2.4 Cropland Agroforestry Practices in Bangladesh**

Chakraborty et al. (2015) conducted a study attempts to examine farmers' preference and perception towards cropland agroforestry (CAF) and its economic benefits in Bangladesh. It surveyed 84 farmers of two sub-districts named Manirampur and Bagherpara under Jessore district of Bangladesh to address the study objectives with the help of a questionnaire during

the period of June to July 2013. According to the survey findings, most of the farmers preferred multipurpose tree species like *Swietenia macrophylla* (67 percent), *Phoenix sylvestris* (48 percent), *Mangifera indica* (48 percent) and *Cocos nucifera* (43 percent). They also found that *Curcuma longa* (92 percent), *Oryza* spp. (56 percent), *Solanum melongena* (43 percent) and *Amorphophallus campanulatus* (33 percent) are the available agriculture crops which were grown in association with trees in the study area. The surveyed farmers report that they practiced CAF to get fuel wood, fodder, juice, fruit and food for family consumption and revenue earnings.

An investigation took place by Ali et al. (2024) in Sadar and Biral upazila within Dinajpur district of northern part of Bangladesh. To establish a sample group, an updated roster of total 266 agroforestry growers was procured from the respective Upazila Agriculture Offices. The study evaluated ten key attributes of agroforestry growers, encompassing factors like age, educational background, farm size, farming experience, family income, extension network engagement, agricultural knowledge, innovation inclination, marketing orientation, and technological attitude. The central focus of the study centered on the transition from croplands to agroforestry orchards. The study revealed that over the period spanning 1990 to 2022, agroforestry farmers in the study region converted cropland into orchards with varying extents, ranging from 13 % to 19.83 %. The substitution of predominant crops such as rice, maize, and wheat, along with minor crops like potatoes, vegetables, mustard, garlic, turmeric, and napier grass, marked the transition to agroforestry practices. Evaluating the consequences of this transition, approximately 60.00 % of growers perceived medium-level impacts on economic aspects, while 70.00 %, 61.25 %, and 58.75 % alleged the effects on environmental conditions, household food security, and social status, respectively as also moderately.

Hasanuzzaman et al. (2014) conducted a study focused on the diversity, composition, people's preferences, spatial variations and purpose of cultivation of agricultural crops in the cropland agroforestry practices of southwestern Bangladesh. A total of 313 cropland agroforests were randomly surveyed from Khulna, Jessore and Satkhira districts of this region. The highest (0.84 to 0.87) crop diversity index (CDI) was found for climber vegetables, followed by tuber vegetables (CDI - 0.78 to 0.81), spices (CDI - 0.75 to 0.81) and the lowest (CDI - 0.20 to 0.40) was found for cereal crops. Among these three districts maximum crop diversity was found in Jessore as the soil is more suitable as well as marketing and transportation facility is higher than the other two districts. Among the cereal crops maximum (95%) preferred paddy (*Oryza sativa*). Among the cash crops maximum

(68%) preferred jute (*Corchorus capsularis*). Among the tuber vegetables maximum (44%) preferred potato (*Solanum tuberosum*). Among the fruity vegetables maximum (42%) preferred brinjal (*Solanum melongena*). Among the leafy vegetables maximum (39%) preferred basil (*Basella camaldulensis*). Among the climber vegetables maximum (36%) preferred bean (*Lablab niger*). Among the pulses maximum (52%) preferred lentil (*Lens culinaris*). Among the spices maximum (42%) preferred green peeper (*Capsicum frutescens*). Among the flowers maximum (70%) preferred rose (*Rosa centifolia*). Among the annuals/perennials maximum (66%) preferred banana (*Musa spp.*). Overall diversity and preference of agricultural crops in southwestern Bangladesh were determined by the local demand and end product.

## **2.5 Climate Change Impacts on Agriculture in Northern Bangladesh**

According to Nelson *et al.* (2009), agriculture is extremely vulnerable to climate change. Higher temperatures eventually reduce yields of desirable crops while encouraging weed and pest proliferation. Changes in precipitation patterns increase the likelihood of short-run crop failures and long-run production declines. Although there will be gains in some crops in some regions of the world, the overall impacts of climate change on agriculture are expected to be negative, threatening global food security. Populations in the developing world, which are already vulnerable and food insecure, are likely to be the most seriously affected.

Shakhawat *et al.* (2020) assessed the effects of clim

ate change on farmland value in Bangladesh using the Ricardian model. Household-level data collected from seven selected agroecological zones in Bangladesh were used to estimate the relationships among farmland value and long-term climate, farm household, and policy variables. The results showed that the current land values of farmers are sensitive to climate. A new variable called “flooding” was added to the Ricardian model, and the results indicated that floods are responsible for reductions in farmland value, especially in lowland areas. Among the socio-economic variables, the availability of extension services and access to irrigation facilities were positively correlated with farmland value. The estimated marginal impact results suggested that increases in temperature were associated with losses in small farmland value, whereas the precipitation levels in both seasons positively influenced farmland value. Selected global climate models predicted that climate change would have a negative impact on land value depending on the climate model and source of farm income.

Sikder & Xiaoying (2014) observed that climate change has become a major issue affecting the agriculture sector. Impacts of climate change in agriculture are global concern but for Bangladesh where lives and livelihoods depend on agriculture, it's becoming a great threat for national food security. Considering crop agriculture as the predominant factor in the national economy, this paper tried to focus on the climate change impact and vulnerability in Bangladeshi Agriculture; it also highlighted various strategies that can be taken in response to climate change, ways to adapt to the altered situation and Bangladesh's saline tolerant, flood tolerant and shorter maturity varieties of rice and other crops.

A study conducted by Ruane *et al.* (2013) provided new sub-regional vulnerability analyses and quantified key uncertainties in climate and production. Temperature increases generally reduce production across all scenarios. Precipitation changes can have either a positive or a negative impact, with a high degree of uncertainty across global climate models. Carbon dioxide impacts on crop production are positive and depend on the emissions pathway. Increasing river flood areas reduce production in affected sub-regions. Precipitation uncertainties from different global climate models and emissions scenarios are reduced when integrated across the large Ganges-Brahmaputra-Meghna Basins' hydrology. Agriculture in Southern Bangladesh is severely affected by sea level rise even when cyclonic surges are not fully considered, with impacts increasing under the higher emissions scenario.

Thomas *et al.* (2013) examined the likely impacts of climate change on agriculture in Bangladesh, and developed recommendations to policymakers to help farmers adapt to the changes. In this study, they used climate data from four general circulation models (GCMs) to evaluate the impact of climate change on agriculture in Bangladesh by 2050. They used the DSSAT (Decision Support System for Agrotechnology Transfer) crop modeling software to evaluate crop yields, first for the 1950 to 2000 period (actual climate) and then for the climates given by the four GCMs for 2050. They evaluated crop yields at 1,789 different points in Bangladesh, using a grid composed of roughly 10 kilometer (km) squares, for 8 different crops in 2000 and 2050. For each crop, they searched for the best cultivar (variety) at each square, rather than limiting our analysis to a single variety for all locations. They also searched for the best planting month in each square. In addition, they explored potential gains in changing fertilizer levels and in using irrigation to compensate for rainfall changes. This analysis indicated that when practiced together, using cultivars better suited for climate change and adjusting planting dates can lessen the impacts of climate change on yields, especially for rice, and in some cases actually result in higher yields. In addition, the analysis

showed that losses in yield due to climate change can be compensated for, for many crops, by increasing the availability of nitrogen in the soil.

Menelsohn (2007) examined the effect that climate change and carbon fertilization between 1960 and 2000 had on agricultural GDP across the world. Although the change in climate has been small, it has been enough to have effects in each region. The small increase in carbon dioxide has also had effects fertilizing plants around the world. These effects have not been visible because there have been many other dramatic changes in agriculture, especially in rapid technical change.

Fischer et al. (2005) conducted a comprehensive assessment of the impacts of climate change on agro-ecosystems over this century is developed, up to 2080 and at a global level, albeit with significant regional detail and concluded that climate change and variability may result in irreparable damage to arable land and water resources in some regions, and with serious local consequences for food production. These losses will be felt most profoundly in developing countries with low capacity to cope and adapt. While the international community has focused on climate change mitigation, the issue of adaptation to climate change is an equally pressing issue and must be put on the international negotiation agenda. This is of critical importance to many developing countries that have contributed little to greenhouse gas emissions thus far and yet, it is these countries that will bear the brunt of the negative impacts of climate change and variability.

## **2.6 Carbon Sequestration Potential of Agroforestry**

Ghale *et al.* (2022) reviewed agroforestry as a sustainable land use practice adopted as a strategy under Kyoto Protocol, plays a crucial role to mitigate the inevitable climate change with a promising potential of carbon sequestration in their biomass and utilization of their numerous resource. Agroforestry is crucial for reducing greenhouse gas emissions, sustaining livelihoods, and partial solutions for biodiversity conservation. Worldwide, agroforestry is practiced by more than 1.2 billion people, on around 1 billion hectares (ha) of land area, while in India, around 25.32 million hectares' area comes under agroforestry. Agroforestry system is the enhancement of overall farm productivity, soil enrichment through litter fall, above and below ground carbon sequestration, maintaining environmental services. Different agroforestry systems are adapted at the global level and periodic monitoring and estimation of area under agroforestry, monitoring of tree and soil carbon stocks is still a challenging task due to the lack of uniform methodology.

A study was conducted by Siarudin *et al.* (2021) in five districts in West Java province to examine potential carbon stock in agroforestry systems practiced by smallholder farmers on degraded landscapes. Six agroforestry systems with differing carbon stocks were identified: gmelina (*Gmelina arborea* Roxb.) + cardamom (*Amomum compactum*); manglid (*Magnolia champaca* (L.) Baill. ex Pierre) + cardamom; caddam (*Neolamarckiacadamba* (Roxb.) Bosser) + cardamom; caddam + elephant grass (*Pennisetum purpureum* Schumach.); mixed-tree + fishpond; and mixed-tree lots. Compared to other systems, mixed-tree lots had the highest carbon stock at 108.9 Mg ha<sup>-1</sup>. Carbon stock variations related to species density and diversity. Farmers from research sites said these systems also prevent soil erosion and help to restore degraded land. Farmers' adoption of agroforestry can be enhanced by the implementation of supportive policies and measures, backed by scientific research.

According to Agroforestry is recognized as one of the important means to reduce CO<sub>2</sub> emissions as well as enhancing carbon sinks. Agroforestry provides unique opportunity to combine the twin objectives of climate change adaptation and mitigation. In India, area under agroforestry was estimated at 25.3 m ha, which can further be increased up to a considerable level. Recent studies under various agroforestry systems in diverse ecological conditions emphasized that agroforestry systems increase and store carbon stocks in above ground biomass and in soil and also has an important role in increasing livelihood security and reducing vulnerability to climate change. In India carbon sequestration potential of agroforestry systems is estimated between 0.25 – 19.14 and 0.01 to 0.60 Mg C/ha/yr for tree and crop component, respectively. The contribution of agroforestry in soil carbon sequestration varied between 0.003 to 3.98 Mg C/ha/yr. The total C sequestered in each component differs greatly depending on region, types of -species, -system, -site quality, and previous land-use. The review indicates that agroforestry systems in addition to accumulate and sequester carbon, provide an excellent opportunity to increase the tree cover to a level of 33% of the total geographical area of the country as desired by the National Forest Policy.

According to Islam *et al.* (2015), tropical agroforestry systems have immense potential to sequester carbon both in aboveground and belowground biomass and soil. Homegarden agroforestry is a popular land-use system in the tropics, sequestering more organic carbon in soil than crops, monoculture plantations and even than other agroforestry systems. Tree diversity and density are reported to affect soil organic carbon content in many of tropical agroforestry systems. Little evidence, however, exists for tropical homegardens. The present study has been conducted to investigate soil organic carbon content in relation to tree species

diversity in the homegarden agroforestry system of north-eastern Bangladesh, to test the hypothesis that homegardens with high species diversity contain more organic carbon in soil than those with low species diversity. The study demonstrated that species-rich homegarden with high tree density can sequester more carbon in soil than species-poor homegardens and thereby contribute more to climate change mitigation.

Abbas *et al.*, (2017) reviewed that agroforestry is recognized as an afforestation activity that, in addition to sequestering carbon dioxide (CO<sub>2</sub>) to soil, conserves biodiversity, protects cropland, works as a windbreak, and provides food and feed to human and livestock, pollen for honey bees, wood for fuel, and timber for shelters construction. Agroforestry is more attractive as a land use practice for the farming community worldwide instead of cropland and forestland management systems. This practice is a win–win situation for the farming community and for the environmental sustainability. Potential of agroforestry to counter the increasing concentration of atmospheric CO<sub>2</sub> by sequestering it in above- and belowground biomass. The role of agroforestry in climate change mitigation worldwide might be recognized to its full potential by overcoming various financial, technical, and institutional barriers.

Yirga (2019) concluded that carbon sequestration potential of agroforestry is greater than other land use system because due to presence of perennial tree in the component. In addition, agroforestry showed a great potential in sequester carbon and contribute to mitigating CO<sub>2</sub> than treeless systems. Agroforestry systems can be advantageous over conventional agricultural system, and forest production methods. They can offer increased productivity, food security, economic benefits, and more diversity in the ecological goods and services provided. In sector wise basis, agriculture contributes 80% of GHG emission because due to dominant position of livestock farming (methane emissions) in Ethiopia's economy also influences the relative contribution of GHG to the total emissions.

Murthy *et al.* (2013) reviewed the role of agroforestry systems in carbon mitigation. Agroforestry provides a unique opportunity to combine the twin objectives of climate change adaptation and mitigation. It has the ability to enhance the resilience of the system for coping with the adverse impacts of climate change. Agroforestry systems offer important opportunities for creating synergies between both adaptation and mitigation actions. Various authors have carried out studies to estimate carbon stocks in different agroforestry systems in

India. Agroforestry systems have the potential to provide significant mitigation options but they require proper management that influences the amount of carbon sequestered.

## **2.7 Agroforestry for Sustainable Land Management**

Jaman *et al.* (2021) studied the effects of single (tree or shrub) and mixed (tree-shrub) plant types on soil C and N dynamics in agroforestry systems by selecting homesteads as an identical study ground. They also studied how the relationships between diversity, richness, density, soil C and N varies across homesteads. There were three main results in this study: first, the soil organic carbon and soil nitrogen contents in mixed plant types (tree-shrub) homesteads was higher than that of the single plant type (tree or shrub) homesteads.

According to Plieninger *et al.* (2020), Key steps to harness agroforestry for sustainable landscape management comprise: (i) moving towards an “agroforestry sustainability science”; (ii) understanding local land-use trajectories, histories, and traditions; (iii) upscaling agroforestry for landscape-scale benefits; (iv) promoting the multiple economic, environmental, social, and cultural values of agroforestry; (v) fostering inclusive forms of landscape governance; and (vi) supporting the innovation process of agroforestry system analysis and design.

Jumiyati & Frimawaty (2024) concluded that agricultural practices that incorporate agroforestry, specifically agrisilviculture, have the potential to effectively address food security concerns, enhance nutritional value, and maintain strong ties with local social and cultural traditions due to their longstanding adoption by communities across generations. It is imperative to formulate optimal agroforestry principles and frameworks that minimize the likelihood of deforestation and degradation of land and forests.

Borelli *et al.* (2017) found that the implementation of urban and peri-urban agroforestry systems – associated with the integration of urban food systems into urban planning – can greatly support the provision of ecosystem services to urban dwellers, thus contributing to the improvement of their livelihood through increased food and nutrition security, energy and fresh water availability, regulation of local climate, carbon sequestration, maintenance of genetic diversity, recreation opportunities and health improvement. In this sense, Agroforestry is emerging as a new urban practice addressed to promote sustainable land use as well as the integration between urban and rural development

## **2.8 Socio-Economic Benefits of Agroforestry**

Hanif *et al.*, (2018) conducted a study designed to identify the present status, management practices and its role in improving the livelihoods of farmers in northern Bangladesh. Data for the study were collected through quantitative and qualitative methods. A total of 29 tree and 38 agricultural crop species were planted by the 102 farmers interviewed. *Mangifera indica* (relative prevalence 49%) is the most predominant species, followed by *Eucalyptus camaldulensis* (relative prevalence 35.4%). Farmers of northern Bangladesh plant trees in cropland for fruits (90%), fuel wood (87%) and timber production (79%). Fruit trees were planted with wider spacing while forest and fuel wood species were planted with narrower spacing. Farmer's livelihoods improved enormously by practicing agroforestry as they have more access to food, fodder and fuel wood which is reflected by greater access to livelihood capitals (except social capital). However, farmers have experienced increased incidences of pests and diseases to the annual crops and trees. Agroforestry practices increase species diversity, ensure economic return and sustain farmer's livelihoods.

A study conducted by K. K. Islam *et al.* (2021) in the Jashore and Mymensingh districts to assess the economic, social and environmental outcomes of two important Date palm and Jackfruit-based traditional agroforestry systems in Bangladesh. The results revealed that the traditional agroforestry systems enhanced farm productivity and the benefit–cost ratio of both systems were much higher than the general agricultural practices in Bangladesh. The traditional agroforestry systems also improved resilience of rural farmers through more efficient water utilization, enhancing soil fertility, improving microclimate, controlling pests and diseases, and diversifying products. At the same time, the farmers' problems were neglected due to the absence of farmers' platforms, and also tradeoffs may arise; thus, the social aspects of the TAS farmers had not developed equally.

## **2.9 Biodiversity Conservation through Agroforestry**

Homegarden agroforestry systems have been proven to be an intermediary for biodiversity conservation. A study conducted by Bardhan *et al.* (2012) to evaluate the effectiveness of home garden agroforestry practices to conserve tree species diversity in Bangladesh and compare them with tree species diversity in National Forests. Based on their results it was concluded that Agroforestry can serve as an important ecological tool in conserving tree

species diversity, particularly on landscapes where National forests fragments represent only a small fraction of the total land area. Creating and maintaining Agroforestry habitats in such human dominated landscapes should be part of the biodiversity conservation strategy.

A case study conducted by McNeely & Schroth (2006) highlighted that the considerable potential of traditional agroforestry practices to support biodiversity conservation, but also show their limits. These include the importance of sufficient areas of natural habitat and of appropriate hunting regulations for maintaining high levels of biodiversity in agroforestry land use mosaics, as well as the critical role of markets for tree products and of a favorable policy environment for agroforestry land uses. In combination the case studies suggest that maintaining diversity in approaches to management of agroforestry systems, along with a pragmatic, undogmatic view on natural resource management, will provide the widest range of options for adapting to changing land use conditions.

According to Nair, Kumar, & Nair (2021a), Agroforestry systems (AFS), which traditionally harbor far more species diversity than conventional agricultural and plantation forest ecosystems, are also experiencing species losses through a process of simplification, e.g., the transformation of shaded coffee and cacao production systems into unshaded crop monocultures with intensive management leading to agro-deforestation. Most tropical AFS, especially the multistrata systems, are outstanding loci for biodiversity conservation and are intrinsically capable of promoting both aboveground and belowground biodiversity. Genetic diversity, another dimension of species diversity, refers to genetic (intra-specific) variations among crop and tree populations; many landraces of crop plants and genetically diverse tree populations occur in AFS.

Udawatta *et al.* (2021) concluded that integration of agroforestry (AF) improves floral, faunal, and soil microbial diversity compared to monocropping, adjacent crop lands, crop alleys, and some forests. Birds, insects, reptiles, amphibians, and other animal counts have shown an increase in AF. Soil organisms including fungi (and mycorrhizae), bacteria, enzyme activity, and insects are generally significantly greater in AF than crop and livestock practices. The greater biodiversity (BD) in nearly all cases has been attributed to features of AF such as heterogeneous vegetation, favorable microclimate, diverse food sources, organic carbon, improved soil conditions (physical, chemical, and biological), protection, and spatial distribution of perennial vegetation. This synthesis demonstrated that AF can conserve and improve BD.

Udawatta *et al.* (2019) conducted a review and revealed that floral, faunal, and soil microbial diversity were significantly greater in AF as compared to monocropping, adjacent crop lands, and within crop alleys and some forests. Among the soil organisms, *Arbuscular mycorrhizae* fungi (AMF), bacteria, and enzyme activities were significantly greater in AF than crop and livestock practices. Agroforestry also creates spatially concentrated high-density BD near trees due to favorable soil-plant-water-microclimate conditions. The greater BD was attributed to heterogeneous vegetation, organic carbon, microclimate, soil conditions, and spatial distribution of trees. Differences in BD between AF and other management types diminished with time. Evenly distributed leaves, litter, roots, dead/live biological material, and microclimate improve soil and microclimate in adjacent crop and pasture areas as the system matures. Results of the study prove that integration of AF can improve BD in agricultural lands. Selection of site suitable tree/shrub/grass-crop combinations can be used to help address soil nutrient deficiencies or environmental conditions.

Atangana *et al.* (2014) determined three assumptions support expected agroforestry effects on biodiversity conservation. First, it is assumed that the adoption of agroforestry practices by farmers induces a reduction of the pressure of deforestation on additional land. Second, agroforestry systems provide new habitats and resources for local plant and animal species that are in part dependent on the forest for survival, and could not survive in a purely agricultural landscape. Third, the value of the conservation of remnants of natural vegetation is greater if the remains are embedded in a landscape dominated by agroforestry elements. This only holds true if the surrounding matrix consists of crop fields or pastureland largely enriched with tree cover.

## **2.10 Challenges to Agroforestry Adoption in Bangladesh**

The adoption of agroforestry in Bangladesh faces multiple challenges, including insecure land tenure, which discourages long-term investments, and limited awareness and technical knowledge among farmers about its benefits and practices. Socioeconomic constraints, such as high initial costs and delayed returns, further impede adoption, compounded by weak market linkages and inadequate infrastructure for agroforestry products. Policy gaps and lack of institutional support, coupled with a preference for monoculture systems in agricultural programs, hinder promotion efforts. Cultural resistance to change and traditional farming preferences also play a role, while environmental stressors like salinity, drought, and flooding reduce the viability of agroforestry systems in vulnerable regions. Addressing these barriers

requires an integrated approach involving policy reforms, education, and market development to enhance the feasibility and attractiveness of agroforestry.

Rana & Moniruzzaman (2021) tried to explore the causes, contributions and challenges of practicing agroforestation as a process of transformative adaptation in the Barind Tract of Bangladesh. The article has found that the farmers have accepted transformation in agricultural pattern by incorporating various fruit-dominated farming systems instead of rice-dominated monoculture. The results also suggest that unreliable rainfall and temperature variations, shortage of laborer for rice farming, economic benefits, and availability of agricultural inputs are the major causes of adaptation of agroforestation. In addition, agroforestation has brought several challenges which includes lacking in proper training of farmers for farm management, financial support for big investment and risk of joblessness to the marginal community. However, an integrated agricultural and rural development policy considering collaboration between farmers and relevant stakeholders is imperative for sustainable agroforestation.

A study was carried out by Islam et al. (2023) to to find out farmers' perceptions and problems towards the adoption of agroforestry practices in the coastal area of Bangladesh. Most of the respondents were middle-aged (45%) with a low literacy rate and large family size (55%). The majority of them (50%) had small-sized land, and they had limited access to agricultural training. A greater part of the respondents (61%) had a very low level of knowledge of agroforestry practice. Silvopasture and homestead agroforestry system was practiced by most of the farmers (77%) without proper concept. Only 11% of the respondents know and practice multistrata agroforestry, which is one of the best agroforestry practice. The perception of the respondents towards the adoption of agroforestry was found low in most of the cases. They expressed a low level of acuity towards agroforestry, and they were not so interested towards the adoption of these practices. "Agroforestry adoption may be hampered by a lack of institutions and policies to support it" and "Lack of knowledge and awareness on agroforestry practice" was identified most significant problems.

## CHAPTER 3

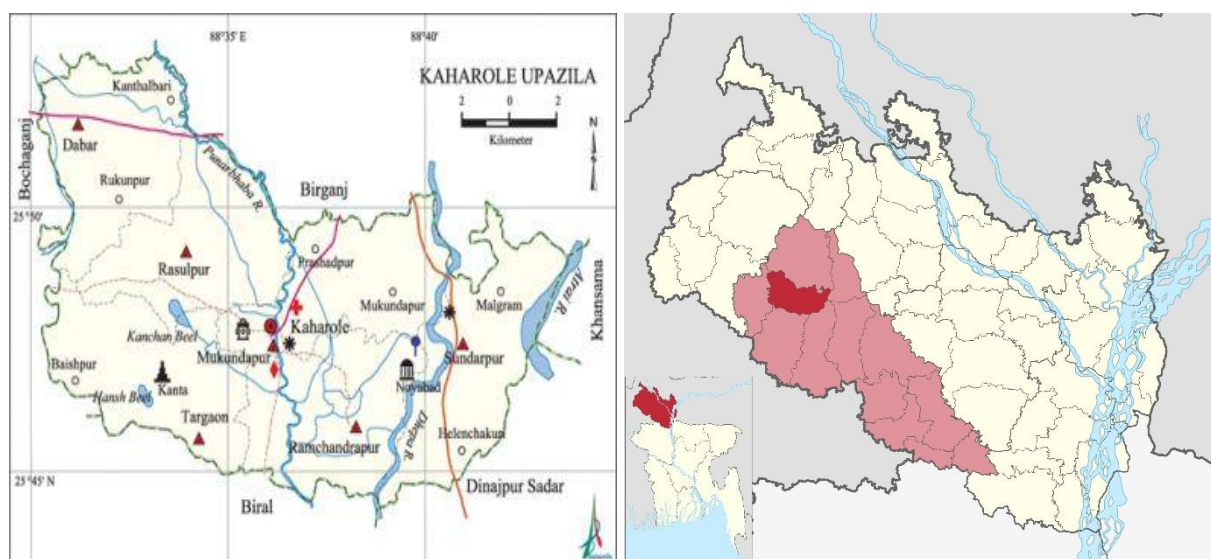
### MATERIALS AND METHODS

This study employs a multi-faceted approach to investigate the role of agroforestry in climate change adaptation and mitigation, focusing on Kaharole Upazila, Dinajpur. The methodology encompasses questionnaire design, stratified sampling, field surveys, data collection and analysis, and policy analysis to ensure a comprehensive understanding of cropland agroforestry practices and their potential benefits.

#### 3.1 Brief Description of the Study Area

##### 3.1.1 Overview of the Study Area

The study was conducted on the 5 villages of 5 No. Sundorpur Union located in Kaharole Upazila of Dinajpur district from January to April 2025 (Fig 3.1). Kaharole upazila lies between 25°44' and 25°53' north latitudes and in between 88°30' and 89°43' east longitudes (M. S. Rahman et al., 2020) the area is 205.5 km<sup>2</sup>. The region experiences challenges related to climate change, including erratic rainfall, drought, and soil degradation, making it a relevant location for assessing the role of agroforestry in climate change adaptation and mitigation (Rahman et al., 2022). Agriculture is the primary economic activity in the selected villages, with most households engaged in farming, agroforestry, and livestock rearing. Smallholder farmers dominate the region, and many practice integrated farming, combining crops with tree cultivation for additional income (Amin et al., 2005).



**Fig. 3.1 Map of Kaharole Upazila of Dianjpur District, Bangladesh (source: Banglapedia)**

### **3.1.2 Land types**

The land in the study areas primarily consists of highland, medium highland making it suitable for different types of agroforestry systems. The soil types vary but generally include loamy and sandy loam soils, which are moderately fertile. The region is well-known for agricultural production, with major crops including rice, maize, jute, wheat, potato and sugarcane along with various fruit and timber trees in homestead, cropland and orchard agroforestry systems (Pakhom et al., 2020).

### **3.1.3 Climatic scenario of the study area**

Hot, wet and humid tropical climate persists in Dinajpur characterized by distinct wet and dry seasons. The annual average temperature ranges from 10°C in winter (December–February) to 35°C in summer (March–May), with occasional heatwaves. The region receives an average annual rainfall of 1,500–2,500 mm, with over 80% of precipitation occurring between June and October due to the southwest monsoon (FAHMIDA, 2017). Climate variability in recent years has led to erratic rainfall, prolonged dry spells, and increasing temperatures, posing significant challenges to agriculture. Droughts and occasional floods impact soil moisture availability and crop productivity, making climate-resilient practices like agroforestry crucial for sustainable farming in the region (Syeda & Nasser, 2012).

## **3.2 Sampling strategy and data collection techniques**

### **3.2.1 Sampling design**

The study employed a stratified random sampling method to select agroforestry farmers from 5 no. Sundarpur Union of Kaharole Upazila to ensure diversity in farm size, agroforestry practices, and socio-economic conditions. A total of 63 farmers who practices cropland agroforestry system randomly selected from the villages of 5 No. Sundarpur Union. The selection was considered different agroforestry fields such as Eucalyptus-maize, Mahogany-maize, Mango- vegetables, Litchi-vegetables etc. Data were collected through semi structured interviews using a pre-tested questionnaire (Appendix XII), field observations to gain insights into agroforestry adoption, climate resilience, and livelihood impacts. This sampling strategy provided a significant understanding of agroforestry's role in climate change adaptation and mitigation in the study area.

### **3.2.2 Preparation of interview schedule**

In order to collect relevant information from the respondents a set of preliminary semi structured survey schedules was used (Appendix XII). The survey schedule was carefully designed keeping the objectives of the study in view. The schedule contained both open and closed form questions. Very easy simple, direct questions and different scales were used to obtain information. The interview was conducted with the farmers of agroforestry field. In this study, the independent variables were age, family size, level of education, farm size, farming experience, agroforestry farming experience, planting system, intension to planting trees in field, changes in productivity since adopting AGF, climate change perception, benefits from agroforestry practice regarding climate change, barriers or challenges to adopt AGF and support received by the respondents for practicing cropland agroforestry. The procedures of measurement of these variables are mentioned below

### **3.2.3 Field Surveys**

Field surveys were conducted in the study area to gather primary data on cropland agroforestry practices, farmers' experiences with climate change, and factors influencing the adoption of agroforestry systems. A semi structured questionnaire and direct field observations were used to collect comprehensive information from cropland agroforestry farmers.

The surveys provided insights into the current status of agroforestry practices, including the types of agroforestry systems in use, the tree species integrated with crops, and variations in management practices among farmers. Respondents shared their experiences with climate change impacts, particularly the effects of drought, temperature fluctuations, and unpredictable rainfall patterns on their agricultural productivity. Many farmers reported significant challenges, such as reduced soil fertility, decreased crop yields, and increased pest infestations, which affected their overall farm sustainability.

Additionally, the surveys identified barriers to agroforestry adoption, with financial constraints, limited technical knowledge, and inadequate institutional support emerging as the most common challenges. Farmers highlighted difficulties in accessing quality tree seedlings, lack of training programs, and insufficient government incentives as major obstacles to expanding agroforestry practices. The field surveys helped in understanding the complex interactions between cropland agroforestry, climate change, and farmer decision-making. The collected data served as a foundation for further analysis and policy recommendations to

enhance the role of agroforestry in climate change adaptation and mitigation in northern Bangladesh.

### **3.2.4 Measurement of independent variables**

#### **i. Age**

The age of respondents was measured by counting the period of time from his birth to the time of interview on the basis of response of the respondent and was expressed in terms of years.

#### **ii. Family size**

Family size of a respondent was determined in terms of the total of members of each respondent. The family member included respondent himself, spouse, sons, daughters and other dependents.

#### **iii. Education**

Education of respondents was measured in terms of classes passed by him. For example, if a respondent passed the final examination of class five in the school, a score of 5 was given for calculating his education score. If a respondent has education outside the school and if the level of education was seemed to equivalent to that of class 5 school, then his score was given as 5. A respondent who did not know reading or writing had education score of zero (0). However, a person who can sign his name only, a score of 0.5 was given.

#### **iv. Farming experience**

The farming experience of the respondents in the study area was counted based on year and categorized into three categories. These are two decades (<20 years), four decades (20-40 years) and above four decades (>40 years).

#### **v. AGF farming experience**

The agroforestry farming experience of the respondents in the study area was also counted based on year and categorized into two decades (<20 years), four decades (20-40 years) and above four decades (>40 years).

#### **vi. Farm size**

Land is the most important capital to a farmer and farm size influences on personal characteristics of a farmer. Farm size was expressed as hectare and was computed by using the following formula.

Farm size = Homestead area + own land under cultivation + land taken other as lease + land taken other as borga + land given other as borga + land under AGF

#### **vii. Cropland agroforestry size**

To assess the extent of agroforestry adoption at the farm level, data on cropland agroforestry size were collected as an independent variable. This involved recording two distinct land areas for each respondent: the total cropland size and the portion of that land under agroforestry practices. Respondents were asked to provide the measurements in local units (e.g., decimals or acres), which were later converted into a uniform unit (hectare) for analysis.

#### **viii. Planting systems of cropland agroforestry practices in the study area**

In the study area, different methods are practiced for woody perennials or tree plantings on cropland, and among these three major methods are identified in most cases, such as scattered plantation, strip plantation, and boundary plantation (Appendix XIII).

Scattered plantation: Woody perennials are grown on the crop field randomly, maintaining different spacing at various designs. The farmers sometimes do not follow any spacing or design rules. Consequently, trees are grown in the cropland in an arbitrary manner.

Strip plantation: Woody perennials are planted on the crop field in strips, and crops are grown there as inter cropping in between the strips.

Boundary plantation: Woody perennials are planted on the edge or on the boundaries of the cropland.

#### **ix. Intension of planting trees in crop field**

To identify the underlying motives for integrating trees into cropland, a structured question was included in the questionnaire, asking respondents: “Why do you intend to plant trees in your crop field?” The options provided were: income generation, fruit consumption, fuelwood, and commercial sale of wood. Respondents were allowed to select one or multiple

options based on their personal objectives. This method enabled a clear understanding of the socioeconomic and household-level needs driving agroforestry adoption. The responses were categorized and quantified in percentage terms to assess the relative importance of each intention. These findings were later analyzed in relation to other variables such as planting patterns, perceived benefits, and challenges, to explore how intention influences agroforestry practices.

#### **x. Changes in Productivity since adopting AGF**

To document the spatial arrangement of trees within cropland, respondents were asked a structured question: “How do you plant trees in your crop field?” The available options included scattered, strip, and boundary planting. Each respondent selected the option that best described their practice, allowing for the classification of planting systems. The responses were recorded in percentages to determine the prevalence of each method. This variable was critical in assessing how spatial design influences agroforestry performance, integration with crops, and farmer preferences. The data were later used in comparative analysis with other factors such as landholding size, purpose of planting, and perceived benefits to explore possible correlations.

#### **xi. Perceived effects of climate change and benefits of agroforestry in relation to climate change**

To assess farmers' perceptions of climate change and their adaptation strategies, interviews and surveys were conducted with agroforestry farmers in the selected study areas. The questionnaire included questions on farmers' experiences with climate variability, including drought, soil erosion, and temperature fluctuations. Farmers were asked to describe how they perceived changes in climate patterns over the years and whether they associated these changes with agricultural productivity. Their awareness of climate change was evaluated based on their ability to identify specific climatic events and their perceived impact on crop yields, soil fertility, and water availability.

The study also investigated the adaptive measures taken by farmers in response to climate-related challenges. Participants were asked about the specific agroforestry practices they had adopted, such as planting drought-resistant tree species, implementing soil conservation techniques, and modifying planting schedules. The extent of proactive adoption of

agroforestry as an adaptation strategy was analyzed by comparing the responses of farmers with different levels of climate awareness.

Access to climate information was another key factor examined in this study. Farmers were questioned about their sources of climate-related knowledge, including agricultural extension services, NGOs, government agencies, and local networks. The study aimed to determine whether farmers who had better access to climate information were more likely to implement agroforestry practices effectively. By analyzing the relationship between climate awareness, adaptation strategies, and agroforestry adoption, this research provided insights into the role of knowledge dissemination in enhancing climate resilience among farming communities.

### **xii. Barriers and Challenges faced by respondents in Agroforestry Adoption**

To identify the key barriers and challenges affecting agroforestry adoption, structured interviews and surveys were conducted with agroforestry farmers in the study area. Farmers were asked whether they faced financial difficulties in establishing or expanding agroforestry systems, including the costs of tree seedlings, labor, and necessary inputs. Land tenure security was another critical factor examined. Farmers were asked whether they owned or leased their land, as secure land ownership often encourages long-term investment in agroforestry. Market access for agroforestry products was also investigated to understand the economic feasibility of agroforestry practices. Farmers were asked about the availability of local or regional markets for timber, fruit, and other agroforestry products, as well as the challenges they faced in selling their produce. Knowledge gaps on agroforestry were also assessed to determine the role of awareness in adoption rates. Farmers were questioned about their understanding of agroforestry benefits, techniques, and long-term impacts.

### **xiii. Policy Support Received by Agroforestry Farmers**

To assess the extent of institutional and policy support experienced by agroforestry practitioners, a structured question was administered to all respondents. They were asked to indicate the frequency of receiving various forms of support related to agroforestry under five key categories: training on agroforestry, access to seedlings, technical advice on agroforestry management, financial support, and market access assistance. Responses were categorized into four levels: regular, frequent, occasional, and never. This ordinal data enabled quantification of the support structure in place and helped identify key service gaps faced by

the farmers. The collected data were analyzed in percentage terms and visually represented to highlight the prevalence and shortcomings of policy and institutional backing.

#### **xiv. Policy Change Suggestions by Respondents to Promote Agroforestry**

To capture grassroots-level insights for improving agroforestry adoption, respondents were asked an open-ended structured question regarding their suggestions for necessary policy interventions. Their responses were categorized into major thematic areas such as: financial support and subsidies, training and capacity building, availability of quality planting materials, market access for tree products, and strengthening extension services. Each suggestion was quantified by calculating the percentage of respondents who emphasized that specific policy need. This approach enabled a clear understanding of farmer priorities and informed the development of practical policy recommendations aimed at promoting agroforestry under climate-vulnerable conditions.

### **3.3 Measuring biodiversity index and estimation of Carbon sequestration**

Data collected from 63 quadrates (20 m x 20m) of 63 agroforestry fields. One sample plot taken from one agroforestry field. Number of species and number of individuals of one species were taken from each plot. Height (m) and girth at breast height (GBH, cm) of all woody perennials in a quadrates were measured. Measuring tape was used to measure GBH and Haga Altimeter was used to take plant height (m).

#### **3.3.1 Diameter at Breast Height (DBH)**

The diameter at breast height (DBH) of each tree was calculated using the girth at breast height (GBH) measurement. GBH was measured at 1.3 meters above ground level using a measuring tape. The DBH was then obtained by applying the formula:

$$DBH = \frac{GBH}{\pi}; \text{ (Islam et al., 2016)}$$

Here, GBH = Girth at breast height,  $\pi$  = Constant (3.1416)

This conversion allowed for accurate estimation of tree diameter, which is essential for calculating basal area and carbon sequestration in agroforestry systems.

### 3.3.2 Stand Density (D)

Stand Density (D) means how many trees (or individuals) there were, on average, per quadrat.

It tells you how crowded or populated the area was with trees.

Stand density =  $\frac{a}{b}$ , (Shukla & Chandel, 1994)

Where:

- a = Total number of individual trees (or plants) counted in all quadrates.
- b = Total number of quadrates studied.

### 3.3.3 Basal area (m<sup>2</sup>/ha)

Basal area was measured which represent the total cross-sectional area of tree stems (at chest height) in a given land area. It tells us how much ground area is occupied by tree trunks — very useful for understanding tree density or biomass. It was calculated by the following formula (Chowdhury et al., 2019),

$$\text{Basal Area (m}^2\text{/ha)} = \frac{\sum \pi \frac{D^2}{4}}{\text{area of all quadrates}} \times 10000$$

Where:

- D = Diameter of the tree (at breast height, 1.3 meters from the ground).
- $\pi = 3.1416$  (a constant from circle area formula).
- The area of all quadrates was the total sample plot area.

### 3.3.4 Relative Density (RD%)

To evaluate the floristic composition and dominance of woody perennials in cropland agroforestry systems, the Relative Density (RD%) of each species was calculated. Relative density expresses the proportion of individuals of a particular species relative to the total number of individuals recorded in all quadrates. This index was calculated using the formula:

$$\text{Relative density (RD\%)} = \frac{\text{Density of a single species}}{\text{Density of all species}} \times 100 ; \text{ (Dallmeier, 1992)}$$

Here, density refers to the number of individuals of a species per unit area (usually per hectare). The values were derived from species count data collected from 63 quadrates (each 20 m × 20 m in size). The resulting RD% provides insight into species dominance and their relative abundance within the agroforestry landscape, thereby helping to characterize biodiversity patterns in the study area.

### **3.3.5 Frequency (F%)**

To assess the distribution pattern of woody perennial species across cropland agroforestry systems, Frequency (F%) was calculated. Frequency refers to the occurrence of a species within the sample plots and indicates how uniformly a species is distributed throughout the study area. The formula used for this calculation was:

$$\text{Frequency (F\%)} = \frac{c}{b} \times 100 ; (\text{Shukla \& Chandel, 1994})$$

Where:

- $c$  = Number of quadrates in which a given species was recorded
- $b$  = Total number of quadrates sampled (in this study, 63 quadrates)

The frequency percentage highlights how widespread each species is across the study area. A higher frequency indicates that a species is more evenly distributed, whereas a lower value suggests a more localized or patchy presence. This metric helped to interpret the ecological adaptability and spatial spread of agroforestry tree species within the croplands of the selected study sites.

### **3.3.6 Relative Frequency (RF%)**

To further understand the prominence of each woody perennial species in terms of distribution, Relative Frequency (RF%) was calculated. While frequency shows how often a species appears across all quadrates, relative frequency provides a proportional comparison of each species' frequency in relation to the total frequency of all recorded species. The formula used was:

$$\text{Relative Frequency (RF\%)} = \frac{F_i}{\sum_{i=1}^{\infty} F_i} \times 100; (\text{Dallmeier, 1992})$$

Where:

- $F_i$  = Frequency of an individual species
- $\sum F_i$  = Sum of the frequencies of all species recorded across the quadrates

This measure enabled the identification of dominant and less common species in terms of their presence across the study area. A species with a higher RF% was interpreted as more spatially prevalent in comparison to others, contributing to a better understanding of species composition and ecological dominance in cropland agroforestry systems.

### 3.3.7 Relative Dominance (RD<sub>0</sub> %)

To assess the proportional contribution of each woody perennial species to the total basal area within the cropland agroforestry system, Relative Dominance (RD<sub>0</sub> %) was calculated. This index provides an estimate of the spatial occupation and ecological importance of individual species based on their basal area measurements. The formula used was:

$$\text{Relative Dominance (RD}_0 \text{ \%)} = \frac{\text{Total basal area of a species in all quadrates}}{\text{Total basal area of all species in all quadrates}} \times 100 \quad ;$$

(Chowdhury et al., 2019)

Basal area (in m<sup>2</sup>) was computed for each individual tree based on DBH (Diameter at Breast Height), and then summed species-wise across all 63 quadrates. By comparing each species' basal area to the total, RD<sub>0</sub> % provided insights into which species occupy more physical space and potentially play a more significant role in resource utilization and ecosystem functioning. This metric was particularly useful in evaluating structural dominance within the agroforestry system.

### 3.3.8 Importance Value Index (IVI)

To determine the overall ecological significance of each woody perennial species within the cropland agroforestry system, the Importance Value Index (IVI) was calculated. IVI combines three key quantitative vegetation attributes—Relative Density (RD %), Relative Frequency (RF %), and Relative Dominance (RD<sub>0</sub> %)—into a single index to reflect a species' abundance, distribution, and spatial occupation. The formula used was:

$$\text{IVI} = \text{RD (\%)} + \text{RF (\%)} + \text{RD}_0 \text{ (\%)} ; \text{ (Rahman et al., 2019)}$$

Here,

Relative Density (RD %): Proportion of individuals of a species relative to the total number of individuals.

Relative Frequency (RF %): Proportion of quadrates in which a species occurred compared to the total for all species.

Relative Dominance (RD<sub>0</sub> %): Proportion of the basal area occupied by a species compared to the total basal area of all species.

The IVI values provided a comprehensive understanding of species' structural and ecological roles in the agroforestry system. Species with higher IVI were considered more dominant and influential in the system's composition and function.

### 3.3.9 Diversity Indices

To evaluate the biodiversity of woody perennials in cropland agroforestry systems, two standard ecological indices were applied: the Shannon–Wiener Diversity Index (H') and Margalef's Species Richness Index (R).

The Shannon–Wiener Index (H') was calculated using the formula:

$$H' = \sum_{i=1}^s p_i \ln p_i ; (\text{Shannon, 1963})$$

Where,  $p_i$  is the proportion of individuals belonging to the  $i$ -th species, and  $s$  is the total number of species. This index accounts for both species abundance and evenness, providing a robust measure of diversity in the studied quadrates.

The Margalef's Index (R), which measures species richness relative to the number of individuals, was computed using:

$$R = \frac{S-1}{\ln(N)} ; (\text{Margalef, 1973})$$

where  $S$  is the total number of species (excluding single-individual species) and  $N$  is the total number of individuals recorded. This index is particularly effective for comparing richness across ecosystems with varying population sizes.

### 3.3.10 Above-Ground Biomass (AGB)

The above-ground biomass (AGB) of trees was estimated using an allometric equation, following the formula:

$$AGB=0.0595 \times \rho D^2 H ; (\text{Chave et al., 2005})$$

Where, D is the diameter at breast height (DBH) in centimeters, H is the total tree height in centimeters, and  $\rho$  is the wood specific gravity ( $\text{g cm}^{-3}$ ) which values were taken from Global wood density database (Zanne et al., 2009).

$$AGB = 6.666 + 12.826 \times ht^{0.5} \times \ln(ht) ; (\text{Habib \& Huda, 2022})$$

Here, AGB = Above ground biomass, ln = Natural logarithm, ht = Height (m), 6.666 = Constant, 12.826 = Constant

These formula provided a standardized method to estimate tree biomass, essential for calculating carbon storage potential in agroforestry systems.

### 3.3.11 Below-Ground Biomass (BGB)

The below-ground biomass (BGB) was estimated by multiplying the above-ground biomass (AGB) by a conversion factor of 0.26, using the formula:

$$BGB=AGB \times 0.26 ; (\text{Hangarge et al., 2012})$$

Where, BGB represents the root biomass and AGB represents the above-ground biomass. This method provided a practical approach to estimate root biomass based on the measured above-ground biomass, which is important for total carbon sequestration assessment in agroforestry systems.

### 3.3.12 Total Biomass and Tree Carbon Stock

The total biomass (TB) was calculated by summing the above-ground biomass (AGB) and below-ground biomass (BGB) using the formula:

$$TB (\text{Mg/ha}) = AGB + BGB ; (\text{Roshni et al., 2023})$$

The tree carbon stock was then estimated by multiplying the total biomass by a carbon fraction factor of 0.5, following the formula:

Tree Carbon Stock (Mg/ha) = Biomass  $\times$  0.5 ; (Sahu et al., 2020)

This approach provided a standard method to quantify the amount of carbon stored in the tree biomass within agroforestry systems.

### **3.4 Statistical analysis**

Both qualitative and quantitative data were analyzed to fulfill the objectives of the study. Descriptive statistics such as frequency, percentage, mean, and standard deviation were used to summarize socio-demographic variables, perceptions of climate change, and agroforestry practices of the respondents. To evaluate biodiversity, species richness and diversity indices were computed using standard ecological formulas. The Shannon–Wiener Diversity Index and Margalef’s Richness Index were applied to assess species diversity and richness within the sampled cropland agroforestry systems. Importance Value Index (IVI) was calculated based on relative density, relative frequency, and relative dominance to determine the ecological dominance of each species. Tree biometric measurements (Diameter at Breast Height and Height) collected from sample plot were used to estimate Above Ground Biomass (AGB) using species-specific or generalized allometric equations. Below Ground Biomass (BGB) was estimated by applying a root-to-shoot ratio, and total biomass was derived by summing AGB and BGB. Total carbon stock was calculated by multiplying the total biomass with a carbon fraction coefficient. The results were tabulated and interpreted accordingly. All data analyses were performed using STAR (Statistical tool for Agricultural Research), Microsoft Excel 2016 and SPSS 25, ensuring consistency in calculations and clear presentation of findings. Graphs, tables, and summary statistics were used to illustrate relationships and patterns relevant to climate change response, carbon stock, and biodiversity parameters.

## **CHAPTER 4**

### **RESULTS AND DISCUSSION**

#### **4.1 Demographic characteristics of the respondents**

##### **4.1.1 Age**

The age of the respondents in the study area ranged from 18 to 65 years, with a mean age of 38.67 years (Table 4.1). The age of the respondents was further categorized into three categories. Most (50.8%) of the respondents were from the young age group. While 36.5% middle age groups and 12.7% of the respondents were from the old age group (Table 4.1).

##### **4.1.2 Family size**

The respondents' family sizes ranged from 3 to 15, with a mean of 6.22 (Table 4.1). The respondents' family sizes were also categorized into three categories; of the respondents, 27% belonged to a small family, followed by 33.3% from a medium-sized family and 39.7% belonged to a large-sized family (Table 4.1).

##### **4.1.3 Education**

The respondents' education level in the study area ranged from sign only to master level; the average respondents passed seven class levels (Table 4.1). The education level was categorized into five categories. Among these, 6.3% illiterate respondents were found in the study area, 47.6 % of the respondents were from secondary level (6-10), 20.6% of the respondents were from primary level (1-5), 7.9% were from can sign only (0.5) and 17.5% were from above secondary level (>10) (Table 4.1).

##### **4.1.4 Farm size**

The farm size of the study area ranged from 0.08 to 2.66 ha with a mean value of 0.54 ha (Table 4.1). The farm size was categorized into five categories. Among these, 12.7% landless (<0.2) respondents were found in the study area, 7.9% of the respondents were from medium (1.01-2.5ha) sized farm, 60.3% and 1.6% of the respondents were from the marginal (0.201-0.6ha) and large (>2.5 ha), 17.5% of the respondents were from small (0.601-1.0) sized farm (Table 4.1).

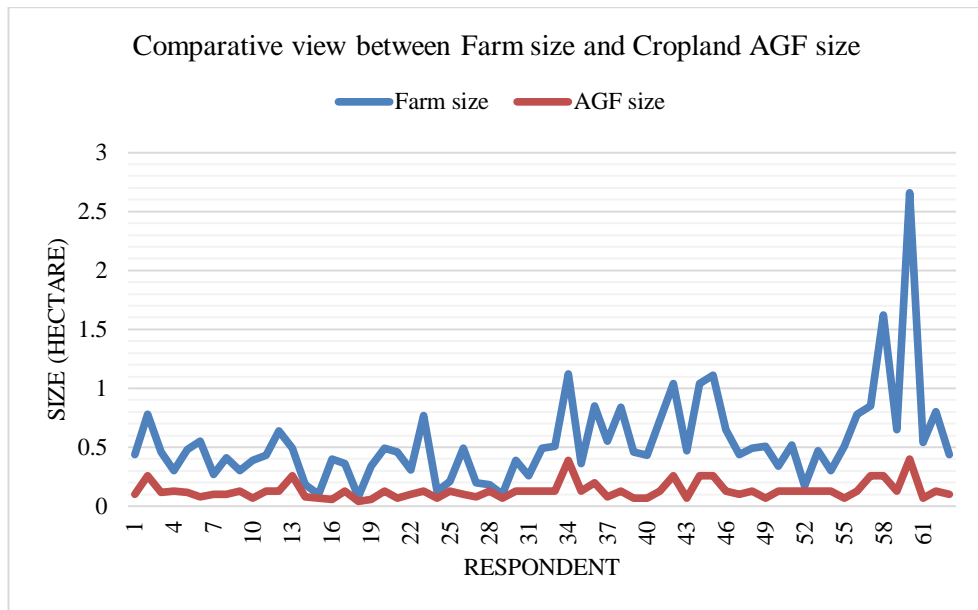
**Table 4.1 Descriptive statistics showing the demographic characters of respondents**

Characteristics	Scoring method	Ranged observed	Categories	Respondents		Mean	SD
				No.	Percent		
Age	No. of year	18-65	Young (18-35)	32	50.8	38.67	9.88
			Middle (36-50)	23	36.5		
			Old (>50)	8	12.7		
Family	Number	3-15	Small (<4)	17	27	6.22	2.50
			Medium (4-6)	21	33.3		
			Large (>6)	25	39.7		
Education	Year of Schooling	0-17	Illiterate (0.0)	4	6.3	7.71	4.14
			Can sign only (0.5)	5	7.9		
			Primary level (1-5)	13	20.6		
			Secondary level (6-10)	30	47.6		
			Above secondary level (>10)	11	17.5		
Farm size	Hectares	0.08-2.66	Landless (<0.2)	8	12.7	0.54	0.39
			Marginal (0.201-0.6)	38	60.3		
			Small (0.601-1.0)	11	17.5		
			Medium (1.01-2.5)	5	7.9		
			Large (>2.5)	1	1.6		
Cropland Agroforestry size	Hectares	0.04-0.40				0.13	0.07

#### 4.1.5 Cropland Agroforestry Field Size

The Cropland Agroforestry size of the study area ranged from 0.04 to 0.40 ha with a mean value of 0.13 ha (Table 4.1). The comparative analysis between total farm size and cropland agroforestry (AGF) size, as presented in Figure 4.1, reveals that while farm sizes vary considerably among respondents, AGF land size remains consistently low across all respondents. The farm size fluctuated between below 0.08 to over 2.66 hectares, whereas AGF cropland size remained below 0.5 hectares for all respondents. This indicates that although farmers possess varying amounts of total farmland, only a small proportion is allocated to agroforestry practices. The results suggest limited integration of trees into

croplands, which may be attributed to factors such as limited awareness, lack of institutional support, or perceived competition between trees and crops.

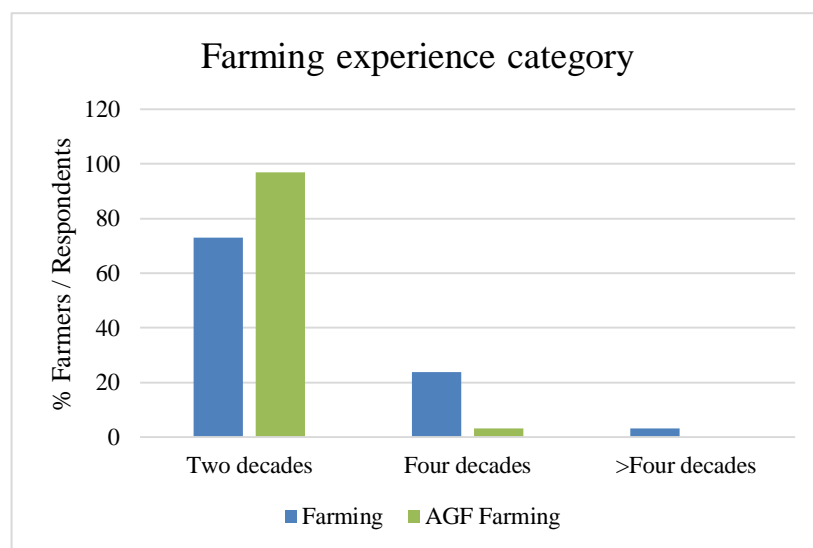


**Fig. 4.1 Farm size and Cropland AGF size of the respondents in the study area**

#### 4.2 Farming experience of the respondents in the study area

##### 4.2.1 Farming experience

The farming experience of the respondents in the study area ranged from 4-45 years, with a mean value of 18.33 years (Appendix I). It was also categorized into three categories. 73% of the respondents had farming experiences of two decades; 23.8% and 3.2% of the respondents had four decades and more than four decades of farming experience (Fig. 4.1).



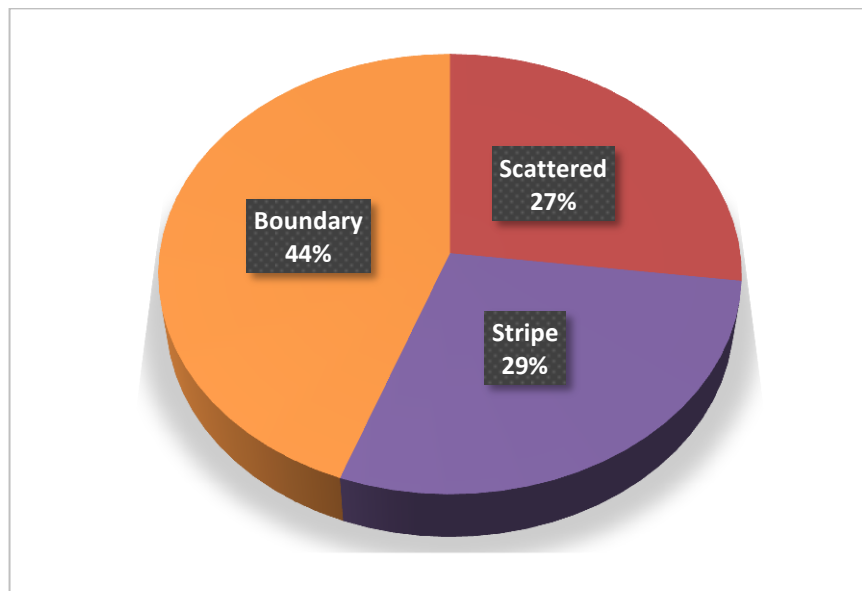
**Fig. 4.2 Farming experience of the respondents in the study area**

#### 4.2.2 Agroforestry (AGF) farming experience

The AGF farming experience of the respondents in the study area ranged from 3 to 40 years, with a mean of 9.43 years (Appendix I). It was categorized into three categories. All the respondents of the study area low agroforestry farming experience i.e. of two decades (Fig. 4.2).

#### 4.3 Planting System in Agroforestry field

The study identified three main agroforestry planting systems practiced by farmers in the study area: boundary, scattered, and strip planting. As shown in Figure 4.3 (Pie Chart), boundary planting was the most commonly adopted system, accounting for 44% of the total respondents. This method is often preferred due to its minimal interference with crop cultivation and efficient use of farm borders. Scattered planting, observed in 27% of the cases, involves randomly placing trees within the crop field and is usually practiced for shade, fruit, or fuelwood purposes. Strip planting, covering 29%, typically includes planting trees in rows within or along the edges of crop fields. The dominance of boundary planting suggests that farmers tend to favor systems that do not significantly reduce their cultivable land.

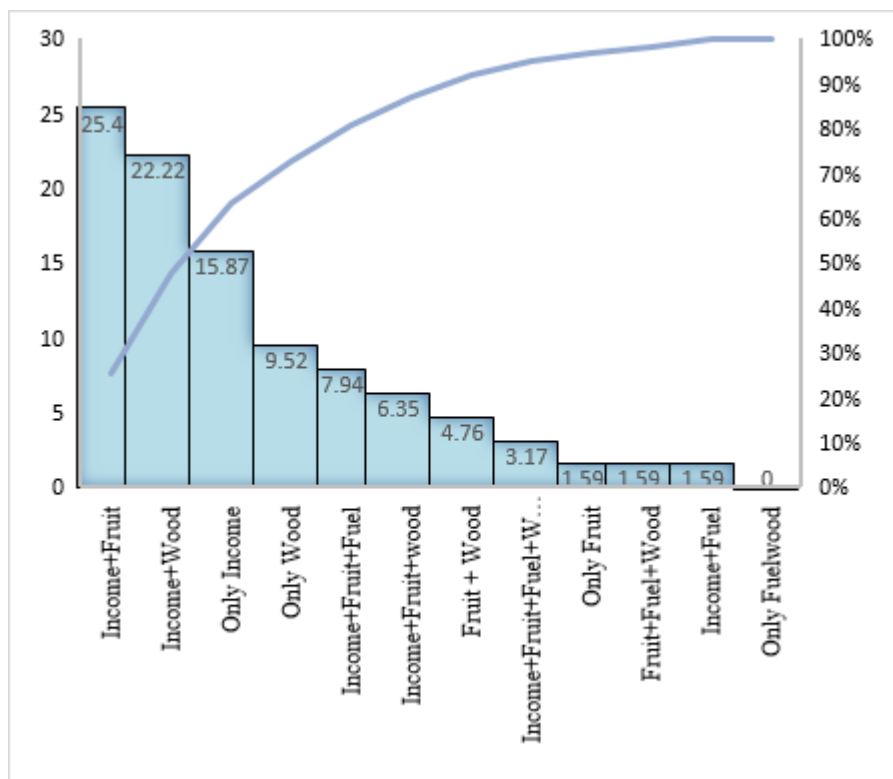


**Fig. 4.3 Planting System of trees in AGF field**

#### 4.4 Intention of planting trees in cropland

The study revealed a range of motivations behind farmers' decisions to plant trees within croplands (Appendix III). The most commonly reported intention was Income + Fruit, cited by 25.4% of respondents, indicating that farmers prioritize both economic return and nutritional benefits. This was followed closely by Income + Wood (22.22%) and Only Income (15.87%), suggesting a strong economic motive behind agroforestry adoption. A smaller percentage of farmers planted trees solely for wood (9.52%) or combined multiple benefits such as Income + Fruit + Fuel (7.94%) and Income + Fruit + Wood (6.35%). Notably, no farmers planted trees solely for fuelwood, indicating it is not a primary concern (Fig. 4.4).

The diversity in planting intentions reflects the multifunctionality of agroforestry systems in the region, where trees are valued not only for immediate income but also for subsistence needs such as fruits and fuel. This aligns with the findings of Rahman et al. (2015), who emphasized that farmers in northern Bangladesh prefer agroforestry practices that provide multiple benefits. Furthermore, the integration of income with other objectives (e.g., wood, fruit, fuel) demonstrates the adaptive strategies of rural households aiming to build resilience under changing climatic and economic conditions.

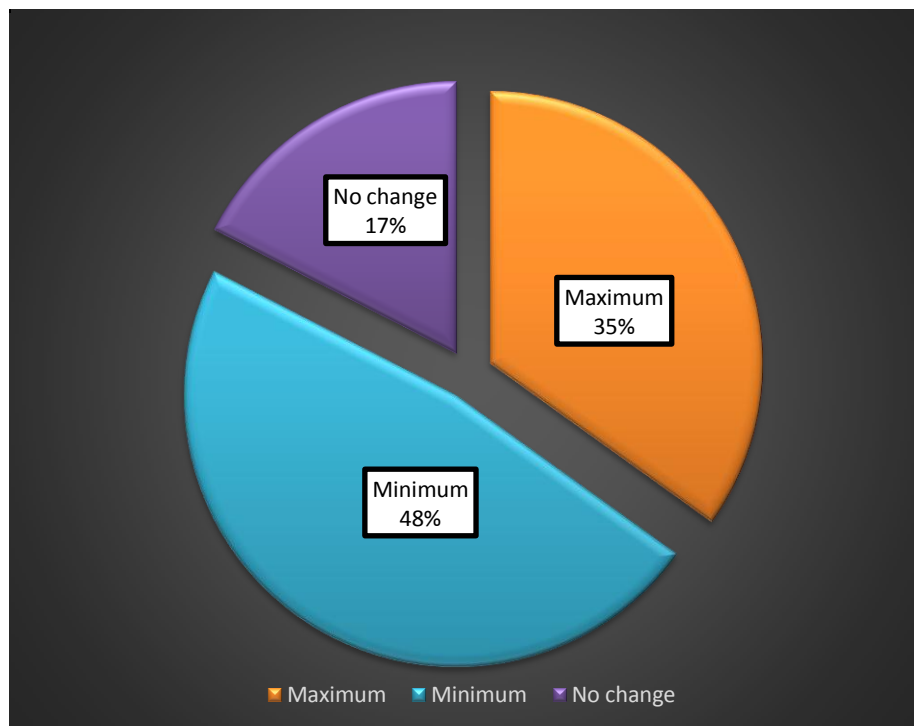


**Fig. 4.4 Distribution of Farmers' Intentions for Planting Trees in Cropland Agroforestry Systems**

#### 4.5 Change in Productivity Since Adopting Agroforestry

The analysis revealed a diverse pattern of productivity change among farmers following the adoption of agroforestry practices (Fig 4.5). A significant proportion of respondents (34.92%) reported a maximum increase in productivity, highlighting the potential of agroforestry. Conversely, 47.62% of the farmers observed a minimum change in productivity, which may be attributed to initial competition between trees and crops for light, water, and nutrients, or poor species-site matching. Meanwhile, 17.46% reported no change in productivity, suggesting that the impacts of agroforestry can be context-specific and influenced by factors such as management practices, species selection, and local ecological conditions.

Similar findings were reported by Awazi & Tchamba (2019), who emphasized that the productivity benefits of agroforestry depend on proper integration and long-term maintenance. Furthermore, Castle et al. (2021) noted that agroforestry systems, when well-managed, can stabilize yields and improve long-term land productivity, particularly under changing climate conditions.



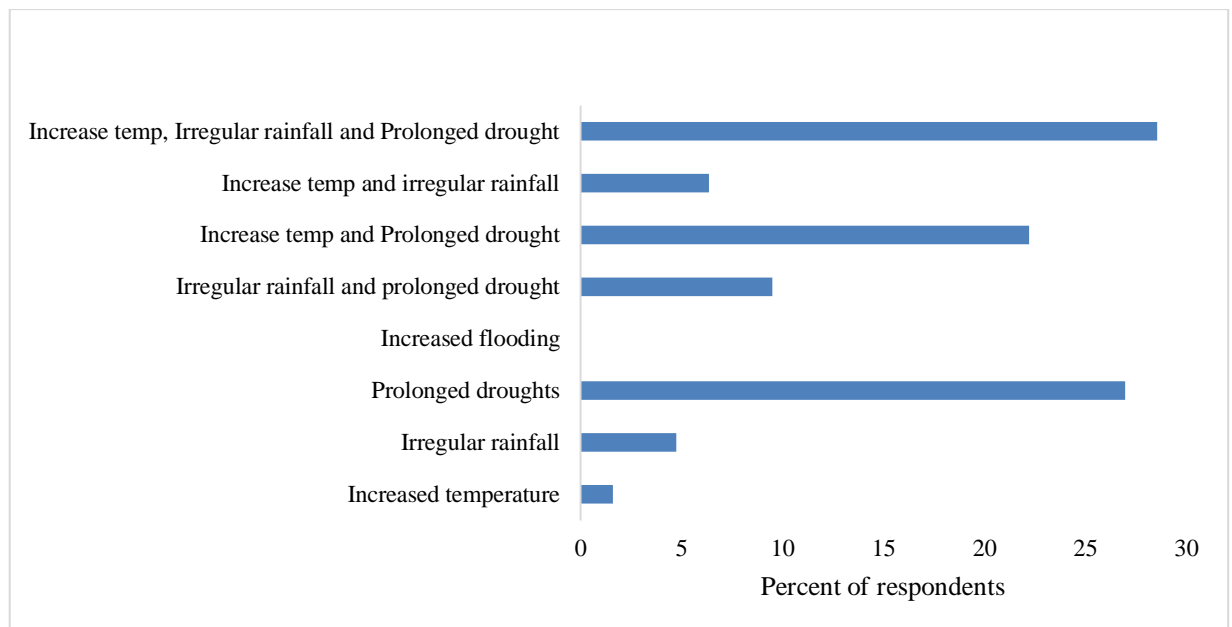
**Fig. 4.5 Changes in productivity since adopting AGF**

## 4.6 Perceived effects of climate change and benefits of agroforestry in relation to climate change

All of the respondents (100%) in the study reported experiencing noticeable changes in the climate over recent years. The most commonly perceived changes included increased temperature, irregular rainfall, prolonged droughts, and more frequent extreme weather events, which have significantly affected crop yields and farming schedules. In response to these challenges, many farmers recognized agroforestry as a beneficial strategy for climate adaptation.

### 4.6.1 Observed climatic changes

The majority of the respondents reported experiencing significant climatic changes in recent years. As illustrated in the figure 4.6, the most commonly cited combination of changes was increased temperature, irregular rainfall, and prolonged drought, reported by 29.37% of farmers. Prolonged droughts alone were also reported by a substantial proportion (27%), followed by increased temperature with prolonged drought (22.22%) and irregular rainfall with prolonged drought (9.52%). Isolated responses such as increased temperature, irregular rainfall, or increased flooding were less frequently observed (Appendix II).

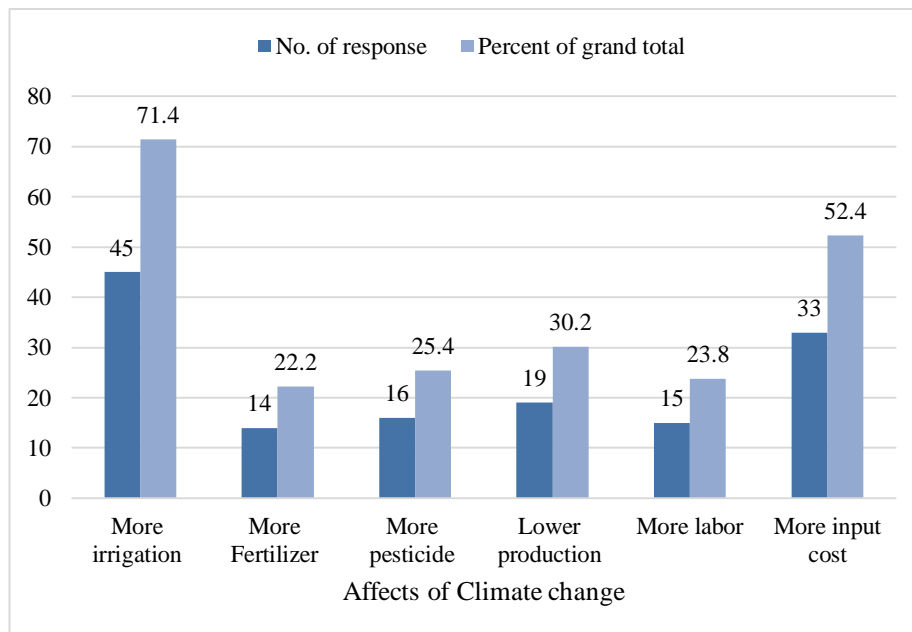


**Fig. 4.6 Perceived Climatic Changes Experienced by Respondents in the Study Area**

These findings suggest that farmers are keenly aware of the multi-dimensional nature of climate stress, particularly the extended dry spells and shifts in rainfall patterns, which have direct implications for crop productivity, soil moisture, and water availability. Similar observations were reported by Sikder & Xiaoying (2014) and Thomas et al. (2013), who highlighted prolonged drought and erratic rainfall as key constraints for agriculture in northern Bangladesh.

#### 4.6.2 Affects of climate change in farming practices

The study revealed several noticeable impacts of climate change on farming practices in the study area (Fig. 4.7) (Appendix IV). The majority of respondents (71.43%) reported a significant increase in irrigation requirements, indicating greater water stress likely due to erratic rainfall and prolonged dry spells. Over half of the farmers (52.38%) noted an overall rise in input costs, while 30.16% experienced reduced crop production. Additionally, 25.40% and 22.22% of respondents observed increased usage of pesticides and fertilizers respectively, suggesting changing pest and nutrient dynamics. Around 23.81% reported the need for more labor, likely due to the need for more intensive farm management under changing climatic conditions. These findings are consistent with observations made by Shakhawat et al. 2020, who highlighted that farmers in Northern Bangladesh are increasingly facing economic and agronomic pressures due to climate variability.



**Fig. 4.7 Perceived Affects of Climate Change on Farming Practices by Respondents**

### 4.6.3 Benefits of Cropland Agroforestry in relation to Climate change

The findings revealed that farmers perceived multiple climate-related benefits from agroforestry practices. Table 4.2 shows A majority of respondents (61.9%) reported a high benefit of agroforestry in providing protection from strong winds, highlighting its role as a natural windbreak. Carbon sequestration was also recognized, with 25.4% noting high benefit and 52.38% medium benefit, indicating strong awareness of agroforestry’s role in mitigating greenhouse gas emissions. Improved soil fertility was moderately acknowledged, with 34.92% identifying medium benefit and 42.86% low benefit. Enhanced water retention was seen as a medium benefit by 44.44% of respondents, showing that agroforestry plays a significant role in improving soil moisture conditions. However, increased resilience to drought received relatively lower high-benefit ratings (7.94%), suggesting farmers may still be uncertain about its effectiveness in extreme drought conditions. Additionally, increased biodiversity was moderately valued, with 26.98% citing high benefit and 31.75% medium benefit. These findings align with existing literature that agroforestry systems enhance ecosystem services and provide resilience to climate change (Jhariya et al., 2019; Quandt et al., 2023).

**Table 4.2 Perceived Benefits of Agroforestry in Relation to Climate Change by Respondents**

Sl. No	Main benefits	Extent of benefits			
		High (%)	Medium (%)	Low (%)	No (%)
1	Improved soil fertility	6.35	34.92	42.86	15.87
2	Enhanced water retention	4.76	44.44	31.75	19.05
3	Increased resilience to drought	7.94	28.57	42.86	20.63
4	Carbon sequestration	25.40	52.38	22.22	0.00
5	Protection from strong winds	61.90	22.22	12.70	3.17
6	Increased biodiversity	26.98	31.75	33.33	7.94

#### 4.7 Barriers and Challenges faced by respondents to Adopt Agroforestry

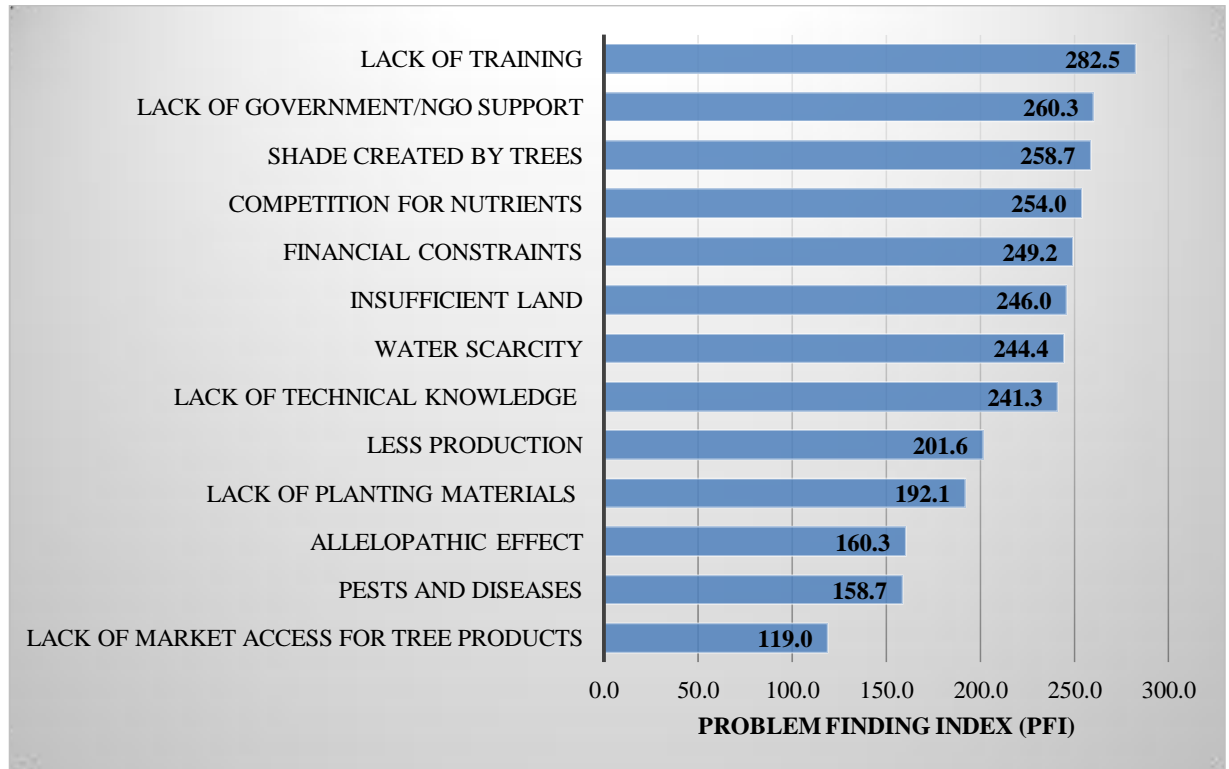
The study revealed several critical barriers that hinder agroforestry adoption and implementation among farmers (Table 4.3). A significant proportion (84.13%) of respondents cited *lack of training* as a high-level challenge, highlighting a substantial gap in skill development and knowledge dissemination. Similarly, *lack of government or NGO support* (74.6%), *shade created by trees* (71.43%), and *financial constraints* (69.84%) were reported as major obstacles. *Insufficient land* was also a widespread issue, with 65.08% marking it as a high concern, reflecting land pressure in agricultural communities.

**Table 4.3 Perceived Barriers and Challenges in Practicing Agroforestry by Respondents**

Barriers/Challenges	Extent of problems			
	High (%)	Medium (%)	Low (%)	No (%)
Lack of technical knowledge	55.56	30.16	14.29	0.00
Insufficient land	65.08	22.22	6.35	6.35
Lack of planting materials	34.92	36.51	14.29	14.29
Financial constraints	69.84	15.87	7.94	6.35
Lack of government/NGO support	74.60	14.29	7.94	3.17
Pests and diseases	15.87	39.68	31.75	12.70
Allelopathic effect	12.70	47.62	26.98	12.70
Shade created by trees	71.43	19.05	6.35	3.17
Lack of market access for tree products	4.76	26.98	50.79	17.46
Competition for nutrients	58.73	36.51	4.76	0.00
Less production	34.92	41.27	14.29	9.52
Water scarcity	58.73	28.57	11.11	1.59
Lack of training	84.13	14.29	1.59	0.00

Technical knowledge deficits were apparent, as 55.56% of farmers expressed that lack of technical knowledge severely hampered their agroforestry practices. Biophysical challenges such as competition for nutrients (58.73%) and water scarcity (58.73%) were also considered high-impact problems. Meanwhile, issues like allelopathic effects (47.62% medium) and pests and diseases (39.68% medium) were moderate-level concerns. Interestingly, lack of

market access for tree products was viewed as a less pressing issue, with 50.79% indicating it posed a low problem, possibly reflecting that most agroforestry outputs are used domestically rather than commercially.



**Fig. 4.8 Ranking of Barriers to Agroforestry Adoption Using Problem Finding Index (PFI)**

To quantitatively assess the severity of various barriers in agroforestry adoption, a Problem Finding Index (PFI) was developed by assigning weights to respondents' perception levels (Appendix V) (Fig. 4.8). The index ranged from 0 (no problem) to 300 (most severe), enabling a standardized comparison of constraints. Results showed that 'lack of training' ranked highest (PFI = 282.5), followed by 'lack of government/NGO support' (PFI = 260.3) and 'financial constraints' (PFI = 249.5). Other major challenges included 'shade created by trees' (PFI = 258.7), 'competition for nutrients' (PFI = 254), and 'water scarcity' (PFI = 244.4). Conversely, constraints like 'lack of market access for tree products' and 'pests and diseases' were found to be less severe, with lower PFI values of 119 and 158.7, respectively. This prioritization of barriers helps identify critical areas requiring intervention to promote sustainable agroforestry practices.

These insights support previous studies (Ali, Ahmad, et al., 2024; Jahan, Rahman, Islam, et al., 2022), emphasizing that both technical and institutional barriers need to be addressed to

improve agroforestry uptake and sustainability. Comprehensive training, better extension support, and financial incentives could significantly mitigate these constraints.

#### 4.8 Policy Support Received by Agroforestry Farmers & Their Suggestion

##### 4.8.1 Policy Support Received by Respondents

The study revealed that policy support and extension services related to agroforestry were extremely limited among respondents (Table 4.4). A vast majority (90.48%) reported never receiving any training on agroforestry, while only 9.52% received such support occasionally. Access to seedlings was also lacking, with 73.02% of respondents stating they had never received any, and just 26.98% having occasional access. Similarly, technical advice on agroforestry management was received occasionally by 38.10% of respondents, but 55.56% reported never receiving such support. Financial assistance was among the least received forms of support, with 82.54% never receiving any and only 17.46% reporting occasional support. Furthermore, 74.60% of respondents never received any market access assistance. These findings highlight a significant gap in institutional support for agroforestry farmers, which may hinder the wider adoption and effective implementation of agroforestry practices (Akter et al., 2022; Saha et al., 2022).

**Table 4.4 Extent of Policy Support Received by Agroforestry Farmers**

Supports/Services	Extent of reception			
	Regular (%)	Frequent (%)	Occasional (%)	Never (%)
Training on agroforestry	0.00	0.00	9.52	90.48
Access to seedlings	0.00	0.00	26.98	73.02
Technical advice on agroforestry management	0.00	6.35	38.10	55.56
Financial support	0.00	0.00	17.46	82.54
Market access assistance	0.00	0.00	25.40	74.60

#### **4.8.2 Policy change Suggestions to promote agroforestry**

To identify practical solutions for promoting agroforestry adoption, farmers were asked to suggest necessary policy interventions. The majority of respondents (92.06%) emphasized the need for strengthening extension services and training. This highlights a critical gap in awareness and technical capacity among farmers, reflecting earlier findings where 90.48% had never received any training on agroforestry practices. Similarly, 85.71% of respondents recommended financial incentives and credit facilities, indicating that lack of financial resources remains a major barrier to tree planting in croplands. Another 58.73% of farmers suggested ensuring access to quality planting materials, which aligns with earlier constraints noted in seedling availability. Additionally, 63.49% of respondents called for the integration of agroforestry into national climate policies, showing awareness of its potential in climate change mitigation and adaptation, particularly given that 100% observed changes in the local climate. Lastly, 42.86% proposed improving market access for agroforestry products, underlining the importance of economic incentives in sustaining agroforestry systems (Appendix VI).

#### **4.9 Stand structure, composition and diversity of woody perennials**

Among the identified 13 woody perennial species in cropland agroforestry practices in the study area, 9 species were most abundant which were seen by Importance Value Index (IVI) in (Table 4.5). From 63 quadrates of cropland agroforestry practices total 715 woody perennial individuals counted (Appendix VII).

##### **4.9.1 Importance value index (IVI) of identified woody perennials of cropland agroforestry practices**

The Importance Value Index (IVI) was calculated to assess the ecological significance and dominance of woody perennial species within the cropland agroforestry systems of the study area (Table 4.5 and Appendix VII). The IVI integrates three metrics—relative density (RD), relative frequency (RF), and relative dominance ( $RD_0$ )—to reflect the overall influence of a species in the agroforestry landscape.

Among the recorded species, *Areca catechu* exhibited the highest IVI (69.08%), indicating its ecological dominance in terms of abundance, spatial frequency, and basal area coverage. This can be attributed to its widespread adoption by farmers due to commercial value and

suitability in mixed cropping systems. *Eucalyptus camaldulensis* (56.12%) and *Swietenia macrophylla* (50.79%) also showed high IVI values, suggesting their significance in terms of both timber production and adaptability to the local environment.

**Table 4.5 Relative Density (RD%), Relative Frequency (RF%), Relative Dominance (RD<sub>0</sub>%), and Importance Value Index (IVI %) of all Woody Perennial Species found in Cropland Agroforestry Systems in the study area**

Species name	RD (%)	RF (%)	RD <sub>0</sub> (%)	IVI (%)
<i>Litchi chinensis</i>	10.77	13.67	4.82	29.25
<i>Mangifera indica</i>	15.94	17.27	7.68	40.89
<i>Areca catechu</i>	36.78	18.71	13.59	69.08
<i>Eucalyptus camaldulensis</i>	14.41	15.11	26.61	56.12
<i>Swietenia macrophylla</i>	8.95	12.95	28.89	50.79
<i>Moringa oleifera</i>	5.87	7.19	2.95	16.02
<i>Azadirachta indica</i>	0.42	2.16	0.68	3.26
<i>Artocarpus heterophyllus</i>	2.24	6.47	12.21	20.92
<i>Ziziphus jujuba</i>	0.84	0.72	0.53	2.09
<i>Citrus sinensis</i>	3.08	3.60	0.78	7.45
<i>Cinnamomum tamala</i>	0.42	0.72	0.11	1.25
<i>Syzygium cumini</i>	0.14	0.72	0.12	0.98
<i>Bombax ceiba</i>	0.14	0.72	1.04	1.90

*Mangifera indica* and *Litchi chinensis* also contributed substantially, with IVIs of 40.89% and 29.25% respectively, reflecting their popularity for fruit production and integration into traditional homestead agroforestry. In contrast, species like *Syzygium cumini*, *Cinnamomum tamala*, and *Bombax ceiba* had very low IVI values (<2%), indicating limited presence and influence within the system. These results align with findings from similar studies (Hasan et al., 2025) that emphasize the dominance of multifunctional species in agroforestry landscapes, often driven by farmers' preferences for income, timber, and fruit benefits.

#### 4.9.2 Shannon–Wiener Diversity Index (H') and Margalef's Index (R) of Woody Perennials

The Shannon–Wiener Diversity Index (H') calculated (Table 4.6) for woody perennials in cropland agroforestry systems of the study area was 1.8428, indicating moderate species diversity. The index reflects both species richness and evenness across the 713 individual trees recorded. *Areca catechu* contributed the highest proportion of individuals ( $P_i = 0.3689$ ), suggesting dominance in the system, though its high abundance reduced overall evenness. In contrast, species like *Azadirachta indica*, *Cinnamomum tamala*, and *Ziziphus jujuba* showed minimal representation, contributing to species richness but not greatly to evenness.

**Table 4.6 Shannon–Wiener Diversity Index (H') of most abundant Woody Perennials found in Cropland Agroforestry in the study area**

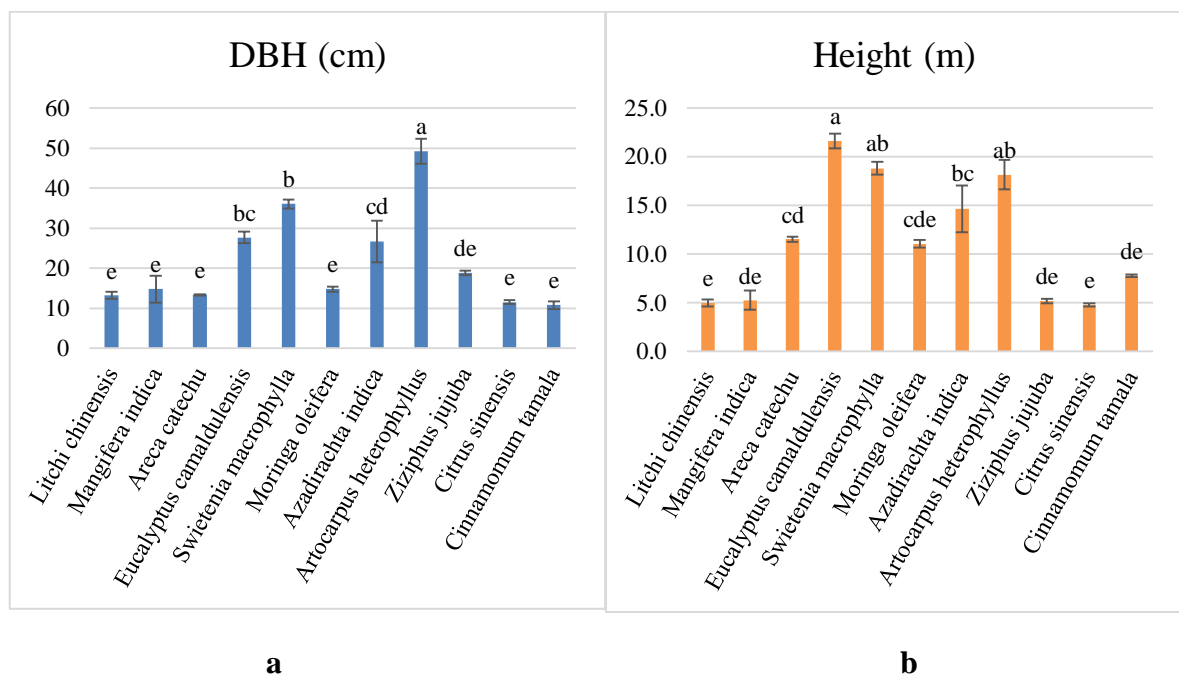
Name of species	n (individuals)	$P_i$	$P_i \times \ln(P_i)$
<i>Litchi chinensis</i>	77	0.11	-0.24
<i>Mangifera indica</i>	114	0.16	-0.29
<i>Areca catechu</i>	263	0.37	-0.37
<i>Eucalyptus camaldulensis</i>	103	0.14	-0.28
<i>Swietenia macrophylla</i>	64	0.09	-0.22
<i>Moringa oleifera</i>	42	0.06	-0.17
<i>Azadirachta indica</i>	3	0.00	-0.02
<i>Artocarpus heterophyllus</i>	16	0.02	-0.09
<i>Ziziphus jujuba</i>	6	0.01	-0.04
<i>Citrus sinensis</i>	22	0.03	-0.11
<i>Cinnamomum tamala</i>	3	0.00	-0.02
<b>Total(N)</b>	<b>715</b>		<b>H' = 1.84</b>

A moderate diversity value suggests that while the system contains multiple tree species, a few dominant ones account for most of the individuals, possibly driven by economic preferences or management practices. Such species composition can influence ecosystem services such as carbon sequestration, resilience to pests, and long-term sustainability (Nair, 2011). Therefore, maintaining or enhancing diversity in agroforestry systems could improve ecological function and climate resilience.

Margalef's Richness Index,  $R = \frac{13-1}{\ln(715)} = 1.521$ , suggests moderate species richness in the cropland agroforestry system. Though 13 species were observed, the dominance of certain species (e.g., *Areca catechu*) may reduce the overall richness value. This highlights the importance of promoting a more even species composition to enhance biodiversity and ecological stability (Sina & Zulkarnaen, 2019).

#### 4.9.3 Height and DBH of Woody Perennials in Cropland Agroforestry

The diameter at breast height (DBH) and total height of individual woody species recorded in cropland agroforestry systems (Fig. 4.9 and Appendix VIII) varied considerably, reflecting the diverse growth characteristics and ecological adaptability of the species. Among the observed species, *Artocarpus heterophyllus* exhibited the highest average DBH (49.20 cm), followed by *Swietenia macrophylla* (36.07 cm) and *Eucalyptus camaldulensis* (27.66 cm), indicating their dominance in terms of trunk girth and potential timber value.

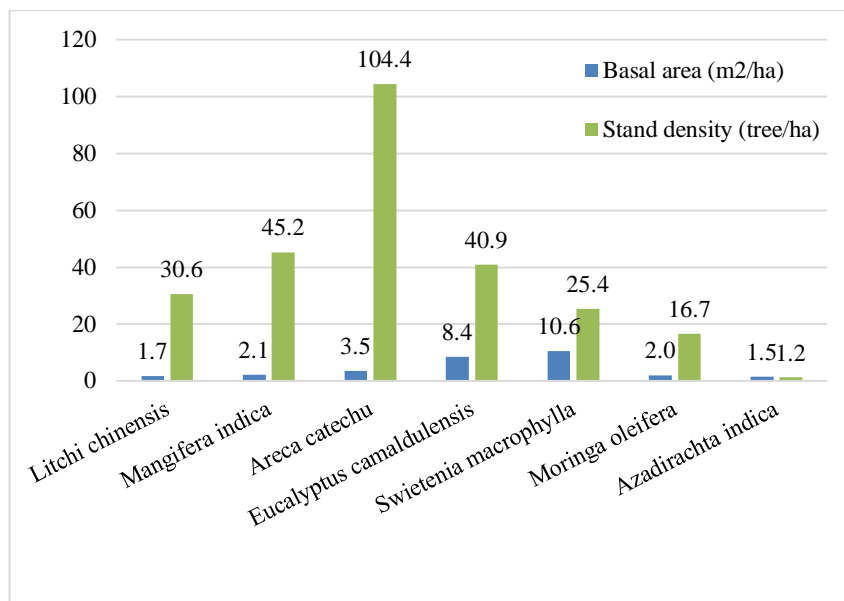


**Fig. 4.9** Bar graphs showing (a) DBH (cm) and (b) height (m) of abundantly found woody perennials of cropland agroforestry practices in the study area. SE bars indicate the standard error of means

In terms of height, *Eucalyptus camaldulensis* reached the greatest average height (21.62 m), followed by *Swietenia macrophylla* (18.82 m) and *Artocarpus heterophyllus* (18.16 m), suggesting their superior vertical growth and competitive capacity for sunlight acquisition in the agroforestry canopy structure. On the other hand, smaller DBH and height values were observed for fruit-bearing species such as *Ziziphus jujuba* (DBH: 18.91 cm, Height: 5.18 m), *Citrus sinensis* (DBH: 11.56 cm, Height: 4.81 m), and *Litchi chinensis* (DBH: 13.22 cm, Height: 5.01 m), reflecting their bushier growth forms and shorter canopy. The variability in DBH and height among the species implies functional diversity in cropland agroforestry, which supports both carbon sequestration and multifunctional benefits (Pakhom et al., 2020).

#### 4.9.4 Stand density and basal area of woody perennials in Cropland Agroforestry practices

The assessment of woody perennials in cropland agroforestry systems revealed considerable variation in stand structure among species (Fig. 4.10 and Appendix IX). Among the surveyed species, *Swietenia macrophylla* exhibited the highest basal area (10.6 m<sup>2</sup>/ha), indicating its dominance in terms of stem size and volume, despite a relatively lower stand density of 25.40 trees/ha. Similarly, *Artocarpus heterophyllus* recorded a substantial basal area (8.97 m<sup>2</sup>/ha) with a sparse stand density of 6.35 trees/ha, reflecting its contribution to canopy biomass despite limited presence. *Eucalyptus* showed a high basal area (8.4 m<sup>2</sup>/ha) combined with moderate density (40.87 trees/ha), suggesting both significant size and frequency.



**Fig. 4.10** Bar chart graph showing both stand density and basal area of abundantly found woody species in Cropland agroforestry practices in the study area

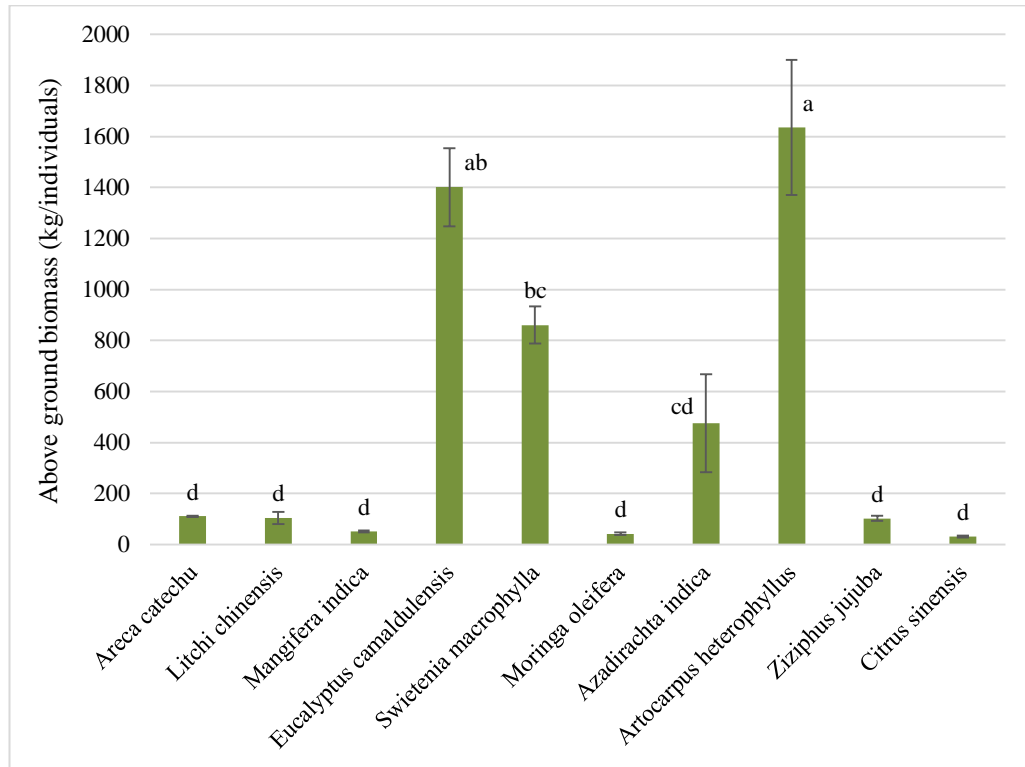
In contrast, *Areca catechu* recorded the highest stand density (104.37 trees/ha) but a relatively lower basal area (3.5 m<sup>2</sup>/ha), indicating a high frequency of thinner-stemmed individuals. *Mangifera indica* and *Litchi chinensis* contributed moderately to both basal area (2.1 and 1.7 m<sup>2</sup>/ha, respectively) and density (45.24 and 30.56 trees/ha), reflecting their balanced structural role in the system. Lower basal area and density values were observed for species such as *Azadirachta indica* (1.5 m<sup>2</sup>/ha, 1.19 trees/ha), *Ziziphus jujuba* (3.52 m<sup>2</sup>/ha, 2.38 trees/ha), and *Citrus sinensis* (1.03 m<sup>2</sup>/ha, 8.73 trees/ha), suggesting limited structural contribution in terms of either size or abundance. *Moringa oleifera*, known for its multipurpose benefits, had a basal area of 2.0 m<sup>2</sup>/ha and density of 16.67 trees/ha, signifying moderate representation. Such structural variation is crucial for ecosystem functioning, biomass accumulation, and carbon sequestration, and indicates the importance of selecting a balanced species mix (Chave et al., 2005).

## **4.10 Total biomass carbon stocks of cropland agroforestry practices**

### **4.10.1 Above Ground Biomass (AGB) per individual tree of a species**

The estimation of species-wise above-ground biomass (AGB) in cropland agroforestry systems revealed substantial variation among the most abundant woody perennials (Fig. 4.11 and Appendix XI). Among the recorded species, *Artocarpus heterophyllus* exhibited the highest mean AGB per individual tree, with 1635.43 kg, followed by *Eucalyptus camaldulensis* (1401.31 kg) and *Swietenia macrophylla* (859.97 kg). These species are known for their fast growth and large trunk diameters, which contribute significantly to overall biomass accumulation and carbon storage potential in agroforestry landscapes. In contrast, relatively lower AGB values were observed for species like *Citrus sinensis* (30.99 kg), *Moringa oleifera* (42.27 kg), and *Mangifera indica* (51.91 kg), reflecting their smaller stature and lighter wood density. Despite their lower biomass, these species may still provide substantial ecological and economic benefits, including food, fodder, and medicinal resources. Interestingly, *Areca catechu* and *Litchi chinensis* showed moderate AGB values of 110.92 kg and 104.80 kg respectively, which aligns with their typical medium-sized canopy and trunk structure in the study area. Notably, *Azadirachta indica*, although less dominant in stand density, demonstrated a considerable AGB of 476.14 kg, underscoring its potential role in long-term carbon sequestration and ecological services. These findings underscore the importance of species selection in agroforestry planning, as species with higher biomass contribute more effectively to carbon sequestration goals. The inclusion of both high-AGB

species (e.g., *Artocarpus*, *Eucalyptus*) and multifunctional, low-AGB species (e.g., *Citrus*, *Moringa*) reflects a balanced strategy for maximizing both ecological sustainability and farmer livelihood in cropland agroforestry systems.



**Fig. 4.11 Above-ground biomass (AGB) for most abundant woody perennials found in the cropland agroforestry**

#### 4.10.2 Woody Biomass and Carbon Stock in Cropland Agroforestry Systems

The estimation of carbon stock from woody perennials in cropland agroforestry systems of the study area reveals significant potential for carbon sequestration. The analysis was carried out by calculating the above-ground biomass (AGB) and below-ground biomass (BGB) for each species using species-specific DBH and height data, then converting total biomass (TB) to carbon stock using a default carbon fraction (0.5), as recommended by the IPCC 2006 guidelines (Eggleston et al., 2006). The total biomass carbon stock across all species was estimated at 66.50 Mg C ha<sup>-1</sup>, which is a substantial contribution to climate change mitigation efforts in the agricultural landscape.

Among the studied species, *Eucalyptus camaldulensis* showed the highest contribution to both biomass and carbon stock, accounting for 52.27 Mg ha<sup>-1</sup> AGB, 13.59 Mg ha<sup>-1</sup> BGB, and a total of 65.86 Mg ha<sup>-1</sup> of biomass, translating into 32.93 Mg C ha<sup>-1</sup>. The dominance

of *Eucalyptus camaldulensis* can be attributed to its fast growth rate, large DBH, and tall stature, which collectively increase its carbon storage capacity. This finding corroborates the work of Behera et al. (2020) and Hernández et al. (2016), who observed that fast-growing hardwoods like Eucalyptus significantly enhance carbon sequestration in agroforestry systems.

**Table 4.7 Total Biomass and Carbon Stock Estimation of Woody Perennials in Cropland Agroforestry Systems (Mg ha<sup>-1</sup>)**

Name of species	Biomass of woody perennials			Total woody Biomass Carbon Mg C ha <sup>-1</sup>
	Above Ground Biomass (AGB) Mg ha <sup>-1</sup>	Below Ground Biomass (BGB) Mg ha <sup>-1</sup>	Total Biomass (TB) Mg ha <sup>-1</sup>	
<i>Areca catechu</i>	11.14	2.90	14.03	7.02
<i>Litchi chinensis</i>	2.94	0.77	3.71	1.86
<i>Mangifera indica</i>	2.36	0.61	2.97	1.49
<i>Eucalyptus camaldulensis</i>	52.27	13.59	65.86	32.93
<i>Swietenia macrophylla</i>	23.89	6.21	30.10	15.05
<i>Moringa oleifera</i>	0.70	0.18	0.89	0.44
<i>Azadirachta indica</i>	0.57	0.15	0.71	0.36
<i>Artocarpus heterophyllus</i>	10.38	2.70	13.08	6.54
<i>Ziziphus jujuba</i>	0.20	0.05	0.26	0.13
<i>Citrus sinensis</i>	0.23	0.06	0.29	0.15
<i>Cinnamomum tamala</i>	0.04	0.01	0.05	0.03
<i>Syzygium cumini</i>	0.07	0.02	0.09	0.05
<i>Bombax ceiba</i>	0.75	0.20	0.95	0.47
Total	105.56	27.45	133.00	66.50

The second-highest contributor was *Swietenia macrophylla*, which accumulated 30.10 Mg ha<sup>-1</sup> of total biomass and stored 15.05 Mg C ha<sup>-1</sup>. Despite being moderately abundant in the quadrates, its high DBH and wood density made it a valuable carbon sink. This aligns with Racelis et al. (2019), who reported *S. macrophylla* as a high-biomass species in mixed agroforestry systems.

Species like *Artocarpus heterophyllus* and *Areca catechu* also made notable contributions to carbon stocks, with  $13.08 \text{ Mg ha}^{-1}$  and  $14.03 \text{ Mg ha}^{-1}$  of total biomass respectively, resulting in  $6.54 \text{ Mg C ha}^{-1}$  and  $7.02 \text{ Mg C ha}^{-1}$ . These species were widely distributed and had moderate to high individual biomass values, contributing significantly despite having lower basal areas compared to *Eucalyptus*. Notably, *A. catechu* had the highest stand density among all species, which compensated for its moderate DBH.

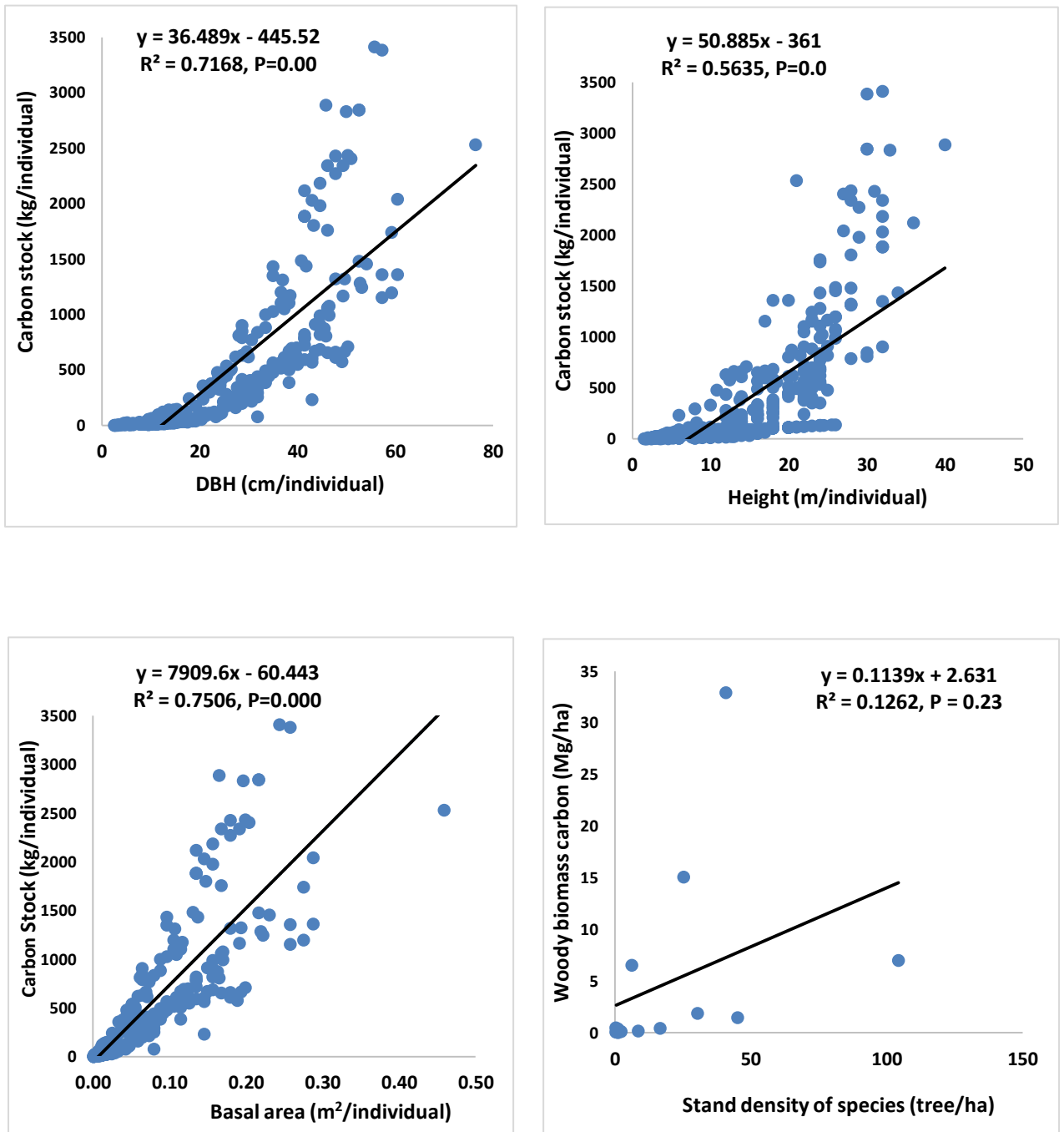
In contrast, species like *Citrus sinensis*, *Ziziphus jujuba*, *Moringa oleifera*, and *Cinnamomum tamala* showed low biomass and carbon contributions, primarily due to their smaller stem girth and height. Their contributions ranged from  $0.26 \text{ Mg ha}^{-1}$  to  $0.89 \text{ Mg ha}^{-1}$  in total biomass and  $0.13 \text{ Mg C ha}^{-1}$  to  $0.44 \text{ Mg C ha}^{-1}$  in carbon stock. However, despite their low carbon accumulation, these species provide important ecosystem services, including food, medicinal value, and microclimatic benefits, which enhance the multifunctionality of agroforestry systems (Nair, 2011).

Overall, the estimated total biomass of  $133.00 \text{ Mg ha}^{-1}$  and carbon stock of  $66.50 \text{ Mg C ha}^{-1}$  demonstrates that cropland agroforestry systems dominated by woody perennials hold significant potential for carbon sequestration. These findings support previous studies in tropical and subtropical regions (Nair et al., 2010; Reppin et al., 2020), which emphasize that integrating trees into agricultural land can substantially offset atmospheric  $\text{CO}_2$  while offering additional socio-economic benefits.

#### **4.10.3 Influence of DBH, Height, Basal Area, and Stand Density on Carbon Sequestration in Cropland Agroforestry**

The regression analysis revealed statistically significant and strong relationships between individual tree carbon stock and biometric variables such as basal area, DBH, and height (Table 4.2 and Appendix XII). Among these, basal area exhibited the strongest correlation with carbon stock ( $R^2 = 0.7506$ ,  $P = 0.000$ ), followed by DBH ( $R^2 = 0.7168$ ,  $P = 0.000$ ) and height ( $R^2 = 0.5635$ ,  $P = 0.000$ ). These results indicate that trees with larger basal area and DBH tend to store more carbon, underscoring their significance in aboveground carbon accumulation. In contrast, the relationship between stand density (tree/ha) and carbon stock ( $\text{Mg/ha}$ ) was found to be statistically insignificant ( $R^2 = 0.1262$ ,  $P = 0.23$ ). This suggests that a higher number of trees per hectare does not necessarily translate into greater carbon storage. This may be attributed to the dominance of smaller or less biomass-contributing individuals in denser stands, which contribute less to total carbon despite their abundance. The weak

correlation also implies that structural characteristics of individual trees (such as size and form) play a more decisive role in biomass and carbon storage than the sheer number of trees.



**Fig. 4.12 Relationship Between Tree Structural Attributes and Carbon Stock in Cropland Agroforestry Systems**

This pattern aligns with findings in other tropical and agroforestry systems, where a few large individuals often contribute disproportionately to total biomass. In the context of climate change mitigation, this highlights the importance of promoting and conserving trees with larger basal area and DBH rather than focusing solely on increasing tree density (Mildrexler et al., 2020). Strategic selection and management of high-biomass species can therefore optimize carbon sequestration in cropland agroforestry system, contributing more effectively to sustainable carbon management.

## CHAPTER V

### SUMMARY AND CONCLUSION

#### 5.1 Summary

This study was conducted in five villages of the 5 No. Sundorpur Union, Kaharole Upazila, Dinajpur district, from February to May 2025. Kaharole Upazila lies between 25°44' and 25°53' N latitudes and 88°30' and 89°43' E longitudes, covering an area of 205.5 km<sup>2</sup> (M. S. Rahman et al., 2020). The region is agriculturally rich, primarily producing rice, maize, jute, wheat, and potato, along with various fruit and timber trees incorporated into homestead, cropland, and orchard-based agroforestry systems (Pakhom et al., 2020). The average annual temperature ranges from 10°C in winter to 35°C in summer, while the area receives 1,500–2,500 mm rainfall annually, mostly from June to October due to the southwest monsoon (FAHMIDA, 2017). Recent climate variability has introduced erratic rainfall, prolonged droughts, and rising temperatures, which are posing serious challenges to traditional farming systems.

A semi-structured interview schedule was designed to collect data from farmers practicing cropland agroforestry. The schedule included both open and closed questions, focusing on variables such as age, family size, education level, farm and agroforestry farm size, general and agroforestry farming experience, tree planting patterns, motivations behind planting trees in field, perceived productivity changes, climate change awareness, access to policy support, and encountered challenges.

Demographically, 50.8% of the respondents were young, 36.5% middle-aged, and 12.7% elderly. Family size varied, with 33.3% in medium, 39.7% in large, and 27% in small-sized families. Education levels were diverse: 6.3% were illiterate, 7.9% could sign only, 20.6% had primary, 47.6% secondary, and 17.5% above secondary education. In terms of landholding, 12.7% were landless, and 60.3% were marginal farmers; only 1.6% held large farms. Cropland agroforestry fields ranged between 0.04 to 0.40 ha. Farmers had an average of 18.33 years of farming experience but limited agroforestry experience (9.43 years).

Tree planting patterns varied, with 44% of farmers using boundary plantation, followed by 27% scattered and 29% stripe plantations. Key motivations for planting trees included income generation combined with fruit consumption (25.4%), income with wood (22.22%),

and income only (15.87%). Other reasons included multi-benefit uses like fruit, wood, and fuel.

Productivity perceptions revealed that 35% observed a maximum, 48% reported a minimum, and 17% noted no change. Climate change was perceived through indicators like increased temperature, irregular rainfall, and prolonged droughts (29.37%), while 27% identified drought alone. Impacts on farming included increased irrigation needs (71.43%), higher input costs (52.4%), reduced production (30.16%), increased use of pesticides (25.4%) and fertilizers (22.22%), and labor requirements (23.81%).

Benefits of agroforestry in the context of climate change adaptation were evident. Wind protection received the highest acknowledgment (61.9%), while 52.38% and 25.4% saw medium and high benefits for carbon stock, respectively. Moderate benefits were perceived for improving soil moisture (34.92%) and drought resilience (28.57%). Major challenges included lack of training, absence of government or NGO support, shade from trees, limited land, and nutrient competition. Notably, most farmers had not received any formal policy support, with 92.06% demanding improved extension services and training.

To assess biodiversity and carbon sequestration, 63 random quadrates (20 m x 20 m) were sampled in cropland agroforestry fields. Each quadrate recorded species count, individual count, girth at breast height (GBH), and height. A total of 715 individuals from 13 woody perennial species were identified. Based on Importance Value Index (IVI), *Areca catechu* ranked highest (69.08%), followed by *Eucalyptus camaldulensis* (56.12%) and *Swietenia macrophylla* (50.79%). Species like *Mangifera indica* and *Litchi chinensis* also had considerable IVI scores, while *Syzygium cumini*, *Cinnamomum tamala*, and *Bombax ceiba* were rare.

The Shannon-Wiener Diversity Index was calculated at 1.84, indicating moderate diversity, while Margalef's Richness Index stood at 1.521. *Artocarpus heterophyllus* exhibited the highest average DBH (49.20 cm), while *Eucalyptus camaldulensis* was the tallest (21.62 m). Fruit species such as *Ziziphus jujuba* and *Citrus sinensis* had the smallest sizes. *Swietenia macrophylla* had the largest basal area (10.6 m<sup>2</sup>/ha), and *Areca catechu* recorded the highest stand density (104.37 individuals/ha).

Biomass and carbon stock estimates highlighted *Eucalyptus camaldulensis* as the top contributor with 65.86 Mg ha<sup>-1</sup> total biomass and 32.93 Mg C ha<sup>-1</sup>. *Swietenia macrophylla*,

*Artocarpus heterophyllus*, and *Areca catechu* also showed significant biomass accumulation. Low carbon-contributing species included *Citrus sinensis*, *Ziziphus jujuba*, and *Moringa oleifera*. Overall, the estimated total biomass of 133.00 Mg ha<sup>-1</sup> and carbon stock of 66.50 Mg C ha<sup>-1</sup> demonstrates that cropland agroforestry systems dominated by woody perennials hold significant potential for carbon sequestration. The study found strong and significant positive relationships between above-ground carbon stock and key tree parameters such as diameter at breast height (DBH), tree height, and basal area, indicating their crucial roles in biomass accumulation in cropland agroforestry systems. Among these, basal area showed the highest correlation with carbon stock, while stand density exhibited a weak and statistically insignificant relationship. These findings highlight that individual tree size metrics are more predictive of carbon storage potential than tree count alone.

## **5.2 Conclusion**

This study highlights the ecological, economic and climate-resilient benefits of cropland agroforestry systems in the Kaharole Upazila of Dinajpur district. It also shows the structure, biodiversity, and carbon sequestration potential of cropland agroforestry practices. The findings reveal that local farmers actively integrate woody perennials into their croplands, primarily for income generation, subsistence use, and as a response to changing environmental conditions. Although the species composition is dominated by a few high-value species, the presence of both timber and fruit trees suggests a balanced integration, contributing to biodiversity conservation. The presence of a diverse range of species indicates moderate species richness and evenness within the system. Furthermore, the significant biomass accumulation observed across the study sites highlights the considerable potential of agroforestry in carbon sequestration offering a nature-based solution to climate change mitigation. In this context, agroforestry emerges as an adaptive strategy that improves microclimatic conditions, supports soil moisture retention, and reduces vulnerability to climatic shocks. Despite these benefits, the adoption of such systems is constrained by limited institutional support, lack of technical knowledge, and land-related challenges. Strengthening extension services, promoting farmer training, and supporting policy interventions are essential to enhance the sustainability and effectiveness of agroforestry practices in the region.

### **5.3 Recommendations**

- i. The study recommends further research on the long-term ecological and socio-economic impacts of cropland agroforestry systems, particularly in relation to biodiversity enhancement and sustainable land use under changing climatic conditions.
- ii. Future studies should focus on a wider geographic area, inclusion of soil sample analysis, weather data and seasonal variations to improve the representativeness of data and better understand the role of agroforestry in climate change adaptation and mitigation.

#### **➤ Limitations of the study**

This study was limited to a specific geographical area and conducted over a short period, which may not fully capture seasonal or long-term ecological dynamics. Understanding how these systems evolve and change under different management practices and environmental conditions requires longer-term monitoring and analysis. The reliance on farmer-reported data may also introduce subjectivity or recall bias. Additionally, the limited sample size and exclusion of rare species with minimal representation may affect the generalizability of the biodiversity and carbon stock estimates.

## REFERENCES

- Abbas, F., Hammad, H. M., Fahad, S., Cerdà, A., Rizwan, M., Farhad, W., Ehsan, S., & Bakhat, H. F. (2017). Agroforestry: a sustainable environmental practice for carbon sequestration under the climate change scenarios—a review. *Environmental Science and Pollution Research* 24:12, 24(12), 11177–11191. <https://doi.org/10.1007/S11356-017-8687-0>
- Agevi, H., Onwonga, R., Kuyah, S., & Tsingalia, M. (2017). Carbon stocks and stock changes in agroforestry practices: a review. *Tropical and Subtropical Agroecosystems*, 20(1).
- Akter, R., Hasan, M. K., Kabir, K. H., Darr, D., & Roshni, N. A. (2022). Agroforestry systems and their impact on livelihood improvement of tribal farmers in a tropical moist deciduous forest in Bangladesh. *Trees, Forests and People*, 9, 100315. <https://doi.org/10.1016/J.TFP.2022.100315>
- Alam, M. (2012). Valuation of tangible benefits of a homestead agroforestry system: a case study from Bangladesh. *Human Ecology*, 40(4), 639–645.
- Ali, M. M., Ahmad, B., Bari, M. S., Pal, A. C., Rahman, M. L., & Sarmin, I. J. (2024). An assessment of agroforestry as a climate- smart practice: Evidences from farmers of northwestern region of Bangladesh. *Agrosystems, Geosciences & Environment*, 7(2), e20501.
- Ali, M. M., Islam, M. A., Islam, M. R., Dipto, S. S., & Bari, M. S. (2024). Assessing the cropland changes into agroforestry and its livelihood outcomes: Evidence from northern Bangladesh. *Trees, Forests and People*, 15, 100497.
- Alías, J. C., Mejías, J. A., & Chaves, N. (2022). Effect of Cropland Abandonment on Soil Carbon Stock in an Agroforestry System in Southwestern Spain. *Land*, 11(3), 425.
- Amin, M. R., Miah, M. M. U., & Mondol, M. A. S. (n.d.). *Farmers' perception towards the consequences of homestead Agroforestry in Dinajpur district.*
- Amonum, J., Babalola, F., & Agera, S. (2009). Agroforestry Systems in Nigeria: Review of Concepts and Practices. *Journal of Research in Forestry, Wildlife and Environment*, 1(1), 18–30. <https://www.ajol.info/index.php/jrfwe/article/view/82812>

- Ashiagbor, G., Oduro, W., Gyiele, L., Siaw, D., Barnes, V. R., Agbenyega, O., Twum-Ampofo, K., Partey, S., Thevathasan, N., Gordon, A., Gray, R., & Odame, H. H. (2020). Toward sustainable land resources management with agroforestry: empirical evidence from the Sunyani west district of Ghana. *Agroforestry Systems*, *94*(2), 527–537. <https://doi.org/10.1007/s10457-019-00419-y>
- Atangana, A., Khasa, D., Chang, S., & Degrande, A. (2014a). Agroforestry and Biodiversity Conservation in Tropical Landscapes. *Tropical Agroforestry*, 227–232. [https://doi.org/10.1007/978-94-007-7723-1\\_11](https://doi.org/10.1007/978-94-007-7723-1_11)
- Atangana, A., Khasa, D., Chang, S., & Degrande, A. (2014b). Definitions and Classification of Agroforestry Systems. *Tropical Agroforestry*, 35–47. [https://doi.org/10.1007/978-94-007-7723-1\\_3](https://doi.org/10.1007/978-94-007-7723-1_3)
- Awazi, N. P. (2024). The Future of Agroforestry Systems for Sustainable Livelihoods: Policy and Governance Dimensions. *Turbulence & Energy Laboratory Annual Conference*, 187–208.
- Awazi, N. P., & Tchamba, N. M. (2019). Enhancing agricultural sustainability and productivity under changing climate conditions through improved agroforestry practices in smallholder farming systems in sub-Saharan Africa. *African Journal of Agricultural Research*, *14*(7), 379–388.
- Bardhan, S., Jose, S., Biswas, S., Kabir, K., & Rogers, W. (2012). Homegarden agroforestry systems: An intermediary for biodiversity conservation in Bangladesh. *Agroforestry Systems*, *85*(1), 29–34. <https://doi.org/10.1007/S10457-012-9515-7/METRICS>
- Baul, T. K., Peuly, T. A., Nandi, R., Schmidt, L. H., & Karmakar, S. (2021). Carbon stocks of homestead forests have a mitigation potential to climate change in Bangladesh. *Scientific Reports*, *11*(1), 9254.
- Behera, L., Ray, L. I., Ranjan Nayak, M., & Mehta, A. (2020). Carbon sequestration potential of Eucalyptus spp.: A review. *E-Planet*, *18*(1), 79–84.
- Borelli, S., Conigliaro, M., Quaglia, S., & Salbitano, F. (2017). Urban and Peri-urban agroforestry as multifunctional land use. *Agroforestry: Anecdotal to Modern Science*, 705–724.

- Cardinael, R., Chevallier, T., Barthès, B. G., Saby, N. P. A., Parent, T., Dupraz, C., Bernoux, M., & Chenu, C. (2015). Impact of alley cropping agroforestry on stocks, forms and spatial distribution of soil organic carbon—A case study in a Mediterranean context. *Geoderma*, *259*, 288–299.
- Castle, S. E., Miller, D. C., Ordonez, P. J., Baylis, K., & Hughes, K. (2021). The impacts of agroforestry interventions on agricultural productivity, ecosystem services, and human well-being in low- and middle- income countries: A systematic review. *Campbell Systematic Reviews*, *17*(2), e1167.
- Chakraborty, M., Haider, M. Z., & Rahaman, M. M. (2015). Farmers preference and perception towards cropland agroforestry in Bangladesh. *Journal of Forest and Environmental Science*, *31*(4), 241–254.
- Chavan, S., Newaj, R., Keerthika, A., Ram, A., Jha, A., & Kumar, A. (2014). Agroforestry for adaptation and mitigation of climate change. *Popular Kheti*, *2*(3), 214–220.
- Chave, J., Andalo, C., Brown, S., Cairns, M. A., Chambers, J. Q., Eamus, D., Fölster, H., Fromard, F., Higuchi, N., & Kira, T. (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia*, *145*, 87–99.
- Chowdhury, M. A., Islam, K. N., Hafiz, N., & Islam, K. (2019). Diversity of trees in a community managed forest: the case of Komolchori VCF, Khagrachari, Bangladesh. *Geology, Ecology, and Landscapes*, *3*(2), 95–103.
- Chowdhury, M. A., Zzaman, R. U., Tarin, N. J., & Hossain, M. J. (2022). Spatial variability of climatic hazards in Bangladesh. *Natural Hazards*, *110*(3), 2329–2351.
- Dagar, J. C., & Tewari, V. P. (2018). Agroforestry: Anecdotal to modern science. *Agroforestry: Anecdotal to Modern Science*, 1–879. <https://doi.org/10.1007/978-981-10-7650-3/COVER>
- Dallmeier, F. (1992). Methods for long-term biodiversity inventory plots in protected tropical forest. *Long-Term Monitoring of Biological Diversity in Tropical Forest Areas: Methods for Establishment and Inventory of Permanent Plot*, 11–46.
- Dastagir, M. R. (2015). Modeling recent climate change induced extreme events in Bangladesh: A review. *Weather and Climate Extremes*, *7*, 49–60.

- Datta, P., & Behera, B. (2023). Climate change adaptation through agroforestry: empirical evidence from Indian Eastern Himalayan Foothills. In *Strategizing agricultural management for climate change mitigation and adaptation* (pp. 167–181). Springer.
- Desmiwati, D., Veriasa, T. O., Aminah, A., Safitri, A. D., Hendarto, K. A., Wisudayati, T. A., Royani, H., Dewi, K. H., Raharjo, S. N. I., & Sari, D. R. (2021). Contribution of agroforestry systems to farmer income in state forest areas: A case study of Parungpanjang, Indonesia. *Forest and Society*, 5(1), 109–119. <https://doi.org/10.24259/fs.v5i1.11223>
- Eggleston, H. S., Buendia, L., Miwa, K., Ngara, T., & Tanabe, K. (2006). *2006 IPCC guidelines for national greenhouse gas inventories*.
- FAHMIDA, M. (2017). *ANALYSIS OF EVAPOTRNSPIRATION AND RAINFALL FOR AMAN RICE CULTIVATION IN DINAJPUR, BANGLADESH*. HAJEE MOHAMMOD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY, DINAJPUR.
- Fischer, G., Shah, M., N. Tubiello, F., & Van Velhuizen, H. (2005). Socio-economic and climate change impacts on agriculture: an integrated assessment, 1990–2080. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 360(1463), 2067–2083.
- Garrett, H., Jose, S., & Gold, M. (2022). *North american agroforestry*. <https://books.google.com/books?hl=en&lr=&id=GYVUEAAAQBAJ&oi=fnd&pg=PA1&ots=2qcBMPiMpF&sig=NSnPuSjGeceMFJ6CUIM9D1KEuZ4>
- Ghale, B., Mitra, E., Sodhi, H. S., Verma, A. K., & Kumar, S. (2022). Carbon sequestration potential of agroforestry systems and its potential in climate change mitigation. *Water, Air, & Soil Pollution*, 233(7), 228.
- Habib, M. E., & Huda, M. E. (2022). Estimation of carbon sequestration in a forest: a case study of Bhawal National Park, Gazipur. *Asian Journal of Research in Agriculture and Forestry*, 8, 19–31.
- Hangarge, L. M., Kulkarni, D. K., Gaikwad, V. B., Mahajan, D. M., & Chaudhari, N. (2012). Carbon sequestration potential of tree species in somjaichi rai (sacred grove) at nandghur village, in bhor region of pune district, Maharashtra state, India. *Annals of Biological Research*, 3(7), 3426–3429.

- Hanif, M. A., Bari, M. S., & Rahman, A. (2015). Potentiality of carbon sequestration by agroforestry species in Bangladesh. *Research on Crops*, *16*(3), 562–567.
- Hanif, M. A., Roy, R. M., Bari, M. S., Ray, P. C., Rahman, M. S., & Hasan, M. F. (2018). Livelihood improvements through agroforestry: Evidence from Northern Bangladesh. *Small-Scale Forestry*, *17*, 505–522.
- Hasan, M. K., Roshni, N. A., & Akter, R. (2024). *Estimating carbon stocks and woody perennials diversity in cropland agroforestry practiced at three different land ecosystems in Bangladesh*.
- Hasan, M. K., Roshni, N. A., & Akter, R. (2025). Estimating carbon stocks and woody perennials diversity in cropland agroforestry on three different land ecosystems in Bangladesh. *Carbon Balance and Management*, *20*(1), 3.
- Hasanuzzaman, M., Hossain, M., & Saroar, M. (2014). Diversity and preference of agricultural crops in the cropland agroforests of southwestern Bangladesh. *International Journal of Agriculture and Crop Sciences*, *7*(7), 364–372.
- Hernández, J., del Pino, A., Vance, E. D., Califra, Á., Del Giorgio, F., Martínez, L., & González-Barrios, P. (2016). Eucalyptus and Pinus stand density effects on soil carbon sequestration. *Forest Ecology and Management*, *368*, 28–38.
- Howlett, D. S., Mosquera-Losada, M. R., Nair, P. K. R., Nair, V. D., & Rigueiro-Rodríguez, A. (2011). Soil Carbon Storage in Silvopastoral Systems and a Treeless Pasture in Northwestern Spain. *Journal of Environmental Quality*, *40*(3), 825–832. <https://doi.org/10.2134/JEQ2010.0145>
- Islam, K. K., Saifullah, M., & Hyakumura, K. (2021). Does traditional Agroforestry a sustainable production system in Bangladesh? An analysis of socioeconomic and ecological perspectives. *Conservation*, *1*(1), 21–35.
- Islam, M. B., Ali, M. Y., Amin, M., & Zaman, S. M. (2011). Climatic variations: farming systems and livelihoods in the high barind tract and coastal areas of Bangladesh. *Climate Change and Food Security in South Asia*, 477–497.
- Islam, M., Dey, A., & Rahman, M. (2015). Effect of Tree Diversity on Soil Organic Carbon Content in the Homegarden Agroforestry System of North-Eastern Bangladesh. *Small-*

*Scale Forestry*, 14(1), 91–101. <https://doi.org/10.1007/S11842-014-9275-5/METRICS>

Islam, M. S., Tripty, N. Y., Abdullah, H. M., & Rahman, M. M. (2023a). Assessment of Farmers Perception and Problems towards Adoption of Agroforestry Practices in Coastal Area of Bangladesh: A Study in Noakhali District. *European Journal of Agriculture and Food Sciences*, 5(6), 48–55. <https://doi.org/10.24018/EJFOOD.2023.5.6.742>

Islam, M. S., Tripty, N. Y., Abdullah, H. M., & Rahman, M. M. (2023b). Assessment of Farmers Perception and Problems towards Adoption of Agroforestry Practices in Coastal Area of Bangladesh: A Study in Noakhali District. *European Journal of Agriculture and Food Sciences*, 5(6), 48–55.

Islam, M. S., Tusher, T. R., Kabir, M. H., Hassan, M. R., & Khan, M. N. H. (2016). Carbon storage and sequestration potentiality of tree species in Madhupur Sal Forest of Bangladesh. *Bangladesh J. Environ. Sci*, 30(2012), 33–39.

Jahan, H., Rahman, M. W., Islam, M. S., Rezwan-Al-Ramim, A., Tuhin, M. M.-U.-J., & Hossain, M. E. (2022). Adoption of agroforestry practices in Bangladesh as a climate change mitigation option: Investment, drivers, and SWOT analysis perspectives. *Environmental Challenges*, 7, 100509.

Jahan, H., Rahman, M. W., Rezwan-Al-Ramim, A., & ... (2022). AGROFORESTRY PRACTICES IN BANGLADESH: PERSPECTIVES ON KNOWLEDGE, PERCEPTION, AND ECONOMIC BENEFITS: Agroforestry practices in .... *Farm ...*, XVII(June), 117–137. <https://fe.baea.org.bd/index.php/home/article/view/11%0Ahttps://fe.baea.org.bd/index.php/home/article/download/11/9>

Jaman, M. S., Hossain, M. F., Islam, M. S., Helal, M. G. J., Jamil, M., & Rahman, M. M. (2016). Quantification of carbon stock and tree diversity of homegardens in Rangpur District, Bangladesh. *Int. J. Agric. For*, 6(5), 169–180.

Jaman, M. S., Muraina, T. O., Dam, Q., Zhang, X., Jamil, M., Bhattarai, S., & Islam, F. (2021). Effects of single and mixed plant types on soil carbon and nitrogen dynamics in homestead agroforestry systems in Northern Bangladesh. *Agriculture, Ecosystems & Environment*, 315, 107434.

- Jhariya, M. K., Banerjee, A., Yadav, D. K., & Raj, A. (2019). Agroforestry and Climate Change: Issues, Challenges, and the Way Forward. *Agroforestry and Climate Change*, 1–34. <https://doi.org/10.1201/9780429057274-1>
- Jinger, D., Kumar, R., Kakade, V., Dinesh, D., Singh, G., Pande, V. C., Bhatnagar, P. R., Rao, B. K., Vishwakarma, A. K., & Kumar, D. (2022). Agroforestry for controlling soil erosion and enhancing system productivity in ravine lands of Western India under climate change scenario. *Environmental Monitoring and Assessment*, 194(4), 267.
- Jumiyati, S., & Frimawaty, E. (2024). APPLICATION OF EDU-AGROTOURISM AND AGROFORESTRY: PATTERNS OF LAND USE ON CONSERVATION IN THE BUFFER AREA. *International Journal of Conservation Science*, 15(1), 657–672.
- Karim, F., Mainuddin, M., Hasan, M., & Kirby, M. (2020). Assessing the Potential Impacts of Climate Changes on Rainfall and Evapotranspiration in the Northwest Region of Bangladesh. *Climate 2020*, Vol. 8, Page 94, 8(8), 94. <https://doi.org/10.3390/CLI8080094>
- Kreft, S., Eckstein, D., & Melchior, I. (2016). *Global climate risk index 2017. Who suffers most from extreme weather events? Weather-related loss events in 2015 and 1996 to 2015.*
- Kumar, A., Singh, V., Shabnam, S., & Oraon, P. R. (2020). Carbon emission, sequestration, credit and economics of wheat under poplar based agroforestry system. *Carbon Management*, 11(6), 673–679.
- Margalef, R. (1973). *Information theory in ecology.*
- Matocha, J., Schroth, G., Hills, T., & Hole, D. (2012). *Integrating Climate Change Adaptation and Mitigation Through Agroforestry and Ecosystem Conservation.* 105–126. [https://doi.org/10.1007/978-94-007-4676-3\\_9](https://doi.org/10.1007/978-94-007-4676-3_9)
- Mbow, C., Van Noordwijk, M., Luedeling, E., Neufeldt, H., Minang, P. A., & Kowero, G. (2014). Agroforestry solutions to address food security and climate change challenges in Africa. *Current Opinion in Environmental Sustainability*, 6(1), 61–67. <https://doi.org/10.1016/J.COSUST.2013.10.014>
- McNeely, J. A., & Schroth, G. (2006). Agroforestry and biodiversity conservation -

- Traditional practices, present dynamics, and lessons for the future. *Biodiversity and Conservation*, 15(2), 549–554. <https://doi.org/10.1007/S10531-005-2087-3/METRICS>
- Mendelsohn, R. (2007). Chapter 60 Past Climate Change Impacts on Agriculture. *Handbook of Agricultural Economics*, 3, 3009–3031. [https://doi.org/10.1016/S1574-0072\(06\)03060-X](https://doi.org/10.1016/S1574-0072(06)03060-X)
- Mildrexler, D. J., Berner, L. T., Law, B. E., Birdsey, R. A., & Moomaw, W. R. (2020). Large trees dominate carbon storage in forests east of the cascade crest in the United States Pacific Northwest. *Frontiers in Forests and Global Change*, 3, 594274.
- Murthy, I. K., Gupta, M., Tomar, S., Munsli, M., Tiwari, R., Hegde, G. T., & Ravindranath, N. H. (2013). Carbon sequestration potential of agroforestry systems in India. *J Earth Sci Climate Change*, 4(1), 1–7.
- Nair, P. K. R. (1985). Classification of agroforestry systems. *Agroforestry Systems*, 3(2), 97–128. <https://doi.org/10.1007/BF00122638/METRICS>
- Nair, P. K. R. (2011). Agroforestry Systems and Environmental Quality: Introduction. *Journal of Environmental Quality*, 40(3), 784–790. <https://doi.org/10.2134/JEQ2011.0076>
- Nair, P. K. R., Kumar, B. M., & Nair, V. D. (2021a). Agroforestry for Biodiversity Conservation. *An Introduction to Agroforestry: Four Decades of Scientific Developments*, 539–562. [https://doi.org/10.1007/978-3-030-75358-0\\_21](https://doi.org/10.1007/978-3-030-75358-0_21)
- Nair, P. K. R., Kumar, B. M., & Nair, V. D. (2021b). Classification of Agroforestry Systems. *An Introduction to Agroforestry: Four Decades of Scientific Developments*, 29–44. [https://doi.org/10.1007/978-3-030-75358-0\\_3](https://doi.org/10.1007/978-3-030-75358-0_3)
- Nair, P. K. R., Kumar, B. M., Nair, V. D., Nair, P. K. R., Kumar, B. M., & Nair, V. D. (2021). Definition and concepts of agroforestry. *An Introduction to Agroforestry: Four Decades of Scientific Developments*, 21–28.
- Nair, P. K. R., Nair, V. D., Kumar, B. M., & Showalter, J. M. (2010). Carbon sequestration in agroforestry systems. *Advances in Agronomy*, 108, 237–307.
- Nath, A., Sileshi, G., Laskar, S., ... K. P.-J. of C., & 2021, undefined. (n.d.). Quantifying carbon stocks and sequestration potential in agroforestry systems under divergent

management scenarios relevant to India's Nationally Determined. *ElsevierAJ Nath, GW Sileshi, SY Laskar, K Pathak, D Reang, A Nath, AK DasJournal of Cleaner Production, 2021•Elsevier.* Retrieved November 3, 2024, from <https://www.sciencedirect.com/science/article/pii/S0959652620348757>

Nelson, G. C., Rosegrant, M. W., Koo, J., Robertson, R., Sulser, T., Zhu, T., Ringler, C., Msangi, S., Palazzo, A., & Batka, M. (2009). *Climate change: Impact on agriculture and costs of adaptation* (Vol. 21). Intl Food Policy Res Inst.

Pakhom, M. N. J., Rahman, M. S., Bari, M. S., & Dhar, M. (2020). Carbon sequestration potentiality of different cropland agroforestry systems in Dinajpur district. *Journal of Science and Technology, 43*, 52.

Picasso, V., & Pizarro, D. (2024). Silvopastoral transitions in Latin America: toward diverse perennial systems. *Agroforestry Systems, 98*(7), 2267–2272.

Plieninger, T., Muñoz-Rojas, J., Buck, L. E., & Scherr, S. J. (2020). Agroforestry for sustainable landscape management. *Sustainability Science, 15*(5), 1255–1266. <https://doi.org/10.1007/S11625-020-00836-4/FIGURES/2>

Quandt, A., Neufeldt, H., & Gorman, K. (2023). Climate change adaptation through agroforestry: opportunities and gaps. *Current Opinion in Environmental Sustainability, 60*, 101244.

Racelis, E., Racelis, D., & Luna, A. (2019). Carbon sequestration by large leaf mahogany (*Swietenia macrophylla* King.) plantation in Mount Makiling forest reserve, Philippines: A decade after. *Journal of Environmental Science and Management, 22*(1).

Rahman, M. R., Hossain, M. K., & Hossain, M. A. (2019). Diversity and composition of tree species in Madhupur national park, tangail, Bangladesh. *Journal of Forest and Environmental Science, 35*(3), 159–172.

Rahman, M. S., Roy, P. R., Ali, M. M., Bari, M. S., Sarmin, I. J., & Rahman, M. A. (2020). Cost-benefit analysis of different agroforestry systems and practices of Kaharole Upazila of Dinajpur District, Bangladesh. *South Asian J. Soc. Stud. Econ, 87–97*.

Rahman, S. A., Foli, S., Pavel, M. A., Mamun, M. A., & Sunderland, T. (2015). Forest, trees and agroforestry: Better livelihoods and ecosystem services from multifunctional

- landscapes. *Int. J. Dev. Sustain*, 4, 479–491.
- Rahman, S., Jama Ali, A., & Raihan, A. (2022). Soil carbon sequestration in agroforestry systems as a mitigation strategy of climate change: a case study from Dinajpur, Bangladesh. *Advances in Environmental and Engineering Research*, 3(4), 1–13.
- Ramachandran Nair, P. K., Mohan Kumar, B., & Nair, V. D. (2009). Agroforestry as a strategy for carbon sequestration. *Journal of Plant Nutrition and Soil Science*, 172(1), 10–23.
- Rana, M. M. P., & Moniruzzaman, M. (2021). Transformative adaptation in agriculture: A case of agroforestation in Bangladesh. *Environmental Challenges*, 2, 100026.
- Reppin, S., Kuyah, S., de Neergaard, A., Oelofse, M., & Rosenstock, T. S. (2020). Contribution of agroforestry to climate change mitigation and livelihoods in Western Kenya. *Agroforestry Systems*, 94(1), 203–220. <https://doi.org/10.1007/s10457-019-00383-7>
- Roshni, N. A., Hasan, M. K., Wadud, M. A., Hasan, A. K., Akter, R., Khan, R. N. A., & Hemel, S. A. K. (2023). Toxic Metal Levels in Forest Soils Caused by Industrialization and Impacts on Tree Biomass Carbon Stock. *Environmental Processes*, 10(3), 45.
- Ruane, A. C., Major, D. C., Yu, W. H., Alam, M., Hussain, S. G., Khan, A. S., Hassan, A., Hossain, B. M. T. Al, Goldberg, R., Horton, R. M., & Rosenzweig, C. (2013). Multi-factor impact analysis of agricultural production in Bangladesh with climate change. *Global Environmental Change*, 23(1), 338–350. <https://doi.org/10.1016/J.GLOENVCHA.2012.09.001>
- Ruba, U. B., & Talucder, M. S. A. (2023). Potentiality of homestead agroforestry for achieving sustainable development goals: Bangladesh perspectives. *Heliyon*, 9(3).
- Saha, S., Hasan, T., Maukeeb, A. B. U. R. M. D., Sarker, M., & Haque, A. R. (2022). Agroforestry Practices for Sustainable Production in Bangladesh: A Review. *Asian Journal of Advances in Research*, 5(1), 186–203.
- Sahu, C., Nayak, H. N., & Sahu, S. K. (2020). Carbon sequestration potential of trees in an urban area: a case study of sambalpur town in eastern india. *Fresenius Environmental Bulletin*, 29(10), 8757–8766.

- Sapkota, T., Vetter, S., Jat, M., ... S. S.-S. of the T., & 2019, undefined. (n.d.). Cost-effective opportunities for climate change mitigation in Indian agriculture. *ElsevierTB Sapkota, SH Vetter, ML Jat, S Sirohi, PB Shirsath, R Singh, HS Jat, P Smith, J HillierScience of the Total Environment, 2019•Elsevier*. Retrieved November 3, 2024, from <https://www.sciencedirect.com/science/article/pii/S0048969718345819>
- Shakhawat Hossain, M., Arshad, M., Qian, L., Kächele, H., Khan, I., Din Il Islam, M., & Golam Mahboob, M. (2020). Climate change impacts on farmland value in Bangladesh. *Ecological Indicators, 112*, 106181. <https://doi.org/10.1016/J.ECOLIND.2020.106181>
- Shannon CB, W. W. (1963). *The Mathematical Theory of Communication*. Urbana (Illinois). Univ. of Illinois Press.
- Shukla, R. S., & Chandel, P. S. (1994). *Plant ecology and soil science*. S. Chand.
- Siarudin, M., Rahman, S. A., Artati, Y., Indrajaya, Y., Narulita, S., Ardha, M. J., & Larjavaara, M. (2021). Carbon sequestration potential of agroforestry systems in degraded landscapes in West Java, Indonesia. *Forests, 12*(6), 714.
- Sikder, R., & Xiaoying, J. (2014). Climate Change Impact and Agriculture of Bangladesh. *Journal of Environment and Earth Science, 4*(1), 35–40. <http://www.iiste.org/Journals/index.php/JEES/article/view/10247>
- Sina, I., & Zulkarnaen, I. (2019). Margalef Index, Simpson Index and Shannon-Weaver Index calculation for diversity and abundance of beetle in tropical forest. *STATMAT: JURNAL STATISTIKA DAN MATEMATIKA, 1*(2).
- Syeda, J. A., & Nasser, M. (2012). Farmers Perception Regarding Climate Change and Crop Production, Especially for Wheat in Dinajpur District. *Journal of Environmental Science and Natural Resources, 5*(2), 129–136.
- Telwala, Y. (2023). Unlocking the potential of agroforestry as a nature-based solution for localizing sustainable development goals: a case study from a drought-prone region in rural India. *Nature-Based Solutions, 3*, 100045.
- Thomas, T. S., Mainuddin, K., Chiang, C., Rahman, A., Haque, A., Islam, N., Quasem, S., & Sun, Y. (2013). *Agriculture and adaptation in Bangladesh: Current and projected impacts of climate change* (Vol. 1281). Intl Food Policy Res Inst.

- Tonucci, R. G., Nair, P. K. R., Nair, V. D., Garcia, R., & Bernardino, F. S. (2011). Soil Carbon Storage in Silvopasture and Related Land-Use Systems in the Brazilian Cerrado. *Journal of Environmental Quality*, 40(3), 833–841. <https://doi.org/10.2134/JEQ2010.0162>
- Toppo, P., & Raj, A. (2018). Role of agroforestry in climate change mitigation. *Journal of Pharmacognosy and Phytochemistry*, 7(2), 241–243. <http://worldagroforestry.org/newsroom/highlights/survivi>
- Torquebiau, E. F. (2000). A renewed perspective on agroforestry concepts and classification. *Comptes Rendus de l'Académie Des Sciences - Series III - Sciences de La Vie*, 323(11), 1009–1017. [https://doi.org/10.1016/S0764-4469\(00\)01239-7](https://doi.org/10.1016/S0764-4469(00)01239-7)
- Udawatta, R. P., Rankoth, L. M., & Jose, S. (2019). Agroforestry and biodiversity. *Sustainability*, 11(10), 2879.
- Udawatta, R. P., Rankoth, L. M., & Jose, S. (2021). Agroforestry for biodiversity conservation. *Agroforestry and Ecosystem Services*, 245–274.
- Van Noordwijk, M. (2018). Agroforestry as part of climate change response. *IOP Conference Series: Earth and Environmental Science*, 200(1), 12002.
- van Noordwijk, M., Coe, R., Sinclair, F. L., Luedeling, E., Bayala, J., Muthuri, C. W., Cooper, P., Kindt, R., Duguma, L., Lamanna, C., & Minang, P. A. (2021). Climate change adaptation in and through agroforestry: four decades of research initiated by Peter Huxley. *Mitigation and Adaptation Strategies for Global Change* 26:5, 26(5), 1–33. <https://doi.org/10.1007/S11027-021-09954-5>
- Yirga, S. A. (2019). Agroforestry for Sustainable Agriculture and Climate Change: A Review. *International Journal of Environmental Sciences & Natural Resources*, 19(5). <https://doi.org/10.19080/ijesnr.2019.19.556022>
- Zanne, A. E. (2009). Global wood density database. *Dryad*.

## APPENDIX

### APPENDIX I

**Table showing Farming experience of the respondents in the study area**

Characteristics	Scoring method	Ranged observed	Categories	Respondents		Mean	SD
				No.	Percent		
Farming experience	Years	4-45	Two decades (<20 years)	46	73	18.33	9.89
			Four deacades (20-40 Years)	15	23.8		
			Above Four (>40 years)	2	3.2		
Agroforestry Farming experience	Years	3-40	Two decades (<20 years)	61	96.8	9.43	5.94
			Four deacades (20-40 Years)	2	3.2		
			Above Four (>40 years)	0	0		

### APPENDIX II

**Pivot table for multiple response analysis: Observed climatic changes by respondents**

Code Labels	%
<b>0</b>	<b>41.27%</b>
0	26.98%
3	26.98%
<b>2</b>	<b>14.29%</b>
0	4.76%
3	9.52%
<b>1</b>	<b>58.73%</b>
0	23.81%
0	1.59%
3	22.22%
<b>2</b>	<b>34.92%</b>
0	6.35%
3	28.57%
<b>Grand Total</b>	<b>100.00%</b>

Code	Climatic changes	%
1-0-0	Increased temperature	1.59
0-2-0	Irregular rainfall	4.76
0-0-3	Prolonged droughts	26.99
0-2-3	Irregular rainfall and prolonged drought	9.52
1-0-3	Increase temp and Prolonged drought	22.22
1-2-0	Increase temp and irregular rainfall	6.35
1-2-3	Increase temp + Irregular rainfall + Prolonged drought	28.57

Here, 1= Increased temperature; 2= Irregular rainfall; 3= prolonged drought

### APPENDIX III

#### Pivot table for multiple response analysis: Intension of Planting trees in Crop field

Code Labels	%
<b>0</b>	<b>17.46%</b>
0	9.52%
0	9.52%
4	9.52%
<b>2</b>	<b>7.94%</b>
0	6.35%
0	1.59%
4	4.76%
3	1.59%
4	1.59%
<b>1</b>	<b>82.54%</b>
<b>0</b>	<b>39.68%</b>
0	38.10%
0	15.87%
4	22.22%
3	1.59%
0	1.59%
<b>2</b>	<b>42.86%</b>
0	31.75%
0	25.40%
4	6.35%
3	11.11%
0	7.94%
4	3.17%
<b>Grand Total</b>	<b>100.00%</b>

Code	Intension	%
0-0-0-4	Only wood	9.52
0-2-0-0	Only fruit	1.59
0-0-3-0	Only Fuelwood	0.00
0-2-0-4	Fruit + Wood	4.76
0-2-3-4	Fruit + Fuelwood + Wood	1.59
1-0-0-0	Only Income	15.87
1-0-0-4	Income + Wood	22.22
1-0-3-0	Income + Fuelwood	1.59
1-2-0-0	Income + Fruit	25.4
1-2-0-4	Income + Fruit + wood	6.35
1-2-3-0	Income + Fruit + Fuelwood	7.94
1-2-3-4	Income +Fruit +Fuelwood +Wood	3.17

Here, 1= Income generation; 2= Fruit Consumption; 3= Fuelwood; 4= Commercial sale of wood

### APPENDIX IV

#### Perceived affects of climate change in farming practices

Affects	No. of response	% of grand total
More irrigation	45	71.4
More Fertilizer	14	22.2
More pesticide	16	25.4
Lower production	19	30.2
More labor	15	23.8
More input cost	33	52.4

## APPENDIX V

### Problem Finding Index (PFI) for ranking Barriers / Challenges to adopt agroforestry practices

<b>Problems</b>	<b>PFI</b>
Lack of market access for tree products	119.0
Pests and diseases	158.7
Allelopathic effect	160.3
Lack of planting materials	192.1
Less production	201.6
Lack of technical knowledge	241.3
Water scarcity	244.4
Insufficient land	246.0
Financial constraints	249.2
Competition for nutrients	254.0
Shade created by trees	258.7
Lack of government/NGO support	260.3
Lack of training	282.5

## APPENDIX VI

### Policy change suggestion to promote agroforestry

<b>Policy recommendation</b>	<b>%</b>
Strengthen extension services and training	92.06349
Ensure access to quality planting materials	58.73016
Provide financial incentives and credit facilities	85.71429
Integrate agroforestry into national climate plans	63.49206
Improve market access for agroforestry products	42.85714

## APPENDIX VII

### Total number of woody perennial individuals in cropland agroforestry practices and their IVI

Sl no.	Name of Species	No. of quadrates in which the species occur	No. of individuals
1	<i>Litchi chinensis</i>	19	77
2	<i>Mangifera indica</i>	24	114
3	<i>Areca catechu</i>	26	263
4	<i>Eucalyptus camaldulensis</i>	21	103
5	<i>Swietenia macrophylla</i>	18	64
6	<i>Moringa oleifera</i>	10	42
7	<i>Azadirachta indica</i>	3	3
8	<i>Artocarpus heterophyllus</i>	9	16
9	<i>Ziziphus jujuba</i>	1	6
10	<i>Citrus sinensis</i>	5	22
11	<i>Cinnamomum tamala</i>	1	3
12	<i>Syzygium cumini</i>	1	1
13	<i>Bombax ceiba</i>	1	1

Total = 715

<i>Sp. no.</i>	1	2	3	4	5	6	7	8	9	10	11	12	13
Density (tree/ha)	30.56	45.24	104.37	40.87	25.40	16.67	1.19	6.35	2.38	8.73	1.19	0.40	0.40
RD (%)	10.77	15.94	36.78	14.41	8.95	5.87	0.42	2.24	0.84	3.08	0.42	0.14	0.14
Frequency (%)	30.16	38.10	41.27	33.33	28.57	15.87	4.76	14.29	1.59	7.94	1.59	1.59	1.59
RF (%)	13.67	17.27	18.71	15.11	12.95	7.19	2.16	6.47	0.72	3.60	0.72	0.72	0.72
Basal area (m <sup>2</sup> )	1.27	2.03	3.60	7.04	7.64	0.78	0.18	3.23	0.14	0.21	0.03	0.03	0.28
RD <sub>0</sub> (%)	4.82	7.68	13.59	26.61	28.89	2.95	0.68	12.21	0.53	0.78	0.11	0.12	1.04
Importance value index (IVI)	29.25	40.89	69.08	56.12	50.79	16.02	3.26	20.92	2.09	7.45	1.25	0.98	1.90

## APPENDIX VIII

### Mean DBH & Height of Woody Perennial Species

Species name	DBH (cm)	Height (m)
<i>Litchi chinensis</i>	13.22 ± 0.88	5.01 ± 0.36
<i>Mangifera indica</i>	14.83 ± 3.36	5.26 ± 0.98
<i>Areca catechu</i>	13.35 ± 0.10	11.53 ± 0.29
<i>Eucalyptus camaldulensis</i>	27.66 ± 1.42	21.62 ± 0.77
<i>Swietenia macrophylla</i>	36.07 ± 1.14	18.82 ± 0.63
<i>Moringa oleifera</i>	14.78 ± 0.67	11.06 ± 0.40
<i>Azadirachta indica</i>	26.63 ± 5.17	14.67 ± 2.40
<i>Artocarpus heterophyllus</i>	49.20 ± 3.15	18.16 ± 1.49
<i>Ziziphus jujuba</i>	18.91 ± 0.54	5.18 ± 0.25
<i>Citrus sinensis</i>	11.56 ± 0.48	4.81 ± 0.15
<i>Cinnamomum tamala</i>	10.82 ± 0.97	7.80 ± 0.12
CV (%)	33.84	38.68

### ANOVA table for DBH

Source	DF	Sum of Square	Mean Square	F Value	Pr(> F)
Species.name	10	67810.1625	6781.0162	197.04	0.0000
Error	1079	37133.7619	34.4150		
Total	1089	104943.9243			

### ANOVA table for Height

Source	DF	Sum of Square	Mean Square	F Value	Pr(> F)
Species.name	10	22476.3178	2247.6318	107.01	0.0000
Error	677	14219.1058	21.0031		
Total	687	36695.4235			

## APPENDIX IX

### Basal Area and Stand Density of Woody Perennials of cropland agroforestry in the study area

Species name	Basal area (m <sup>2</sup> /ha)	Stand density (tree/ha)
<i>Litchi chinensis</i>	1.7	30.56
<i>Mangifera indica</i>	2.1	45.24
<i>Areca catechu</i>	3.5	104.37
<i>Eucalyptus camaldulensis</i>	8.4	40.87
<i>Swietenia macrophylla</i>	10.6	25.40
<i>Moringa oleifera</i>	2.0	16.67
<i>Azadirachta indica</i>	1.5	1.19
<i>Artocarpus heterophyllus</i>	8.97	6.35
<i>Ziziphus jujuba</i>	3.52	2.38
<i>Citrus sinensis</i>	1.03	8.73

## APPENDIX X

### Wood specific gravity (g cm<sup>-3</sup>) of woody perennials of cropland agroforestry in the study area (Source: Global wood density database)

Name of species	Wood density (g/cm <sup>3</sup> ), oven dry mass/fresh volume
<i>Litchi chinensis</i>	0.960
<i>Mangifera indica</i>	0.680
<i>Eucalyptus camaldulensis</i>	0.916
<i>Swietenia macrophylla</i>	0.490
<i>Swietenia macrophylla</i>	0.510
<i>Moringa oleifera</i>	0.262
<i>Azadirachta indica</i>	0.660
<i>Artocarpus heterophyllus</i>	0.551
<i>Ziziphus jujuba</i>	0.920
<i>Citrus sinensis</i>	0.780
<i>Cinnamomum tamala</i>	0.640
<i>Syzygium cumini</i>	0.760
<i>Bombax ceiba</i>	0.350

## APPENDIX XI

### Mean Above Ground Biomass (AGB) of Woody perennials of Cropland Agroforestry practices in the study area

Name of Species	AGB (kg/individual)
<i>Areca catechu</i>	110.92 ± 2.47
<i>Litchi chinensis</i>	104.80 ± 23.92
<i>Mangifera indica</i>	51.91 ± 3.27
<i>Eucalyptus camaldulensis</i>	1401.31 ± 152.66
<i>Swietenia macrophylla</i>	859.97 ± 72.69
<i>Moringa oleifera</i>	42.27 ± 4.66
<i>Azadirachta indica</i>	476.14 ± 191.73
<i>Artocarpus heterophyllus</i>	1635.43 ± 265.97
<i>Ziziphus jujuba</i>	102.45 ± 10.34
<i>Citrus sinensis</i>	30.99 ± 2.82
<i>Cinnamomum tamala</i>	35.53 ± 7.04
<i>Syzygium cumini</i>	181.85 ± 0.00
<i>Bombax ceiba</i>	59.21 ± 0.00
CV (%)	155.49

### ANOVA for Above Ground Biomass (AGB) of Woody perennials of Cropland Agroforestry practices in the study area

Source	DF	Sum of Square	Mean Square	F Value	Pr(> F)
Species.name	9	182644468.8169	20293829.8685	56.63	0.0000
Error	675	241871008.7066	358327.4203		
Total	684	424515477.5235			

## APPENDIX XII

### ANOVA: Regression analysis between DBH (cm/individual) & Carbon stock (kg/individual)

	df	SS	MS	F	P
Regression	1	1.22E+08	1.22E+08	1741.095	1.2E-190
Residual	713	48025148	69803.99		
Total	714	1.7E+08			

**ANOVA: Regression analysis between Height (m/individual) & Carbon stock (kg/individual)**

	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>P</i>
Regression	1	95542120	95542120	888.0626	5.9E-126
Residual	713	74018404	107584.9		
Total	714	1.7E+08			

**ANOVA: Regression analysis between Basal area (m<sup>2</sup>/individual) & Carbon stock (kg/individual)**

	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>P</i>
Regression	1	1.27E+08	1.27E+08	2071.111	1.1E-209
Residual	713	42280876	61454.76		
Total	714	1.7E+08			

**ANOVA: Regression analysis between Stand density (tree/ha) & Carbon stock (Mg/ha)**

	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>P</i>
Regression	1	134.8995	134.8995	1.588874	0.233569
Residual	11	933.9287	84.90261		
Total	12	1068.828			

## APPENDIX XIII

### An interview schedule on

**Farmers perception on Cropland Agroforestry practices and its role to mitigate climate change impact**

SI No. : Upazilla :

Name of the respondent : Occupation :

Village : GIS :

Union :

1. Age	2. Family size		3. Farming experience	4. AGF farming experience
	Male	Female		

#### 5. Education level:

- a. Cannot read & write (yes/no)
- b. Can sign only (yes/no)
- c. Primary/ secondary/ Higher (Class.....)

#### 6. Farm size:

Sl. No.	Use	Local unit	Hectare
	Homestead area		
	Own land under own cultivation		
	Land taken from others as lease		
	Land taken from others as borga		
	Land given others as borga		
	Land use under AGF		
	Total land		

#### 7. Agroforestry Practices (YES/NO)

Type of Agroforestry		Area (if yes)
Homestead agroforestry	Yes/No	
Cropland agroforestry	Yes/No	
Mixed fruit gardens	Yes/No	
Other.....	Yes/No	

#### 8. Planting system of trees in cropland

- Scattered
- Strip
- Boundary

**9. Why you intended to plant trees in crop field?**

- Income generation
- Fruit consumption
- Fuelwood
- Commercial sale of wood

**10. Changes in Productivity since adopting AGF**

Any changes in the productivity since adopting AGF	
Maximum	
Minimum	
No change	

**11. Perceived effects of climate change and benefits of agroforestry in relation to climate change**

(i) **A. Have you noticed any changes in the climate in recent years? (Yes/ No)**  
**If yes, what kind of changes have you noticed?**

- Increased temperature
- Irregular rainfall
- Prolonged droughts
- Increased flooding
- Other

**B. Has climate change affected your farming practices? (Yes/ No)**

**If yes, explain**

- More irrigation
- More Fertilizer
- More pesticide
- Lower production
- More labor
- More input cost

**ii) What are the main benefits you have experienced from agroforestry in relation to climate change?**

SL No	Main benefits	Extent of benefits			
		High	Medium	Low	No
1	Improved soil fertility				
2	Enhanced water retention				
3	Increased resilience to drought				
4	Carbon sequestration				
5	Protection from strong winds				
6	Increased biodiversity				
7	Other				

### 12. Barriers and Challenges faced by respondents in Agroforestry Adoption

Barriers/Challenges	Extent of problems			
	High	Medium	Low	No
Lack of technical knowledge				
Insufficient land				
Lack of planting materials				
Financial constraints				
Lack of government/NGO support				
Pests and diseases				
Allelopathic effect				
Shade created by trees				
Lack of market access for tree products				
Competition for nutrients				
Less production				
Water scarcity				
Lack of training				

### 13. Access to policy support services

Supports/Services	Extent of reception			
	Regular	Frequent	Occasional	Never
Training on agroforestry				
Access to seedlings				
Technical advice on agroforestry management				
Financial support				
Market access assistance				
Other				

### 14. What policy changes would you suggest to promote agroforestry?

---

.....

Signature of the interviewer

#### Appendix XIV: Photographs of study site



Purbo Shadipur, 5 no. Sundorpur, Kaharole



Helenchakuri, 5 no. Sundorpur, Kaharole



Uttarpara, 5 no. Sundorpur, Kaharole



Khalpara, 5 no. Sundorpur, Kaharole

**Captured moments while interviewing with respondents**



**Boundary plantation of Woody Perennials**



**Scattered Plantation**



**Strip Plantation**