Carbon Sequestration Potentiality in Three Agro-ecological Zones of Bangladesh under Different Agroforestry Systems

A THESIS

BY

MOBASWARATUN JANNAT NONY
Student No. 1805101
Session: 2018
Semester: July-December, 2019

MASTER OF SCIENCE (M.S.)
IN
AGROFORESTRY AND ENVIRONMENT

DEPARTMENT OF AGROFORESTRY AND ENVIRONMENT

HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY, DINAJPUR-5200

DECEMBER, 2019

Carbon Sequestration Potentiality in Three Agro-ecological Zones of Bangladesh under Different Agroforestry Systems

A THESIS

BY

MOBASWARATUN JANNAT NONY
Student No. 1805101
Session: 2018
Semester: July-December, 2019

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-5200

DECEMBER, 2019

Carbon Sequestration Potentiality in Three Agro-ecological Zonses of Bangladesh under Different Agroforestry Systems

A THESIS

BY

MOBASWARATUN JANNAT NONY
Student No. 1805101
Session: 2018
Semester: July-December, 2019

Approved as to style and contents by

....
Prof. Dr. Md. Shafiqul Bari
Supervisor

....
Prof. Dr. Md. Shoaibur Rahman
Co-Supervisor

....
Prof. Dr. Md. Shoaibur Rahman
Chairman
Examination Committee
And
Chairman

DEPARTMENT OF AGROFORESTRY AND ENVIRONMENT

HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY

UNIVERSITY, DINAJPUR-5200

DECEMBER, 2019

DEDICATED

TO MY

BELOVED PARENTS

&

HONORABLE TEACHERS

ACKNOWLEDGEMENTS

All the praises, gratitude and thanks are due to the omniscient, omnipresent and omnipotent Allah who enabled me to pursue education in Agriculture discipline and to complete this thesis for the degree of Master of Science (MS) in Agroforestry and Environmental Science. I wish to express my sincere appreciation, profound gratitude and best regards to my supervisor, Prof. Dr. Md. Shafiqul Bari, Department of Agroforestry and Environment, Hajee Mohammad Danesh Science and Technology University, Dinajpur, for his guidance and supervision in carrying out the research work, continuous inspiration, constructive comments and encouragement during my research work and guidance in preparation of manuscript of the thesis.

I am grateful to my co-supervisor Prof. Dr. Md. Shoaibur Rahman, Chairman, Department of Agroforestry and Environment, Hajee Mohammad Danesh Science and Technology University, Dinajpur, for his co-operation and helpful suggestions to conduct this research work and in the preparation of this manuscript.

I am also grateful to the respected teachers of the Department of Agroforestry and Environment, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Md. Hafiz Al Amin, Md. Abu Hanif and Md. Manik Miah, Assistant Professor, for their endless encouragement during the entire period of studies.

I would like to express my cordial thanks to my friends Md. Sujan Kabir, Mst. Efte Ara and Md. Sakil Rana, for assisting me in the field for data collection. Here I also would like to acknowledge laboratory and field staffs specially Md. Abdul Kuddus for their active help during the research period. The author also express special thanks to the BAS-USDA program in Agriculture and Life Sciences for funding this experiment.

I express my gratefulness to I am indebted to my last but not least profound and grateful gratitude to my beloved parents, friends and all

of my relatives for their inspiration, blessing and encouragement that opened the gate of my higher studies in my life.

The Author

November, 2019

HSTU, Dinajpur

Carbon Sequestration Potentiality in Three Agro-ecological Zones of Bangladesh under Different Agroforestry Systems

ABSTRACT

A field study was conducted to evaluate the carbon sequestration potentiality in different agroforestry systems in the northern part of Bangladesh, Dinajpur districts during October, 2018 to March, 2019. The experiment was laid out in three agro-ecological zones; AEZ 1-Old Himalayan piedmont plain (Birganj), AEZ 3-Tista meander flood plain (Parbotipur) and AEZ 25-Level barind tract (Dinajpur sadar). The Experimental plot was selected randomly in different locations from each experimental unit (AEZ), in a randomized complete block design (RCBD) with four replications. The treatments were: Factor A- five agroforestry systems like homestead, eucalyptus and mahogany cropland based, mango and litchi orchards based agroforestry system and Factor B- three AEZs like AEZ 1, AEZ 3 and AEZ 25. Data were recorded from tree growing parameters (height, diameter at breast height) and under storied vegetation (herbs, shrubs and crops) to estimate the total biomass accumulation and also soil carbon was estimated. In case of the main effect of different agroforestry system on carbon sequestrations, it was observed that there was significantly difference in respect of tree height (m), DBH (cm), no of tree per hectare, under storey vegetation and soil carbon stock (t/ha). The highest total carbon sequestrations (563.12 t/ha) was recorded from homestead agroforestry systems and the lowest (64.66 t/ha) was obtained from mahogany cropland based agroforestry system. In case of soil carbon sequestration, eucalyptus based cropland agroforestry system sequestrated the highest amount (29.92 t/ha) of carbon and mango based orchard agroforestry sequestrated the lowest amount (25.67 t/ha) of carbon. The main effect of agro-ecological zones (AEZ) on carbon sequestrations also significantly varied. The highest amount of carbon (307.56 t/ha) was sequestrated by AEZ 25 and the lowest (159.68 t/ha) was from AEZ 3. Again, in the interaction effect of AEZ and agroforestry systems on carbon sequestrations, the highest carbon sequestration capacity (676.27 t/ha) was found in S_1T_1 (AEZ 1 + homestead agroforestry system) and the lowest (43.87 t/ha) was found in S_2T_3 (AEZ 3 + mahogany based cropland agroforestry system). The findings of this study concluded that among the five agroforestry systems, homestead agroforestry system sequestrated more carbon and a better option for reducing atmospheric carbon. Again, among the three AEZs, AEZ 25 gave the maximum carbon sequestration potentiality. In case of economic value of carbon sequestration, homestead agroforestry system also gave the maximum (29558.5 $/ha) monetary return. Therefore, emphasis should be given in homestead agroforestry systems to get better ecological impact in the northern region of Bangladesh. Moreover, judicious tree plantation program should be done in AEZ3 and AEZ 1 for the equilibrium carbon sequestration capacity among different AEZs.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABBREVIATION AND ACRONYMS

AEZ:	Agro-ecological zone
AGFS:	Agroforestry System
AGB:	Aboveground biomass
AGCS:	Aboveground carbon stock
AGF:	Agroforestry
AGTB:	Above ground tree biomass
ANOVA:	Analysis of variance
BBS:	Bangladesh Bureau of Statistics
BGB:	Belowground biomass
BGCS:	Belowground carbon stock
BGTB:	Belowground tree biomass
C:	Carbon
CDM:	Clean Development Mechanisms
CM:	Centimeters
CO_2:	Carbon dioxide
CSP:	Carbon sequestration potential
CV%:	Coefficients of variation in percentage
DBH :	Diameter at breast height
FAO:	Food and agricultural organizations
GHGs:	Green house gases
IPCC:	Intergovernmental panel on climate change

kg/m^2 : Kilogram per meter square

kg/tree: Kilogram per tree

kg/m^2 C: Kilogram per meter square carbon

LHGB: Leaf litter, herb, grass biomass

LHGCS: Leaf litter, herb, and grass carbon stock

LHGCseq: Leaf litter, herb, and grass carbon sequestration

M: Meters

NT/ha: Number of trees per hectors

RCBD: Randomized complete block design

SOC: Soil organic carbon

t/ha: Ton/hectare

t/ha C: Tone per hectorcarbon

TH: Tree height

TASCseq: Total agroforestry system carbon sequestration

TTB: Total tree biomass

TTCS: Total tree carbon stock

TTCseq: Total tree carbon sequestration

CHAPTER I

INTRODUCTION

Global climate change and biodiversity conservation are the two burning issues which have an immense attention to scientific community and policy makers in the recent decades (Saha *et al*., 2009; IPCC, 2013). Increasing level of atmospheric CO_2 due to burning of fossil fuels, cement production and deforestation is the main driver of climate change. The concentration of CO_2 in the atmosphere has been increasing from starting point of industrial revolution and during the period of 1750-2011, it was raised to 391ppm (IPCC, 2013). A recent prediction reveals that if the rising trend of CO_2 is continue in this manner it would elevate the atmospheric temperature by 2-4.2 °C by the year of 2050 (Anderson and Bows, 2011; IPCC, 2013). It will ultimately induce to melt out of the polar ice which would increase the sea level rise by 5 m and consequently, the coastal region will be adversely affected by saline water particularly in developing countries like Bangladesh (Rahman *et al*., 2014). Also, the livelihoods pattern will be changed that would cause people to migrate towards urban areas (IPCC, 2013). The urban areas has also exhibited with warmer climate than the peri-urban areas due to high level of fossil fuel combustion and elevated proportion of imperious surface (Doygun and Alphan,2006; Weng and Yang, 2006, Liu and Li, 2012). Natural events and human activities are believed to be contributing to an increase in average global temperatures, this is reportedly caused by emission of greenhouse gases (GHGs) through anthropogenic activities including land-use change, deforestation, biomass burning, draining of wetlands, soil cultivation and fossil fuel combustion (Shah, 2013).

Carbon sequestration is the process of capture and long-term storage of atmospheric carbon dioxide to mitigate global warming and to avoid dangerous impacts of climate change (FAO, 2000). It is a natural and deliberate process by which CO_2 is either removed from the atmosphere or diverted from the emission sources and stored in the ocean, terrestrial environments and geologic formation. Carbon sequestration is the removal of carbon from the atmosphere by storing it in atmosphere (IPCC, 2000). Carbon sequestration in soil is the process of transferring CO_2 from the atmosphere into the soil through crop residues and other organic solids in a form which not immediately re-emitted. Carbon sequestration in soil can be accomplished by management systems which adds high amount of biomass, causes minimal disturbance, enhances faunal activity and conserves not only soil but also water. This carbon storages or reservoirs are also known as carbon pools. Carbon pool refers to a systems or mechanism which has the capacity to accumulate or release. It can be natural or human induced. Examples are forest biomass, wood products, soils, and the atmosphere. Carbon pools in a forest are a complex mixture of live and dead organic matter and minerals. Human induced carbon pools are geological storages of carbon dioxide. The quantity of carbon in a pool is known as carbon stock. There are four components of carbon storage in a forest ecosystems. They are trees, plant growing on the forest floor (under-storey material), detritus such as leaf litter or decaying matter and forest soils. The use of forest is also a financially viable technique to reduce emission from atmosphere. It could also bring significant benefits to the local communities involved and consequently helps in reducing poverty at the same time. Forestry projects can bring social, economic, and local environmental benefits to millions of people. (Clyde, P., 2012).

Carbon sequestration is important because it captures carbon dioxide and sequestration could play an important role in reducing greenhouse gas emissions into the atmosphere. It enables low-carbon electricity generation from power plants. As reported by INCCA in their report, 'Green House Gas Emission2007', 38% of CO_2 emissions in India is done from electric power generation. This carbon share can be reduced by using carbon sequestration technology. Carbon sequestration technologies can dramatically reduce CO_2 emissions by

80-90% from power plants that burn fossil fuels. For instance - if it is applied to a 500 MW coal-fired power plant, which emits roughly 3 million tons of CO_2 per year, the amount of GHG emissions avoided (with a 90% reduction efficiency) would be equivalent to planting more than 62 million trees, and waiting at least 10 years for them to grow and to avoiding annual electricity-related emissions from more than 3,00,000 homes. Another reason of importance is, forests, which acts as carbon sinks and store CO_2 in large amount.

The use of forest is a financially viable technique to reduce emission. It could also bring significant benefits to the local communities involved and consequently helps in reducing poverty at the same time. Forestry projects can bring social, economic, and local environmental benefits to millions of people (Clyde, P., 2012). Shin *et al.* (2007) reported that diversified forest ecosystems, i.e., wet forest lands, rain forests, moist deciduous forest, semi-arid areas and mangroves, Bangladesh forestry sector is acting as an important carbon sink. It has been estimated that about 5000 species of higher plants with thick foliage and species diversity occur in Bangladesh. Carbon assessment has been carried out by the Forest Department in Sundarbans reserve forest and protected area. The results revealed that the carbon stock in Sundarban reserved forest were105.6 megaton in 4,11,693 ha area, which converts to 256 Mg C ha-1. The carbon stock (above ground and root carbon) in six protected area in Bangladesh namely Dudpukuria-dhopachari wildlife sanctuary, Fasiakhali wildlife sanctuary, Inani national park, Medhakachapia national park, Sitakundo reserved forest, and Teknaf wildlife sanctuary area contained 105.46 Mg ha^{-1}, 110.16 Mg ha^{-1}, 25.99 Mg ha^{-1}, 187.75 Mg ha^{-1}, 22.51 Mg ha^{-1} and 43.08 Mg ha^{-1} respectively.Therefore, some studies have been done before regarding to carbon sequestration in social forest, reserve forest and homestead agroforestry in Bangladesh. But still no studies have been done about carbon sequestration in different agroforestry systems in northern part of Bangladesh. Considering these circumstances, this research work was conducted in order to bring new ideas and dataset for estimating carbon storage in different agroforestry systems in the three AEZs of Bangladesh.

Objectives

i. To assess the total carbon stock and accumulation in some commonly agroforestry systems in three agro-ecological zones of Bangladesh.
ii. To identify the best agroforestry systems that can contribute to carbon sequestration.
iii. To identify the best AEZ in Dinajpur district in respect of carbon sequestration potentiality.

CHAPTER II

REVIEW OF LITERATURE

Carbon sequestration is a major environmental issues of this century because global climate change mainly caused by rising levels of carbon dioxide and other greenhouse gases and sequestration activities can help prevent global climate change by enhancing carbon storage in trees and soils, preserving existing tree and soil carbon, and by reducing emissions of CO_2, methane (CH_4) and nitrous oxide (N_2O). The role of Agroforestry practices on carbon sequestration under different agro-ecological zones was a major concerned of this research work and Bangladesh has inadequate information especially in regard to quantification of carbon stock in different agroforestry practices. Keeping this in view, an attempt has been made to review findings on carbon sequestrations with particular emphasis on above and below ground biomass accumulations, carbon stock and carbon sequestration in some agroforestry practices. This chapter present the available literatures from the sources accessible are reviewed under the following heads.

2.1 Carbon sequestration
2.2 Global concept of carbon sequestration in agroforestry
2.3 Carbon cycle
2.4 Greenhouse gases
2.5 Climate change and its impacts on Bangladesh
2.6 Carbon sequestration potential of agroforestry systems
2.7 Carbon sequestration in tree biomass
2.8 Carbon sequestration for different agroforestry systems
2.9 Carbon stock and biodiversity
2.10 Kyoto protocol in respect of carbon sequestration
2.11 Clean development mechanism (CDM)
2.12 Status of carbon assessment in Bangladesh
2.13 Concept of soil carbon and soil carbon sequestration

2.14. Soil carbon sequestration to mitigate climate change

2.1 Carbon sequestration

Carbon sequestration is the removal of carbon from the atmosphere by storing it in the biosphere (IPCC, 2000). It is also the capture and storage of carbon that would otherwise be emitted or remained to the atmosphere (FAO, 2000). (IPCC, 2001) describes carbon sequestration as 'the process of increasing the carbon content in reservoir other than the atmosphere.' Carbon sequestration is also the removal of additional carbon from the atmosphere and depositing it in other reservoir principally through change in land use (Mandal *et al.,* 2005). The most common process of storing carbon occurs during the photosynthesis in trees and plants, which absorb carbon dioxide during growth. Trees both in above and below ground biomass continue to accumulate carbon until they reach the maturity; at that point about half of the average dry weight of tree will be carbon (Anonymous,2004). Forests and wooded areas are natural carbon sinks. This means that trees store carbon by sequestrating atmospheric carbon in the growth of wood biomass through the process of photosynthesis and thereby increasing the soil organic carbon (SOC) (Brown and Pearce, 1994).

Deforestation is responsible for up to 20% of greenhouse gas emissions worldwide, with most forest land cleared for agricultural use. When managed effectively, forests are net carbon sinks, able to absorb permanently about one-tenth of global CO_2 emissions into biomass, soil and forest products. It is believed that the goal of reducing carbon sources and increasing the carbon sink can be achieved efficiently by protecting and conserving the carbon pools in existing forests (Brown *et al.,* 1996). Due to sensitiveness of forests and forest sectors to climate change (Lindner *et al.,* 2002), the issue of using forests to absorb atmospheric carbon should be well understood. Since forest ecosystems exchange large amounts of CO_2 with the atmosphere through photosynthesis and respiration, they are able to sequester large amounts of carbon intergrowth stages (Schimel *et al.,* 2001). Thus, additional to various goods and services being provided to human beings, forests act as a natural storage for carbon at the global scale, contributing approximately 80% of terrestrial aboveground, and 40% of terrestrial belowground carbon storage (Kirschbaum, 1996).

2.2 Global concept of carbon sequestration in agroforestry

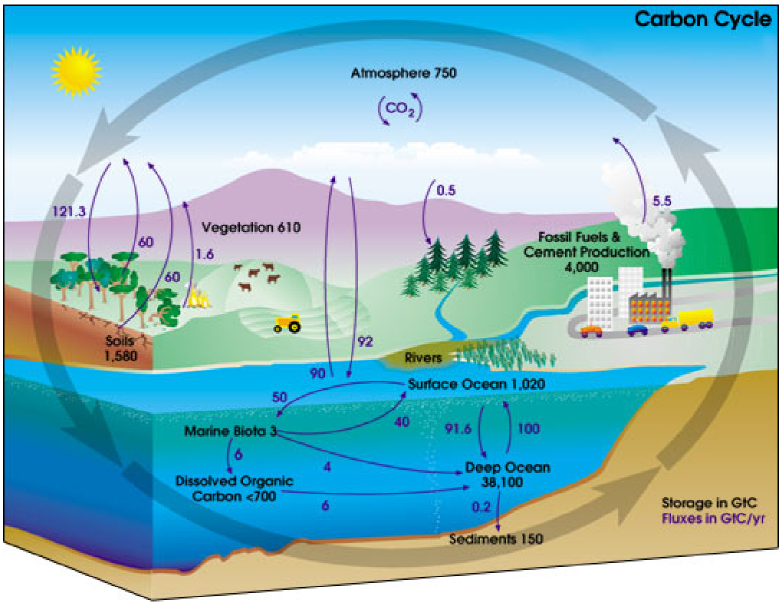
Global warming refers to an increase in temperature in the earth's atmosphere is caused primarily by the increase in atmospheric concentrations of greenhouse gases (GHGs), the most common of which is CO_2. The current GHG concentrations are estimated to be 30% more than the preindustrial level (IPCC), 2007). The method of promotion of carbon (C) sequestration in the biosphere is widely accepted as a strategy for reducing the GHG concentrations in the atmosphere. This entails storing of atmospheric C in the biosphere, and it is believed that this can be achieved by promoting land use practices such as afforestation and reforestation including agroforestry (Montagnini and Nair, 2004). The IPCC special report on Land Use, Land-Use Change and Forestry (LULUCF) shows that net increase in global C stocks are estimated to be 0.026 Pg (billion tons) C year-1 for improved agroforestry management and 0.39Pg C year-1 for agroforestry-related land-use changes in 2010 (IPCC, 2007). Montagnini and Nair (2004) claimed that with proper design and management, agroforestry systems could be effective C sequestration model. Wright *et al.* (2001) even suggested that agroforestry would be the only systems that could realistically be implemented to mitigate the atmospheric CO_2 through terrestrial C sequestration. In spite of these postulated benefits, the C sequestration potential (CSP) of agroforestry systems remains largely unexplored (Nair and Nair, 2003).

Albrecht and Kandji (2003) observed that removing atmospheric carbon (C) and storing it in the terrestrial biosphere is one of the options, which have been proposed to compensate greenhouse gas (GHG) emissions. Agricultural lands are believed to be a major potential sink and could absorb large quantities of C if trees are reintroduced to these systems and judiciously managed together with crops and/or animals. Thus, the importance of agroforestry as a land-use systems is receiving wider recognition not only in terms of agricultural sustainability but also in issues related to climate change. The objective of this paper was to analyze C storage data in some tropical agroforestry systems and to discuss the role they can play in reducing the concentration of CO_2 in the atmosphere. The C sequestration potential of agroforestry systems is estimated between 12 and 228 Mg ha^{-1} with a median value of 95 Mg ha^{-1}. Therefore, based on the earth's area that is suitable for the practice (585–1215 × 106 ha), 1.1–2.2 Pg C could be stored in the terrestrial ecosystems over the next 50 years. Long rotation system such as agroforestry, home garden and boundary plantings can sequester sizeable quantities of C in plant biomass and in long-lasting wood products. Soil C sequestration constitutes another realistic option achievable in many agroforestry systems. In conclusion, the potential of agroforestry for CO_2 mitigation is well recognized. However, there are a number of shortcomings that need to be emphasized. These include the uncertainties related to future shifts in global climate, land-use and land cover, the poor performance of trees and crops on substandard soils and dry environments, pests and diseases such as nematodes. In addition, more efforts are needed to improve methods for estimating C stocks and trace gas balances such as nitrous oxide and methane to determine net benefits of agroforestry on the atmosphere.

2.3 Carbon cycle

The carbon cycle is the circulation and transformation of carbon back and forth between living things and the environment. Carbon is an element, something that cannot be broken down into a simpler substance. Other examples of elements are oxygen, nitrogen, calcium, iron and hydrogen. Carbon compounds are present in living things like plants and animals and in nonliving things like rocks and soil. Carbon compounds can exist as solids (such as diamonds or coal), liquids (such as crude oil) or gases (such as carbon dioxide). Carbon is often referred to as the "building block of life" because living things are based on carbon and carbon compounds (TEEIC, 2017).

The amount of carbon on the earth and in Earth's atmosphere is fixed, and that fixed amount of carbon is dynamic, always changing into different carbon compounds and moving between living and nonliving things. Carbon is released to the atmosphere from what are called "carbon sources" and stored in plants, animals, rocks, and water in what are called "carbon sinks." This process occurs in a number of steps. In the first step, through photosynthesis plants take carbon dioxide out of the atmosphere and release oxygen. The carbon dioxide is converted into carbon compounds that make up the body of the plant, which are stored in both the aboveground parts of the plants (shoots and leaves), and the belowground parts (roots). In the next step, animals eat the plants, breath in the oxygen, and exhale carbon dioxide. The carbon dioxide created by animals is then available for plants to use in photosynthesis. Carbon stored in plants that are not eaten by animals eventually decomposes after the plants die, and is either released into the atmosphere or stored in the soil (TEEIC, 2017).



Source: (TEEIC, 2017)

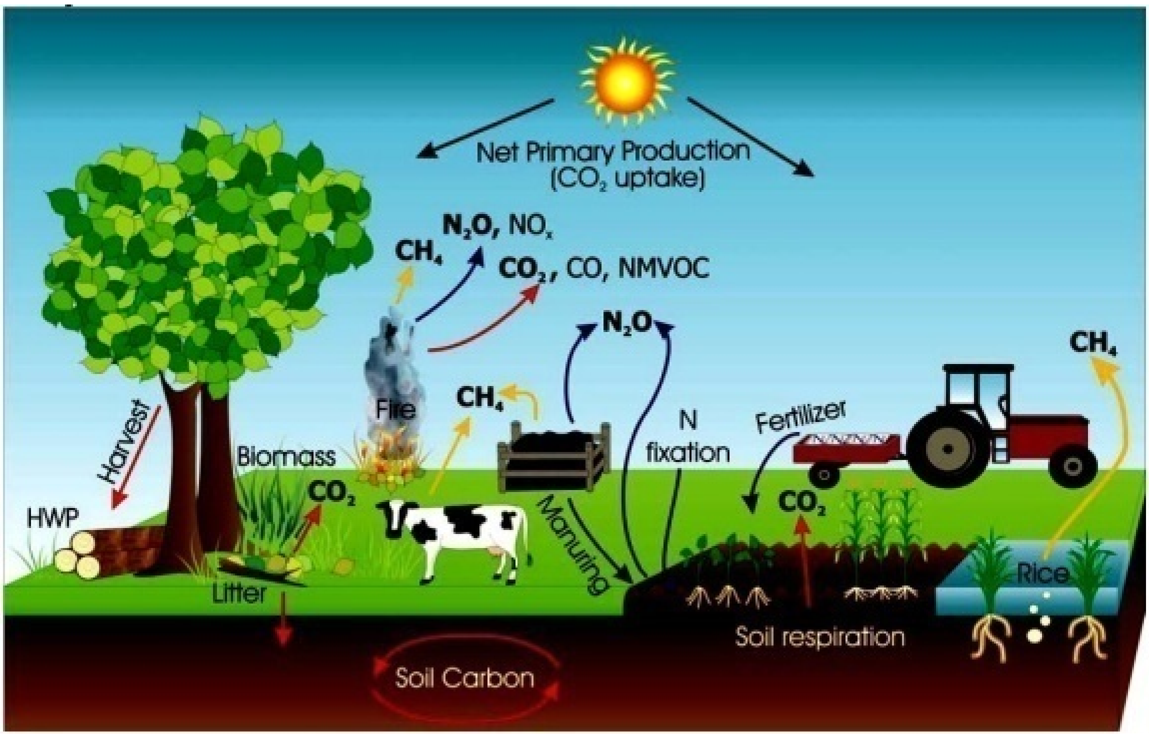
Fig 2.1: Carbon cycle

2.4 Greenhouse gases

Global awareness of environmental issues has increased on an unprecedented scale. Deforestation, land degradation, desertification, loss of biodiversity, global warming and climate change are some of the environmental issues linked directly to the terrestrial ecosystems, both natural and human-managed. Forests, grasslands and croplands constitute over 63% of the global land area. Terrestrial ecosystems play a critical role in the global carbon cycle. Global rise in demand for food, fodder, fuel and round wood is increasing the pressure on land-use systems and conservation and sustainable development of land-use systems are critical for meeting those demands sustainably and stabilizing CO_2 concentration in the atmosphere to mitigate global climate change (Ravindranath and Madelene, 2008).

Greenhouse gases are an essential part of the atmosphere and work to trap and reflect energy from the sun. The earth's surface radiates energy from the sun as infrared energy. Greenhouse gases absorb some of the infrared energy and radiate it back towards the earth (Jacoby *et al.,* 1998). This process keeps the earth at a life-sustaining temperature. The main greenhouse gases are water vapor, CO_2, methane, nitrous oxide, tropospheric ozone, HFCs, PFCs, SF6, halons and CFCs. Water vapor and clouds are responsible for the majority of the absorbed and reflected energy on Earth (Jacoby *et al.,* 1998). Water vapor is not considered an anthropogenic greenhouse gas since human activity has little direct effect on its atmospheric concentrations (although human activities that increase other greenhouse gases may indirectly increase the atmospheric concentrations of water vapor) (EIA, 2003). CO_2, CH_4 and N_2O are responsible for a smaller fraction of the absorbed and reflected energy. However, CO_2, methane, and nitrous oxide are currently entering the atmosphere at rates greatly enhanced by human activities. These greenhouse gases have atmospheric lifetimes on the scale of tens to hundreds of years, as a result they tend to accumulate in the atmosphere. As they reach higher atmospheric concentrations, the greenhouse gases absorb and radiate more energy. This process increases average global temperatures. The temperature increases are driving the threat of global climate change (Karl and Trenberth, 2003). This means that one molecule of methane has an impact on global warming equivalent to 23 molecules of CO_2 and one molecule of nitrous oxide has an impact on global warming equivalent to 296 molecules of CO_2. On this basis, CO_2 accounts for 84% of the total amount of greenhouse gas emissions in the U.S. (USEPA, 2003).

Figueroa *et al.* (2007) observed that there is growing concern that anthropogenic CO_2 emissions are contributing to global climate change. Therefore, it is critical to develop technologies for mitigating this problem. One very promising approach to reducing CO_2 emissions is CO_2 capture at a power plant, transport to an injection site, and sequestration for long-term storage in any of a variety of suitable geologic formations. The department of energy's carbon sequestration program is actively pursuing this goal. CO_2 capture from coal-derived power generation can be achieved by various approaches: post-combustion capture, pre-combustion capture, and oxy combustion. All three of these pathways are under investigation, some at an early stage of development. A wide variety of separation techniques is being pursued, including gas phase separation, absorption into a liquid, and adsorption on a solid, as well as hybrid processes, such as adsorption/membrane systems. Current efforts cover not only improvements to state-of-the-art technologies but also development of several innovative concepts, such as metal organic frameworks, ionic liquids, and enzyme-based systems.



Source: (IPPC, 2006)

Fig 2.2: The main greenhouse gas emission sources in ecosystems

2.5 Climate change and its impacts on Bangladesh

According to FAO (2008) climate refers to the characteristic conditions of the earth's lower surface atmosphere at a specific location and weather refers to the day-to-day fluctuations in these conditions at the same location. The variables that are commonly used by meteorologists to measure daily weather phenomena are air temperature, precipitation (e.g., rain, sleet, snow and hail), atmospheric pressure and humidity, wind, and sunshine and cloud cover. When these weather phenomena are measured systems at a specific location over several years, a record of observations is accumulated from which averages, ranges, maximums and minimums for each variable can be computed, along with the frequency and duration of more extreme events.

United Nations Framework Convention on Climate Change (UNFCCC) defined that climate change is the change that can be attributed "directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods" (ISDR,2008).

Ross (2009) noted that global climate change is a widespread and growing concern that has led to extensive international discussions and negotiations. Responses to this concern have focused on reducing emissions of greenhouse gases, especially carbon dioxide and on measuring carbon absorbed by and stored in forests, soils, and oceans. One option for slowing the rise of greenhouse gas concentrations in the atmosphere, and thus possible climate change, is to increase the amount of carbon removed by and stored in forests.

Bangladesh is one of the largest deltas in the world which is highly vulnerable to natural disasters because of its geographic location and the physical, social as well as economic conditions of Bangladesh are very typical to any of the most vulnerable countries to natural disasters in the world (Denissen, 2012). Bangladesh has got a population of around 150 million (2011) with a life expectancy at birth of around 63 years, and an adult literacy rate of 47.5% (Denissen, 2012). Bangladesh ranks 140 of 177 nations in the recent Human Development Report. Bangladesh has an average annual population growth rate of around 2% (4.6% in urban areas), almost 75% of the population lives in rural areas and a population density of 954.4 (people per sq. km.). Bangladesh is predominantly agricultural with two thirds of the population engaged in farming or agro-based industrial activity mainly. The climate of Bangladesh can be characterized by high temperatures, heavy rainfall, high humidity and fairly marked three seasonal variations like hot summer, shrinking winter and medium to heavy rains during the rainy season (Denissen, 2012).

Bangladesh experiences different types of natural disasters almost every year because of the global warming as well as climate change impacts, these are:

Floods / flash floods (Almost 80% of the total area of the country is prone to flooding).

Cyclones and storm surges (South and south-eastern parts of the country were hit by tropical cyclones during the last few years).

Salinity intrusion (Almost the whole coastal belt along the bay of bengal is experiencing salinity problem).

Extreme temperature and drought (North and north-western regions of the country are suffering because of the extreme temperature problem) (Denissen, 2012).

2.6 Carbon sequestration potential of agroforestry systems

Agroforestry has played a significant role in enhancing land productivity and improving livelihoods in both developed and developing countries. Although carbon sequestration through afforestation and reforestation of degraded natural forests has been considered useful in climate change mitigation, agroforestry offers some distinct advantages. The planting of trees along with crops improves soil fertility, controls and prevents soil erosion, controls water logging, checks acidification and eutrophication of streams and rivers, increases local biodiversity, decreases pressure on natural forests for fuel and provides fodder for livestock (Makundi, 2004). The effectiveness of agroforestry systems in storing carbon depends on both environmental and socio-economic factors and in humid tropics, agroforestry systems have the potential to sequester over 70 Mg/ha in the top 20 cm of the soil (Mutuo, 2005).The carbon storage capacity in agroforestry varies across species and geography (Newaj, 2008). Further, the amount of carbon in any agroforestry systems depends on the structure and function of different components within the systems put into practice (Schroeder, 1993; Albrecht and Kandji, 2003). The fact that agroforestry systems can function as both source and sink of carbon has been presented in literature (Montagnini and Nair, 2004; Dixon, 1995). There is also clear evidence to suggest that the type of agroforestry systems greatly influences the source or sink role of the trees. For example, agri-silvicultural systems where trees and crops are grown together are net sinks while agro silvi-pastoral systems are possibly sources of GHGs (Kandji *et al.,* 2006). Practices like tillage, controlled burning, manuring, application of chemical fertilizers and frequent soil disturbance can lead to significant emissions of GHGs (Montagnini and Nair, 2004). According to the IPCC (2007) agroforestry systems offer important opportunities of creating synergies between both adaptation and mitigation actions with a technical mitigation potential of 1.1-2.2 PgC in terrestrial ecosystems over the next 50 years. Additionally, 630 Mha of unproductive croplands and grasslands could be converted to agroforestry representing a carbon sequestration potential of 391,000 MgC/yr by 2010 and 586,000 MgC/yr by 2040 (Jose, 2009).

The estimates of potential for carbon storage in different kinds of agroforestry systems are also observed from previews literatures. In Southeast Asia, agri-silvicultural systems have the capacity to store 12-228 MgC/ha in humid tropical lands and 68-81 MgC/ha in dry lowlands. Highest potential for carbon storage can be observed for North American silvipastoral systems with a range of 90-198 MgC/ha. The potential to sequester carbon in aboveground components in agroforestry systems is estimated to be 2.1×10^{9} $MgCyear^{-1}$ in tropical and 1.9×10^{9} $MgCyear^{-1}$ in temperate biomes (Oelbermann, 2004).

Agroforestry systems can have indirect effects on carbon sequestration as it helps decrease pressure on natural forests that are the largest sinks of terrestrial carbon they also conserve soils and thus enhance carbon storage in trees and soils. Effects of agroforestry practices on the soil carbon pool indicated a rate of increase by 2-3 MgC/ha/yr (Garg, 1998).

Phanikumar *et al.* (2009) estimated carbon sequestration potential with special reference to agroforestry in cold deserts of Ladakh revealed that the Nubra Valley (Trans-Himalayan region) which is covered with more than 5,75,000 agroforestry plantations. These species has been found to sequester more than 75,000 tons of carbon. Also every year these plantations are contributing 400 tons of leaf litter to the ground, which is one of the best sources of soil organic carbon.

The carbon sequestration potential of agroforestry systems has established theoretically; however field measurements to validate these concepts are limited. The inherent variability in the estimates of potential carbon storage in agroforestry systems and the lack of uniform methodologies has made comparisons difficult (Jose, 2009). Few studies of specific agroforestry practices have proved potential for carbon sequestration (Roshetko *et al.,* 2002; Takimoto *et al.,* 2008).

2.7 Carbon sequestration in tree biomass

Chavan and Rasal (2010) studied the above ground carbon (AGC), below ground carbon (BGC) and mean organic carbon (MOC) in *Ficus religiosa* is 4.27, 0.641 and 4.91 t/tree respectively. It is followed by *Ficus bengalensis* (3.89, 0.57, 4.46 t/tree). *Mangifera indica* (3.13, 0.46, 3.59 t/tree), *Delonix regia* (2.12, 0.31, 2.44 t/tree), *Butea monosperma* (2.10, 0.31, 2.41 t/tree), *Peltaforum pterocarpum* (2.01, 0.29, 2.30 t/tree), *Azadirachta indica* (1.91, 0.26, 2.08 t/tree), *Pongamia pinnata* (1.57, 0.23, 1.80 t/tree), and *Hyophorbe amercaulismort* (1.53, 0.23, 1.76 t/tree), respectively. Remaining all trees is having carbon content below1.5 t/tree.

Prasad *et al.* (2010) reported that the total dry biomass of some agroforestry tree species varied from species to species. The highest dry biomass was recorded in *Albizia procera* with (314.49 kg/tree) which was followed by *Eucalyptus tereticornis* (154.59 kg/tree) and *Dalbergia sissoo* (106.31 kg/tree).

Firdaus *et al.* (2010) reported higher biomass production of *Jatropha curcas* from the aboveground portion of the tree compared to the belowground portion could be explained by the ability of the tree to adapt to drought without having to extend its root systems to obtain water. There was an increase of C in biomass during a 32-month period with an increase of mean whole tree (aboveground and belowground) C of 13.0 Mg C/ha.

Chavan and Rasal (2011) studied the total above and below ground carbon content after six years of age in different fruit trees and found maximum in *Annona reticulata* (83.1KgC/ha) as compared to *Annona squamosa* (73.50KgC/ha), *Tamarindus indica* (36.96KgC/ha), *Emblica officinalis* (33.07KgC/ha), *Mangiferaindica* (30.60KgC/ha) and *Achras sapota* (12.86KgC/ha), respectively.

Patel (2012) studied the above ground carbon sequestration in 3 years old different *Eucalyptus clones* and registered maximum in clone P-411 (34.64 kg) and least in clone P- 2049 (2.62 kg). Hellings *et al.* (2012) reported that the 32 month old *Jatropha curcas* produced above ground biomass of 12.68 kg and below ground biomass of 3.95 kg.

Rizvi *et al.* (2011) estimated carbon stock as tree biomass in poplar based agroforestry systems in Saharanpur District. Carbon stock in stem wood, aboveground and belowground biomass was estimated to be 16.30, 25.24 and 6.71 tonC/ ha, respectively. Whereas, in the case of agri-silviculture systems, the values were 42.36, 65.62 and 17.44 ton C/ha respectively. Total carbon stock as tree biomass in boundary and agri-silviculture systems was estimated to be 31.95 and 83.07 ton C/ha, respectively at a rotation period of 7 years.

A study was conducted in mature coffee plantation in south-west Tago to determine carbon and nutrient stocks in shaded and open grown coffee systems. Biomass of *Albizia* trees was predicted by allometry, whereas biomass of coffee bushes was estimated through destructive sampling. Above and below ground biomass estimates were 140 Mg/ha and 32 Mg/ha in the coffee + *Albizia* association and 29.7 Mg/ha and 18.7 Mg/ha in the open grown systems, respectively. *Albizia* trees contributed 87% of total aboveground biomass and 55% of total root biomass in the shaded coffee systems. Individual coffee bushes consistently had higher biomass in the open grown than in the shaded coffee systems. Total C stock was 81 Mg/ha in the shaded coffee systems and only 22.9 Mg/ha for coffee grown in the open (Dossa *et al.,* 2008).

Abbas *et al.* (2011) stated that average contribution of stem portion of the tree was 49.01% of the total tree biomass, and branches showed 31.17%, leaves 1.98%, twigs 1.05% and roots 16.65% of the total tree biomass. So, it was found that the major part of the total tree biomass was present in the stem portion of *Olea ferruginea.* Among the tree components, stem had the maximum and twigs had the minimum contribution to the total tree biomass.

Ramchandran *et al.* (2007) revealed the total above and below ground biomass carbon stock in Kolli hills in different forest types was 2.74 Tg of which the semi-evergreen forest contributed 22%, the deciduous forest contributed to the maximum of 57% and the other forest types contributed 21%. Vegetation biomass carbon density of 0.60 Tg ha^{-1} in semi-evergreen forests, 1.57 Tg ha^{-1} in deciduous forests, 0.35 Tg ha^{-1} in secondary deciduous forests, 0.22 Tg ha^{-1} in thorn forests and 0.01 Tg ha^{-1} in *Euphorbia* forests was recorded.

2.8 Carbon sequestration for different agroforestry systems

2.8.1 Homestead agroforestry

Jaman *et al.* (2016) reported that homestead agroforestry system hold a large potential for carbon sequestration, especially for climate change mitigation and adaptation under changing environment. This is because of the multifunctional ecosystem services of homestead for storing carbon. In this research total above and below ground carbon stock and tree species diversity were quantified in homestead around four villages of two upazilas of Rangpur district situated in northern part of Bangladesh. A total of 64 homestead were sampled on size, diameter at breast height (DBH) of trees and tree height. Using allometric equations mean above and below ground biomass carbon stocks (AGB+BGB) were found 53.53Mg ha^{-1}. Mean carbon stock per unit area was higher in small homestead (69.15 Mg ha^{-1}) compared to medium (47.96 Mg ha^{-1}) and large (39.93 Mg ha^{-1}) homestead. In total 1671 trees were sampled and 32 different tree species were identified and recorded. The Shannon Wiener index was used to evaluate the tree diversity per homestead and it ranged from 1.00 to 2.2 with a mean value of 1.64. These results imply that homestead can serve as an important ecological tool in terms of carbon sequestration and conservation of tree species diversity. However, specific homestead management plan is necessary for increased carbon sequestration potentiality and conservation of species diversity should be encouraged for further investigation in this region.

Brakas and Aune (2011) conducted a study to assess the standing biomass and carbon accumulation in the smallholder farming systems of Claveria, the Philippines. Nineteen land use types were identified and the age and standing biomass assessed by field measurements and the use of allometric equations. Aboveground C stock varied from 2.9 to 234 Mg ha^{-1}. The highest stock was observed in the preserved forest followed by homestead whereas the lowest was observed in the grasslands. In general, C accumulation in aboveground biomass decreased with increasing tree diversity. The highest rate of C accumulation was found in mango (*Mangifera indica* L.) plantation (17.9 Mg ha^{-1} $year^{-1}$) followed by banana (*Musa* spp.)+fruit trees (13.6 Mg $ha^{-1}year^{-1}$). Low (<1 Mg ha^{-1} $year^{-1}$) rates of C accumulation were observed in coconut (*Cocos nucifera* L.) plantations, coconut+ banana, bush fallow, and grasslands. Agroforestry systems like homegardens and corn (*Zea mays* L.)+timber and fruit trees can have both high rates of C accumulation and high tree diversity, implying the synergy between C accumulation and maintenance of tree diversity.

James *et al.* (2002) reported that many small holder agroforestry systems in Southeast Asia are species-rich and tree-rich systems that produce non-wood and wood products for both home use and market sale. Due to their high biomass, these systems may contain large carbon stocks. While the agroforestry systems of individual farmers are of limited size, on a per area basis smallholder systems accumulate significant amounts of C, equaling the amount of C stored in some secondary forests over similar time periods. Their ability to simultaneously address smallholders' livelihood needs and store large amounts of C makes smallholder agroforestry systems viable project prototype under the clean development mechanism (CDM) of the kyoto protocol, which has the dual objective of reducing greenhouse gas emissions and contributing to sustainable development. Smallholder agroforestry systems promoted through a CDM project must be economically viable independent of C payments. Although often smallholder systems are environmentally and socio-economically viable, to enhance productivity and profitability smallholder-focused CDM projects should provide farmers with technical and marketing assistance. To assure success, project sites should meet a set of preconditions, including areas of underutilized low-biomass land use systems that are available for rehabilitation, smallholders interested in tree farming, accessible markets for tree products, a supportive local government and sufficient infrastructure; and a transparent and equitable relationship between project partners. Questions of leakage and additionally should not be problematic and can be addressed through the project design and establishment of quantifiable and equitable baseline data. However, smallholder focused CDM projects would have high transaction costs. The subsequent challenge is thus to develop mechanisms that reduce these costs: (a) the costs associated with information (e.g., technology, markets) more accessible to multiple clients; (b) facilitating and enforcing smallholder agreements and (c) designing feasible monitoring systems.

2.8.2 Cropland agroforestry

Murthy *et al.* (2013) in the study conducted by Indian Institute of Science as a part of the larger study on natural resource monitoring in selected village ecosystems of southern India falling in different agro-ecological zones. The study was conducted in 4 villages each in Karnataka and Tamil Nadu where all the trees on croplands were inventoried. The results obtain from the study as follows; among the karnataka villages, the highest biomass carbon stock was recorded in Sirsimakki (about 5 tC/ha of biomass carbon), followed by Lukkeri, a coastal village (8.5 t/ha of biomass carbon). In the Tamil Nadu villages, the biomass stocks in 2 of the 4 villages is higher than that recorded in the Karnataka villages and it is in the range of 1.3 to 12 t/ha. The biomass carbon stock varies from village to village but is significant. Even if one takes an average of carbon stock (3.93 tC/ ha) and if one considers a conservative crop area of about 100 million hectare, the carbon stock in agroforestry systems could be estimated to be 392.84 MtC for India.

Also, in a study done by Kumar (2010) on four different agroforestry systems (*Populus deltoides* block plantation + wheat, *Eucalyptu*s hybrid boundary plantation + wheat, *Populus deltoides* boundary plantation + wheat and *Populus deltoides* block plantation + lemon grass), all 9-year old block and boundary plantations, it was observed that total carbon sequestration [in trees] was 70.59, 21.38, 116.29 and 18.53 $tCha^{-1}$ in systems *Populus deltoids* + wheat followed by 68.53, 20.63, 113.03 and 17.60 $tCha^{-1}$ in systems *Populus deltoids* + lemon grass, respectively, with a greater potential for carbon sequestration in boundary plantations of *Populus deltoides* and *Eucalyptus* hybrid. In a study on mitigation potential of block plantations in farm forestry, Hooda *et al.* (2007) estimated a mitigation potential of 48.5, 62.7, 61.7, 60.8, 37.6 tC/ ha/yr for Khair, Chir pine, mixed plantations, Mango and Kino respectively, based farm forestry systems in Uttaranchal.

Rizvi *et al.* (2011) revealed that the biomass production and carbon stock of *Populus deltioides* based agri-silviculture and boundary plantation systems were 267.34 kg/tree and 249.01 kg/tree, respectively at the age of 7 years. Timber production of poplar tree in boundary systems was found to be lower than that in agri-silviculture systems. Total dry biomass was computed from stem wood biomass by assuming it to be 51% of the total biomass, because studies suggested that stem wood biomass accounted for 49.7-51.7% of the total biomass. Thereafter aboveground and belowground biomass have been estimated by considering their contribution to the total biomass in the order of 79 % and 21%, respectively.

Maikhuri *et al.* (2000) estimated species wise annual carbon sequestration potential of planted tree species on abandoned agricultural land (3.9 t/ha/yr) and degraded forest land (1.79 t/ha/yr). The highest carbon sequestration was found for *Alnus nepaliensis* 0.256 tC/ha/yr and *Dalbergia sissoo* 0.141 tC/ha/ yr intercropped with wheat and paddy. In a 6 year old *Gmelina arborea* based agri-silvicultural systems 31.37 tC/ha was sequestered (Swamy*et al.*2003). In another study the carbon sequestration in monocropping of trees and food crops were 40% and 84% less than agri-silviculture indicating that agroforestry systems have more potential to sequester carbon (Dhyani *et al.*2009). In an agri-silvicultural systems, *Dalbergia sissoo* at age 11 years was able to accumulate 48-52 t/ha of biomass (Newaj and Dhyani, 2008). Carbon dynamics involving different pruning treatments were studied in an agri-silvicultural systems where tree biomass was 23.61 to 34.49 tC/ha with black gram-mustard. In a study on poplar based agri-silvicultural systems, the total biomass in the systems was 25.2 t/ha, 113.6% higher than sole wheat cultivation, where net carbon storage was 34.61 tC/ha compared to 18.74 tC/ha in sole wheat cultivation (Chauhan *et al*. 2010). In a systems comprising *Albizia* and mixed tree species like Mandarin accumulated 1.3 t biomass/ha storing 6939 kg/ha in tree and crop biomass was reported (Sharma *et al.* 1995).

Scholes *et al.* (2001) carried out an experiment on “Storing carbon on land”. He showed that comparison with croplands, village forestry lands tend to be less disturbed, supporting mature and productive woody vegetation, explaining a moderate trend toward higher soil organic carbon densities in this land use and underlining the global importance of forestry land in soil carbon sequestration.

Scandrett *et al.* (2010) found that total organic carbon (TOC) levels in the topsoil were depleted under intensive land management practices, however the carbon levels in the subsoils suggested that increases in land use intensity resulted in higher TOC levels below 10 Cm. This emphasises the importance of sampling at depth when assessing soil carbon dynamics in relation to land use. After 12 years of intensive cultivation however, some fields showed little change in TOC levels, which is likely a function of the protective nature of the high clay and silt content (~70%) of the soil and the associated use of minimum tillage.

2.8.3 Orchard agroforestry

Barua and Haque (2013) reported the impacts of tree and horticultural plantations and grassland on soil characteristics in the degraded hills of Chittagong District, Bangladesh on this paper. The carbon sequestration potential and the present value of carbon revenue flow were also estimated for the degraded hills of Chittagong using *A. auriculiformis* plantations for the purpose. The results showed that the change of land use from degraded hill to vegetation cover had altered the physico-chemical characteristics of soil in the study area. The organic carbon concentration and storage under vegetated land uses were significantly ($p < 0{\cdot}05$) higher than those in the degraded hill areas. The results also showed that about 17 million megagram carbon (MgC) could be sequestered in the degraded hill areas of Chittagong District by planting *A. auriculiformis* trees in a 15-year rotation. The present value of revenue flow generated by this sequestration at the current international market carbon price and assuming a realistic market interest rate could be as high as US$ 326 million. The net present value of the revenue stream is expected to be positive.

Verma *et al.* (2002) studied tree crop interaction in agri-horticulture systems and found that the fruit tree crop combinations suppressed growth and yield attributes of wheat. The reduction in wheat yield over sole cropping was 17.9, 21.3, 25.2 and 28.2 % with tree crop combinations Grewia + Almond + Wheat (17.85 q ha^{-1}), Morus + Almond + wheat (17.10 q ha^{-1}), Grewia + Wheat (16.26 q ha^{-1}) and Morus + Wheat (15.61 q ha^{-1}), respectively. Increase in nitrogen level by 25% more than the recommended level enhanced the grain and straw yield below the tree crown in equal or even higher magnitude to that obtained outside the crown at recommended level of nitrogen.

Koul and Panwar (2008) revealed the biomass and carbon sequestration potential in seven different land use systems. The total biomass (t/ha) accumulated at the time of observation was maximum in natural forest of *Shorea robusta* (1980.04 t/ha) which was followed by plantation of *Dalbergia sissoo* (393.15 t/ha), *teagarden* (281.49 t/ha), plantation of *Terminalia arjuna* (251.46 t/ha), *Mangifera indica* based agri-horticulture agroforestry systems (36 t/ha), *Oryza sativa* based sole agriculture crop (10.81 t/ha) and least in fallow land (1.31 t/ha), respectively.

They also observed the same trend for the rate of biomass accumulation (t/ha/yr) *i.e.* in natural forest of *S. robusta* (66 t/ha/yr) which was followed by plantation of *D. sissoo* (43.68 t/ha/yr), tea garden (28.15 t/ha/yr), plantation of *T. arjuna* (28.10 t/ha/yr)*, M. indica* based agri-horticulture agroforestry systems (6.81 t/ha/yr), *O. sativa* based sole agriculture crop (10.81 t/ha/yr)and fallow land(1.31 t/ha/yr), respectively.

Hanif *et al.* (2014) reported that carbon sequestration potentiality of different agroforestry species in the northern part of Bangladesh to combat with the pessimistic impact of climate change. Agroforestry as a land-use systemsis receiving wider recognition not only in terms of agricultural sustainability but also in issues related to climate change. The potentiality to sequester carbon by agroforestry species (*Albizia lebbeck, Leucaena leucophala and Melia azedarach*) in sub-tropical regions like Bangladesh is promising. The carbon sequestration potential of three agroforestry species under the study ranges from 115-135 Mg $Cha^{-1}Y^{-1}$ at the age of seven years after plantation. Among the multipurpose tree species, *Leucaena leucophala* (135 Mg $Cha^{-1}Y^{-1}$) sequestrates the maximum amount of carbon while *Albizia lebbeck* (115 Mg $Cha^{-1}Y^{-1}$) sequestrates the least amount of carbon from the atmosphere and *Melia azedarach* sequestrate 120 Mg $Cha^{-1}Y^{-1}$. Therefore, carbon sequestration potentiality of the studied agroforestry species may be ranked as *Leucaena leucocephala* > *Melia azedarach* > *Albizia lebbeck.*

Andre *et al.* (2011) reported that total systems carbon in the Senegal River valley was 115 ton ha^{-1} in the forest zone and only 18 ton ha^{-1} when the land was under cultivation. Cultivated systems have reduced carbon contents due to reduced tree cover and increased mineralization due to surface disturbance.

Oyedele *et al.* (2010) observed that soil organic carbon and total N were significantly higher under forest and tree crops in comparison to pasture, no tilled and tilled plots. Madhusudanan (2011) also reported significantly maximum soil carbon sequestration in *Casuarina equisetifolia* (1.79%), followed by *Albizia procera* (1.35%), *Eucalyptus* *tereticornis* (1.12%) and least in *Gmelina arborea* (0.68%) respectively in south gujarat area of India.

2.9 Carbon stock and biodiversity

Schroth *et al.* (2011) said that agroforestry systems distinguish themselves from other forms of agriculture through their ability to store higher amounts of carbon in their biomass and often also to conserve more biodiversity. However, in both regards they are generally inferior to forests. Therefore, the impact of agroforestry practices on landscape C stocks and biodiversity needs to be analyzed both in terms of the interactions between agroforestry and forest, which may be positive or negative, and in terms of the conservation of C and biodiversity in the farming systems themselves. This paper argues that in forest frontier situations, the most important characteristic of land use systems in terms of C and biodiversity conservation is to be "land-sparing" (i.e. minimizing forest conversion), which requires a certain level of intensification.

2.10 Kyoto protocol in respect of carbon sequestration

The kyoto protocol is an international agreement setting targets for industrialized countries to cut their greenhouse gas emissions. It contains legally binding commitments, in addition to those included in Annex B of the Protocol (most organization for economic cooperation and development countries and countries with economies in transition) agreed to reduce their anthropogenic greenhouse gas emissions (carbon dioxide, methane, nitrous oxide, hydroflurocarbons, perflurocarbons, and sulfur hexafluoride) by at least 5% below 1990 levels in the commitment period 2008 to 2012.The kyoto protocol entered into force on 16 February 2005 (IPCC, 2007).

Responding to concerns that human activities are increasing concentrations of 'green house gases'(such as carbon dioxide and methane) in the atmosphere and causing potentially damaging climate change and global warming, nearly all nations of the world joined together in 1992 to sign the UNFCC. The main objective of the framework convention was to stabilize green house gas concentration in the atmosphere at the level that would prevent dangerous anthropogenic interference with the climate systems through the adoption of a global protocol called the kyoto protocol. The kyoto protocol is a binding commitment that would assist in implementing the UNFCC goals. The kyoto protocol entered into force on 16 February, 2005 (IPCC, 2007).

Shin *et al.* (2007) reported that the kyoto protocol provides for the involvement of developing countries in an atmospheric greenhouse gas reduction regime under its CDM. Carbon credits are gained from reforestation and afforestation activities in developing countries. Bangladesh, a densely populated tropical country in south asia, has a huge degraded forestland which can be reforested by CDM projects. To realize the potential of the forestry sector in developing countries for full-scale emission mitigation, the carbon sequestration potential of different species in different types of plantations should be integrated with the carbon trading systems under the CDM of the Kyoto Protocol. This paper discusses the prospects and problems of carbon trading in Bangladesh, in relation to the CDM, in the context of global warming and the potential associated consequences. The paper analyzes the effects of reforestation projects on carbon sequestration in Bangladesh, in general, and in the hilly Chittagong region, in particular, and concludes by demonstrating the carbon trading opportunities. Results showed that tree tissue in the forests of Bangladesh stored 92 tons of carbon per hectare (tC/ha), on average. The results also revealed a gross stock of 190 tC/ha in the plantations of 13 tree species, ranging in age from 6 to 23 years. The paper confirms the huge atmospheric CO_2 offset by the forests if the degraded forestlands are reforested by CDM projects, indicating the potential of Bangladesh to participate in carbon trading for both its economic and environmental benefit. Within the forestry sector itself, some constraints are identified; nevertheless, the results of the study can expedite policy decisions regarding Bangladesh's participation in carbon trading through the CDM.

2.11 Clean Development Mechanism (CDM)

CDM is the ability of Annex-I countries to invest in climate-friendly activities in non-Annex-I countries (or more generally developing countries). The aim of this scheme is to encourage climate-friendly projects in places where it is cheaper to invest. Under its provisions, industrialized countries can receive certified emissions reduction credits (CERs) for reductions achieved from a greenhouse gas reduction project in a “host” non- Annex-I country. CERs can be used by the industrialized country to meet its compliance requirements.

Among the three flexibility mechanism of Kyoto protocol, CDM is the one aimed at helping industrialized countries to meet their greenhouse gas reduction targets. Developing countries could view CDM as an opportunity not only to attract investment capital and Environmentally Sustainable Technologies but also to implement innovative technical, institutional and financial interventions to promote energy efficiency, renewable energy and forestry activities that contribute to sustainable development (Sathaye *et al.* 2006). Project specially designed and implement in developing countries under CDM, leading to carbon emission reduction or sequestration will receive payment from institutions and agencies in Annex B (Annex I countries with commitment to reduce GHG emissions) countries for every tones of carbon emission avoided or sequestered (Sathaye *et al.*2006).

Miah *et al.* (2010) reported that in their book title “forest to climate change mitigation” under the sub title “clean mechanism in Bangladesh” which stated that Bangladesh has huge degraded forestlands which can be reforested by the CDM projects. To realize the potential of the forestry sector in developing countries for full-scale emission mitigation, understanding carbon sequestration potential of different species in different types of plantations are important. This chapter deals with carbon sequestrating potentials of the A/R activities with the possible incorporation with the CDM in Bangladesh. The chapter finds that generally the forests of Bangladesh can sequester 92 tC ha^{-1}, on average and 190 $tCha^{-1}$ in the reforested degraded hill forests in particular. This chapter confirms the potential contribution of the carbon sequestration of the forests of Bangladesh, and positively argues the incorporation of forests with the CDM activities. The A/R CDM policy makers in Bangladesh can get this chapter useful to them.

2.12Status of carbon assessment in Bangladesh

Shin *et al.* (2007) reported that diversified forest ecosystems, i.e., wet forestlands, rain forests, moist deciduous forest, semi-arid areas and mangroves, Bangladesh forestry sector is acting as an important carbon sink. It has been estimated that about 5000 species of higher plants with thick foliage and species diversity occur in Bangladesh. On an average, 92 tC ha^{-1} is stored by the existing tree tissues in the forests of Bangladesh. Among them, closed large-crown forests 121 tC ha^{-1}, closed small-crown forests 87 tC ha^{-1}, disturbed closed forests 110 tC ha^{-1} and disturbed open 49 tC ha^{-1}. ESSD (1998) reported that forest soils in Bangladesh stored carbon at a rate of 115 tC ha^{-1},100 tC ha^{-1} and 60 tC ha^{-1} in moist, seasonal and dry soils, respectively. Shin *et al.* (2007) commented that due to the over extraction of the forest resources and encroachment in the forests, soil carbon reduce fast. Danesh *et al.* (2011) reported that in the reforested degraded hill forests contain 190 $tCha^{-1}$in particular.

In Bangladesh carbon assessment has been carried out by the forest department in sundarbans reserve forest and protected area. The results revealed that the carbon stock in sundarban reserved forest were105.6 megaton in 4,11,693 ha area, which converts to 256 Mg C ha^{-1}. The carbon stock (above ground and root carbon) in six protected area in Bangladesh namely Dudpukuria-dhopachari wildlife sanctuary, Fasiakhali wildlife sanctuary, Inaninational park, Medhakachapia national park, Sitakundo reserved forest, and Teknaf wildlife sanctuary area contained 105.46 Mg ha^{-1}, 110.16 Mg ha^{-1}, 25.99 Mg ha^{-1}, 187.75 Mg ha^{-1}, 22.51 Mg ha^{-1} and 43.08 Mg ha^{-1} respectively.

From the above discussion, it is clear that there is no mentionable research in accounting carbon stock in terms of different agroforestry systems in northern part of Bangladesh. Therefore, the present study has the immense importance to enlarge the assessment of carbon sequestration database as well as it enabled the policy makers to take action plan for national environmental sustainability issues.

2.13 Concept of soil carbon and soil carbon sequestration

Soil is a thin mantle usually up to 2 m depth that covers most of the earth solid surface. Soils are the home to a wide range of organisms act as a repository for soil carbon (Mckenzie *et al*. 2004). Soil carbon refers to total carbon in soils which includes both inorganic and organic carbon forms. In carbon trading framework, emphasis given on organic forms of carbon in soil, because the inorganic form is relatively stable and not strongly influenced by land management. Inorganic soil carbon is the result of both weathering of rocks and of carbonic acid in soil precipitating as carbonate minerals such as calcite and dolomite (Lal, 2007). Agricultural land abandonment in mediterranean environment provides ecosystems services via soil carbon sequestration. Abandonment of agricultural land leads to several consequences for ecosystems functions. Agricultural abandonment may be a significant and low cost strategy for carbon sequestration and mitigation of anthropogenic CO_2 emissions due to the vegetation recovery and increase in soil organic matter. The aim of this study to estimate the influence of different soil regions (areas characterized by atypical climate and parent material association) and bioclimates (zones with homogenous climatic regions). (Novora, A. 2017).

Human appropriation of land for agriculture has greatly alter the terrestrial carbon balance, creating a large but uncertain carbon debt in soils. Estimating the size and spatial distribution of SOC loss due to land use and land cover change has been difficult but is a critical step in understanding whether SOC sequestration can be an effective climate mitigation strategy. In this study, a machine learning based model was filtered using a global compilation of SOC data and the history database of the global environment (Sanderman *et al*. 2017).

2.14 Soil carbon sequestration to mitigate climate change

The increase in atmospheric concentration of CO_2 by 31% since 1750 from fossil fuel combustion and land use change necessitates identification of strategies for mitigating the threat of the attendant global warming. Since the industrial revolution, global emissions of carbon are estimated at 270 +- 30 Pg (Pg= petegram=10 15g= 1 billion ton) due to fossil fuel combustion and 136+- 55 Pg due to land use change and soil cultivation. Emission due to land use change include those by deforestration, biomass burning etc. (Lal, R. 2004).

Mineral soils have major carbon reserves in the world. Varied figures are available in literature on carbon sequestration worldwide. According to several authors (Batjes 1996, Eswaran, *et al*. 1993, Post, *et al*. 1982) estimated sequestrated organic carbon ranged from 1115 to 2200 Pg in 1m soil profile. Hughton (2013) estimated 1580 Pg carbon in 1m soil depth. According to IPCC, estimated inorganic carbon was 1750 pg. It is also predicted that 2500 pg carbon present in within 2m soil depth (Amundson, 2001).

CHAPTER III

MATERIALS AND METHODS

The methods and procedures for conducting this study has been discussed which include the study areas, the sampling technique, data collections and procedures followed for the estimation of biomass and carbon sequestration.

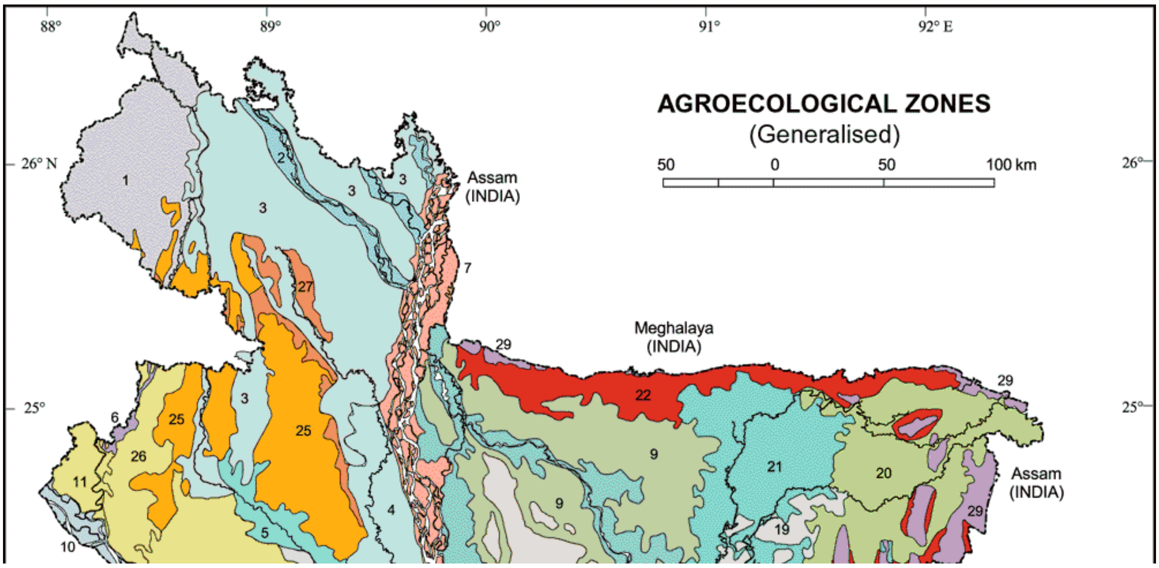
3.1 Study area

3.1.1 Geographical location of Dinajpur

Dinajpur district situated between $25^0$13"and $25^0$54"on the north latitudes and between $88^0$23"and $89^0$18" on the east longitudes now and the district is bounded by Panchagarh and Thakurgaon district on the north. On the south it is bounded by Joypurhat, Gaibanda district and India, on the east by Rangpur and Nilphamari district and on the west by the West Bengal, India. The map shows the boundary area of Thakurgaon, Panchagarh and Dinajpur districts.

3.1.2 Climate of Dinajpur

Dinajpur district experiences temperate and pleasant climate. It shows high temperature, humidity and coldness. The mean temperature of this district ranges from 10.7^0C to 22.8^0C during winter and it varies from 23.4^0C to 34.1^0C during summer. Summer spans from April to June and winter spans from October to March. The month of July and August enjoy heavy rainfall in most of the period. The month of January experiences about 81% humidity and the month of July experiences about 87% humidity in the air. Annual average highest temperature is 33.5°C, lowest temperature is 10.5°C and annual rainfall is 2536 mm.



1 Old Himalayan Piedmont Plain

3 Tista meander flood plain

25 Level barind tract

Fig 3.1: Map Showing AEZ with study area

3.1.3 Characteristics of Soil of Dinajpur

The land of Dinajpur district experiences Old Himalayan Piedmont Plain in most of its part. It also sees an old of the Teesta alluvial fan with a braid river landscape. Complex soil patterns of broad sandy or loamy ridges inter mixed with shallow channels or basins are found in this district. But the district mainly enjoys loamy soils. Two groups of soil such as kiar and poli are experienced. The soil of Barind tract in south east region of this district experiences the old alluvium taking the form of mixed brown and grey silty loam and the central part of meander floodplains along the river little Jamuna and the valley of Karotoa river. The soil characteristics of Birganj, Parbotipur and Dinajpur sadar are present in appendix II-IV.

3.2 Experimental period

The study period was from August, 2018 to March, 2019.

3.3 Experimental design

The experiment was laid out in factorial randomized complete block design (RCBD) with four (04) replication. The two factors were- Factor A: five (5) agroforestry systems, Factor B: three agro-ecological zones.

3.4 Experimental treatments

The experiments consist of five (05) agroforestry systems in three (3) agro-ecological zones.

Factor A: Agroforestry Systems

T_1 = Homestead agroforestry system

T_2 = Eucalyptus cropland based agroforestry system

T_3 = Mahogany cropland based agroforestry system

T_4 = Mango orchard based agroforestry system

T_5 = Litchi orchard based agroforestry system

Factor B: Agro-ecological zones

S_1 = AEZ 1- Old Himalayan piedmont plain (Birganj upazila)

S_2 = AEZ 3- Tista meander flood plain (Parbotipur upazila)

S_3 = AEZ 25- Level barind tract (Dinajpur sadar)

Treatment combinations

S_1T_1 = AEZ 1 + Homestead agroforestry system

S_1T_2 = AEZ 1 + Eucalyptus cropland based agroforestry system

S_1T_3 = AEZ 1 + Mahogany cropland based agroforestry system

S_1T_4 = AEZ 1 + Mango orchard based agroforestry system

S_1T_5 = AEZ 1 + Litchi orchard based agroforestry system

S_2T_1= AEZ 3 + Homestead agroforestry system

S_2T_2= AEZ 3 + Eucalyptus cropland based agroforestry system

S_2T_3= AEZ 3 + Mahogany cropland based agroforestry system

S_2T_4= AEZ 3 + Mango orchard based agroforestry system

S_2T_5= AEZ 3 + Litchi orchard based agroforestry system

S_3T_1= AEZ 25 +Homestead agroforestry system

S_3T_2= AEZ 25 + Eucalyptus cropland based agroforestry system

S_3T_3= AEZ 25 + Mahogany cropland based agroforestry system

S_3T_4= AEZ 25 + Mango orchard based agroforestry system

S_3T_5= AEZ 25 + Litchi orchard based agroforestry system

3.5 Sampling

A stratified random sampling method was used in selecting the sampling area (AEZs) in Dinajpur districts. Three upazila were selected from each AEZ viz; Birganj upazila from AEZ 1, Parbotipur upazila from AEZ 3 and Dinajpur sadar upazila from AEZ 25 as shown in Fig 7 bellow. The stratified random sampling design is useful where there is large variation between sampling area (AEZ) and sampling plots (Upazilla), in which important sources of variability follow a consistent pattern (Gomez and Gomez, 1984). It is important if the sampling plots from the same stratum (within AEZ) are more similar than those from different strata (different AEZ). Thus, the simple random sampling design was used to collect data from each sampling units (observations) within the sampling plots.

However, fifteen observations were recorded from each AEZ having total of sixty (60) observations. Each sampling unit consist of five (05) agroforestry systems (treatments) viz; cropland agroforestry, homestead agroforestry, orchard agroforestry. In each case, four replications were recorded.

3.6 Description of agro-ecological zones and study location

The land area of AEZ is recognized on the basis of hydrology, physiography, soil types, tidal activity, cropping patterns and seasons. In fact an agro-ecological zone indicates an area characterized by homogenous agricultural and ecological characteristics. This homogeneity is more prominent in the sub-region and unit levels. The agro-ecological zones of Bangladesh have been identified on the basis of four elements such as physiography, soils, land levels in relation to flooding and agro-climatology. Bangladesh has been divided into 30 agro-ecological zones, 88 agro-ecological sub-regions which have been further subdivided into 535 agro-ecological units (FAO/UNDP, 1988).

Physiography forms the primary element in defining the agro-ecological regions in Bangladesh. Soils form the second element in defining and differentiating agro-ecological zones as soil conditions determine important properties for plant growth, moisture supply, root aeration and nutrient supply. The third factor is land level in relation to flooding. The fourth element considered in identifying agro-ecological zones in Bangladesh comprises the four climatic parameters. The combined agro-climatic zones could be superimposed on the zones and sub-regions to create unique agro-ecological units (FAO/UNDP, 1988). For the purpose of this study, only agro-ecological zone of concerned are described below.

3.6.1 AEZ 1- Old Himalayan piedmont plain

Old Himalayan Piedmont Plain (4,008 sq km) this distinctive region is developed in an old Tista alluvial fan extending from the foot of the Himalayas. It has a complex relief pattern. Deep, rapidly permeable sandy loams and sandy clay loams are predominant in this region. They are strongly acidic in topsoil and moderately acidic in subsoils; low in weather able K minerals. Seven general soil types occur in the region, of which non-calcareous brown floodplain soils, black terai soils, and non-calcareous dark grey floodplain soils predominate. Organic matter contents are generally higher than in most floodplain soils of

Bangladesh. The natural fertility of the soil is moderate but well sustained. Soil fertility problems include rapid leaching of N, K, S, Ca, Mg and B. Most of Panchagarh and Thakurgaon districts and the northwestern part of Dinajpur district are included in this zone (FAO/UNDP, 1988).

Area and Location: The Birganj upazila occupies an area of 413.0 sq. km. including 11.05 sq. km forest area. It is located 25°48" and 26°04 " north latitudes and 88°29" and 88°44" east longitudes. It is situated on the bank of Dhepa river, midway between Dinajpur and Thakurgaon. Birganj consists of 11 unions/wards, 187 mauzas/mahallas, and 186 villages (BBS, 2014).

Sampling plots: The experiments were conducted at the following union/location; Birgonjunion, Chotosidhley, Vognagar, Volanathpur, Chakay, Birgonj

3.6.2 AEZ 3- Tista meander flood plain

Tista Meander Floodplain (9,468 sq km) this region occupies the major part of the Tista floodplain as well as the floodplain of the Atria, little Jamuna, Karatoya, Dharla and Dudhkumar rivers. Most areas have broad floodplain ridges and almost level basins. There is an overall pattern of olive brown, rapidly permeable, loamy soils on the floodplain ridges, and grey or dark grey, slowly permeable, heavy silt loam or silty clay loam soils on the lower land and parent materials medium in weatherable K minerals. Eight general soil types occur in the region, moderately acidic throughout, low in organic matter content on the higher land, but moderate in the lower parts. Fertility level is low to medium. Soils, in general, have good moisture holding capacity (FAO/UNDP, 1988).

Area and location: The Parbatipur upazila occupies an area of 395.1 sq. km. It is located between 25°65" north latitudes and 88°92" east longitudes. The upazila is bounded on the north by Khansama Upazila, on the east by Saidpur Upazila of Nilphamari zila, on the south by

Phulbari upazila and west bengal state of India and on the west by Dinajpur Sadar Upazila. Chirirbandar has 10 unions/wards, 1 paurasava, 194 mauzas/mahallas, and 230 villages (BBS, 2014).

Sampling plots: The experiments were conducted at the following union/location; Johanabad, Dararpur; Monmothpur; Choto horipur, Noyapara, Koibottopara, Chondipur and Parbotiur.

3.6.3 AEZ 25- Level barind tract

Level Barind Tract (8 sq km) this region is developed over madhupur clay. The landscape is almost level. The predominant soils have grey, silty, puddled topsoil with ploughpan. Shallow grey terrace soil and deep grey terrace soils are the major components of general soil types of the area. The soils are low in available moisture holding capacity and slightly acidic to acidic in reaction. Organic matter status is very low and most of the available nutrients are limiting (FAO/UNDP, 1988).

Area and Location: The Dinajpur Sadar upazila occupies an area of 354.73 sq. km. including 0.49 sq km. forest area. It is located between 25°28" and 25°48" north latitudes and between 88°34" and 88°46" east longitudes. The upazila is bounded on the north by Kaharole Upazila and Khansama Upazila, on the east by Atrai river and Chirirbandar Upazila, on the south by West Bengal State of India and on the west by Biral Upazila. Dinajpur Sadar has 14 Unions/Wards, 299 Mauzas/Mahallas, and 205 villages. Member of Parliament: Iqbalur Rahim (BBS, 2014).

Sampling plots: The experiments were conducted at the following union/location; Noshipur, Subra, Dighon, Kornai and Sheikhpara.

3.7 Methodology (Sampling Techniques)

The methodological procedures employed for this experiment varies due to different agroforestry systems. However, eight (08) year aged eucalyptus and twelve (12) year aged mahogany tree were selected as an experimental tree in cropland. In case of orchard, ten year old mango and litchi tree were considered. In homestead, age was silent due to high variability and species diversity. Here, only matured trees with diameter > 5cm were considered for this experiment. On the other hand, leaf litter, herb, grass or rice biomass was sampled using 1×1m quadrant method. All biomass was collected and fresh weight was recorded and then taken to laboratory and dry it at 70^0C, dry weight was also recorded. The procedures for measuring stand density from different systems are as follows:

3.7.1 Homestead

Sample of 20×20m quadrant was employed in this case. All woody trees with DBH > 5cm were considered for observations. Also in this case DBH and height were all measured.

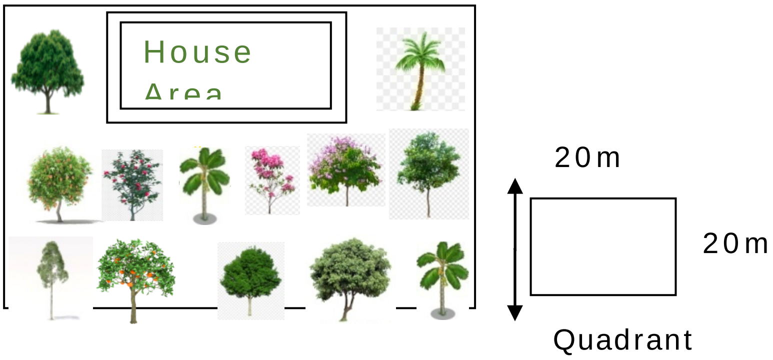


Fig. 3.2: Showing sketch of measuring sample in homestead

3.7.2 Cropland

A sample unit of 20 m transect line was laid along the rows of trees in the boundary of the cropland, number of tree were counted with their DBH and height were measured. The distance was then converted in 400 m^2 and finally in hectors. The diagram below showed the scale of measurement in cropland.

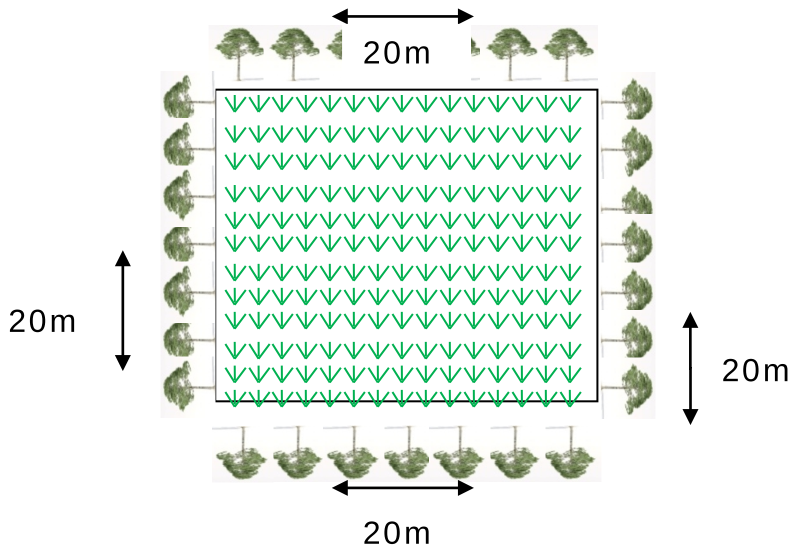


Fig3.3: Showing sketch of measurement in boundary cropland

3.7.3 Orchard

In this case also, sample unit of 20×20m quadrant was used in respect of mango and litchi orchard. Tree height and DBH were also measured.

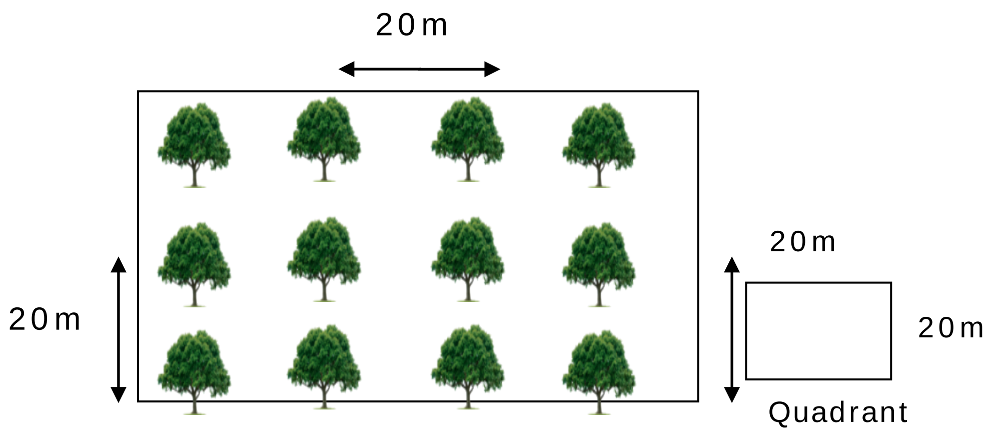


Fig 3.4: Showing sketch of measuring of orchard plantations

3.8 Tree Biomass Estimation

The biomass of tree is the sum of aboveground and belowground biomass content. For accurate measure of biomass in tree, it has to be felled. To avoid this, the standing woody biomass has been estimated using important growth parameter such as DBH and height. Tree height and DBH are the most common independent variables needed for the estimation of tree volume (Avery and Burkhart, 2001).

3.8.1 Tree height (m)

The height of tree was measured from ground level to the tip of the tree with the help of Hager Altimeter. The height of all trees per sample unit per replication was recorded and its average was calculated.

3.8.2 Diameter at breast height (cm)

The diameter at breast height (DBH) of stem of the trees was measured in centimeters at breast height (1.37 m from ground level) with the help of diameter ruler. The observations of diameter were taken on all the trees per sample unit per replications and its average was also calculated in each land use systems.

3.8.3 Aboveground tree biomass (kg/tree)

Assessment of aboveground tree biomass can be undertaken non-destructively using allometric biomass regression equations. For aboveground tree biomass (AGTB) calculation IPCC recommended methodology was used. In this systems, allometric equation for estimating biomass (kg/tree) from tree diameter 5-60 cm of different zones developed by (Chave *et al.*2005) on the basis of climate and forest stand types.

(AGB)est = 0.0509 x ρD2H(Chave *et al.*2005)

Note: AGB = Estimated aboveground tree biomass (kg/tree)

D = DBH, diameter at breast height (cm)

H = tree height (m)

ρ = Wood specific gravity (Mg m^{-3})

Palms

Usually palm species such as *Cocos nucifera, Phoenix sylvestris, Areca catechu* are common in homestead of Bangladesh (Kabir and Webb, 2010). The following equations for palms will be used for AGB calculation:

$AGB = 6.666 + 12.826 \times ht^{0.5} \times \ln(ht)$ (Brown *et al.,* 2001).

AGB = Above ground biomass; ln = Natural logarithm; ht = Height

3.8.4 Belowground Tree biomass (kg/tree)

Belowground tree biomass (BGTB) of trees was calculated by multiplying AGTB with a default value of 0.27, provided by IPCC (IPCC, 2006). The belowground biomass has also been calculated by multiplying the above ground biomass (AGB) by 0.26 factors as the root: shoot ratio (Hangarge *et al.,* 2012).

$$\text{Below ground biomass} = \text{Aboveground biomass} \times 0.26$$

3.8.5 Total tree biomass (kg/tree)

Total tree biomass (TTB) was calculated by summing aboveground biomass and belowground biomass.

$$\text{Total biomass} = AGB + BGB$$

3.9 Estimation of leaf litter, herb, and grass biomass (kg/m^2)

Litter fall from the trees and shrubs, herbs, grass was collected under the canopies of stands by using quadrates of 1 x 1 m^2. Three quadrates randomly placed and collected all the vegetation or rice present. Fresh weight and dried at 65-75^{0}C for 72 h, and weighed on a digital balance and litter fall or rice biomass per kg/m^2 was calculated using the formula below.

$$LGH = \frac{W_{field}}{A} \times \frac{W_{subsample,dry}}{W_{subsample,wet}} \times \frac{1}{10000}$$

Where,

LHG= biomass of leaf litter, herbs, and grass [t ha^{-1}]

A= size of the area in which leaf litter, herbs, and grass were collected [ha]

W field = *weight* of the fresh field sample of leaf litter, herbs, and grass, destructively sampled within an area of size A [g];

W subsample, dry = weight of the oven-dry sub-sample of leaf litter, herbs, and grass taken to the laboratory to determine moisture content [g]; and

W subsample, wet = weight of the fresh sub-sample of leaf litter, herbs, and grass taken to the laboratory to determine moisture content [g].

3.10 Estimation of carbon stock in trees (tC/ha)

Generally, for any plant species 50% of its biomass is considered as carbon (Pearson *et al.* 2005) i.e.

$$\text{Carbon Stock in tree biomass} = \text{Biomass x } 0.5$$

3.11 Estimation of carbon stock in Leaf litter, herb, and grass (LHG) (tC/ha)

The carbon content in LHGB is calculated by multiplying LHG with the IPCC (2006) default carbon fraction of 0.47. The biomass of branches and leaves are 45% and 11% of stem biomass respectively (Sharma, 2003).

$$\text{Carbon Stock in LHG } (kg/m^2) = \text{Biomass} \times 0.47$$

3.12 Estimation of Carbon Sequestered (t/ha) by tree

To estimate CO_2sequestration of crops and trees, the biomass carbon was multiplied with a factor of 3.67 for all species by using a formula and the total carbon stock can also be converted to tons of CO_2 equivalent by multiplying it by 44/12 or 3.67 (Pearson *et al.*2007).

$$\text{Estimated Carbon sequestration (t/ha)} = \text{Biomass carbon} \times 3.67$$

3.13 Total carbon sequestration (t/ha) by vegetation

In order to achieve the total carbon sequestration by a particular agroforestry systems, total biomass should be summed.

Total agroforestry systems carbon sequestration

= Tree CO_2 sequestration + LHG CO_2 sequestration + soil CO_2 sequestration

3.14 Determination of organic carbon in soil

For the determination of organic carbon in soil by wet oxidation method, the reaction is carried out with 3 ml $K_2Cr_2O_7$ and 6 ml H_2SO_4 in small vials and Cr^{3+} resulting from organic carbon oxidation is determined by spectrophotometry. No special equipment is needed and handling is reduced to a minimum, enabling over 100 samples per day to be analyzed. There is one important detail in the operation protocol: the vials are placed inside an insulator block during oxidation. Heat insulation retards the cooling of vials, which results in a high organic carbon recovery (over 0.90). The improved method is feasible, simple and easy to perform. Reproducibility was lower than 10% and recoveries from certified reference materials were about 90%. The simplified method is recommended for widespread organic carbon content sampling (Mingorance *et al*. 2007).

3.15 Calculation of organic carbon storage in soil

Organic Carbon concentration of different agroforestry systems in 0-15 cm depth was varied due to different agroforestry systems and AEZs.

1) For 0-15 cm soil depth:

1 ha soil with 15 cm depth weighs 2×10^6 kg (According to Rahman, M. M, 2013)

Say, Organic carbon = x% was present on the soil

That means, 100 kg soil contains x kg organic carbon

Therefore, 2×10^6 kg soil contains $\frac{2 \times 10^6 \times x}{100}$ kg organic carbon per ha

2) For, 16-30 cm soil depth:

1 ha soil with 15 cm depth weighs 2×10^6 kg (According to Rahman, M. M, 2013)

Say, Organic carbon = x% was present on the soil

That means, 100 kg soil contains x kg organic carbon

Therefore, 2×10^6 kg soil contains $\frac{2 \times 10^6 \times x}{100}$ kg organic carbon per ha

3.16 Statistical analysis

Data were statistically analyzed using the “Analysis of variance” (ANOVA) technique with the help the computer software Statistics-10. The means differences were adjusted by Tukey HSD test.

CHAPTER IV
RESULTS AND DISCUSSIONS

The study was conducted to estimate the biomass accumulation and carbon sequestration from different Agro ecological zones (AEZ) in Dinajpur district, Bangladesh. The results of the study are presented in Table 4.1 to 4.9 in this chapter. Moreover, the findings of the study and interpretations of the results are discussed under the following sub heading to achieve the objectives of the study.

4.1 Main effect of different agroforestry systems on biomass accumulation

4.1.1 Tree Height (m) of different agroforestry systems

Height of trees (m) was significantly varied in respect of different agroforestry systems (Table 4.1). It was observed that the tallest tree stand (15.21 m) was recorded from Eucalyptus cropland based agroforestry systems (T_2) which was followed by Mahogany cropland based agroforestry systems (T_3). On the other hand, the shortest tree stand (6.67 m) was recorded from Mango Orchard based agroforestry systems (T_4). From the result, it showed that tree height at different agroforestry practices controlled by different factors such as growth habit, climatic and soil attributes, age, genetic makeup, management practices followed etc. Actually, the tree height is one of the growth variables that strongly influenced by the site conditions. Paige and Daniel (2014) explained that trees in high density stands may demonstrate accelerated development relative to sparser stands. In our study, eucalyptus were grown in the boundary of cropland that's why it got enough space and natural resources for quick grow. Moreover, in nature eucalyptus is a fast growing tree species.

4.1.2 Diameter at breast height (cm) of different agroforestry systems

The diameter at breath height (DBH) of trees was also varied according to the agroforestry systems (Table 4.1). It was observed that mango orchard based agroforestry systems (T_4) gave the widest DBH (31.38cm) which followed by litchi orchard based agroforestry systems (T_5). On the other hand, the smallest DBH (15.00cm) was recorded from mahogany cropland based agroforestry systems (T_3) which was followed by eucalyptus cropland based agroforestry systems (T_2). Indeed, in case of fruit garden, the tree species i.e. mango and litchi get more care, more nutrients and standard space. Therefore, the diameter growth was highest as compare to other agroforestry systems. The mean DBH of the present study was partially similar to Jaman *et al.* (2016), who found the mean DBH of home gardens in Ranpur districts was 11.23 cm. Variation in DBH might be due to variation of different agroforestry practices which are also influenced by rainfall, local temperature, soil type and management practices. The effect of planting density on tree size (DBH) has been investigated for several species. Similar variations of DBH under different land use systems were also reported by Chavan and Rasal (2010). Prasad *et al.* (2010) reported similar findings with DBH/collar diameter in *A. procera*.

4.1.3 Aboveground tree biomass (kg/tree) of different agroforestry systems

The aboveground tree biomass (AGTB) was also affected by the variation of different agroforestry systems (Table 4.1). The highest ABG (116.75kg) was recorded from mango orchard based agroforestry systems (T_4) which is followed by litchi orchard based agroforestry systems (T_5). Again, the lowest ABG (156.17kg) was observed from mahogany cropland based agroforestry systems (T_4) and it was followed by homestead agroforestry systems (T_1). However, the ranking of different agroforestry systems in respect of AGTB were T_4>T_5>T_3>T_1>T_2. Actually, tree biomass is depend on the tree volume which is also the cumulative impact of tree height and DBH. The factors like forest type, tree density, tree age and local climatic factors all affect the total AGTB as pointed out by numerous researchers. Prasad *et al.* (2010) reported that total dry biomass of some agroforestry tree species varied from species to species.

4.1.4Belowground tree biomass (kg/tree) of different agroforestry systems

The belowground tree biomass (BGTB) was also varied according to different agroforestry systems (Table 4.1). It was observed that mango orchard based agroforestry systems (T_4) gave the highest (96.23kg) BGTB which was followed by litchi orchard based agroforestry system (T_5). On the other hand, the lowest BGTB (40.61kg) was obtained from mahogany cropland based agroforestry systems (T_3) which was followed by homestead (T_1) and eucalyptus cropland based agroforestry systems (T_2).The ranking of different agroforestry systems in respect of AGTB were $T_4>T_5>T_3>T_1>T_2$. The belowground biomass can be calculated by multiplying the aboveground biomass (AGB) by 0.26 factors as the root: shoot ratio (Hangarge *et al.,* 2012). Similar scenarios were found in order to estimate the root biomass using aboveground data developed by FAO (2000).

4.1.5 Total tree biomass (kg/tree) of different agroforestry systems

The total tree biomass (TTB) was significantly varied with the agroforestry systems (Table 4.1). The highest TTB (466.33kg) was found from mango orchard based agroforestry systems (T_4) which was followed by litchi orchard based agroforestry systems (T_5). On the other hand, the lowest TTB (196.78kg) was recorded from mahogany based cropland agroforestry systems (T_3) which was followed by homestead agroforestry systems (T_1). The ranking of different agroforestry systems in respect of AGTB and BGTB were $T_4>T_5>T_3>T_1>T_2$, because mango field get proper space and it has the ability to absorb sufficient nutrients and its height is considerable with other fruit trees. Khaki and Wani (2011) estimated maximum total ground biomass (181.34 t/ha) in *Shorea robusta* pure forest, which was followed by Agrisilviculture systems (46.02 t/ha) and lowest in natural grass land (4.47 t/ha). In Brazil, Schroth *et al.* (2002) observed that multi-strata systems had an aboveground biomass of 13.2-42.3 Mg ha^{-1} and a belowground biomass of 4.3-12.9 Mg ha^{-1} compared to those of monoculture at 7.7-56.7 Mg ha^{-1} and 3.2-17.1 Mg ha^{-1}, respectively.

4.1.6 Leaf litter, herbs, grass biomass (kg/m^2) of different agroforestry systems

Leaf litter, herb, grass biomass (LHGB) was also varied from agroforestry systems (Table 4.1). Study reveals that homestead agroforestry systems (T_1) produces the highest LHGB (1.51kg) which was followed by litchi orchard based agroforestry systems (T_5). The smallest LHGB (0.52kg) was observed from biomass under mango orchard based agroforestry systems (T_5) followed by eucalyptus (T_2) and mahogany cropland based agroforestry systems (T_3). Maximum biomass produced by agroforestry practices might be attributed due to the organic soil condition and habit of growth. Ding and Su (2010) reported that tree shading have great influenced in crop yield. Moreover, he also explain that, changes of incident photo synthetically active radiation (PAR), air temperature (Ta) and CO_2 concentration were the basic reasons of yield variation among different regions. The similar findings were confronted with Patel, S.S, (2012).

Table 4.1: Main effect of agroforestry systems on biomass accumulation

Agroforestry systems	Tree height (m)	DBH (cm)	AGB (kg/tree)	BGB (kg/tree)	TTB (kg/tree)	LHG (kg/m²)
Homestead	10.98 c	19.35 c	213.24 c	55.44 c	268.68 c	1.51 a
Cropland (E)	15.21 a	16.49 d	221.49 c	57.59 c	279.08 c	0.57 cd
Cropland (M)	13.04 b	15.00 e	156.17 d	40.61 d	196.78 d	0.60 bc
Orchard (Ma)	7.38 d	31.38 a	370.10 a	96.23 a	466.33 a	0.52 d
Orchard (L)	6.67 d	29.33 b	294.61 b	76.60 b	371.21 b	0.66 b
CV (%)	7.69	3.65	11.18	11.18	11.18	7.88

In a column, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per Tukey HSD test).

4.1.7 Number of trees per hectare (no/ha) of different agroforestry systems

The number of trees (NT/ha) was significantly varied for different agroforestry systems (Table4.3). The maximum tree stands (1026.2/ha) was recorded from homestead agroforestry systems (T_1) which was followed by litchi orchard based agroforestry systems (T_5). On the other hand, the minimum tree stands (115.8/ha) was recorded from mahogany cropland based agroforestry systems (T_3) which was followed by eucalyptus cropland based agroforestry systems (T_2). The number of trees per hectares varied according to different agroforestry practices (Newaj and Dhyani, 2008).

4.2 Main effect of different agroforestry systems on carbon stock

4.2.1Aboveground carbon stock (kg/tree) of different agroforestry systems

Aboveground carbon stock (AGCS) was significantly varied according to agroforestry systems (Table 4.2). The highest AGCS (185.05kg) was found from mango orchard based agroforestry systems (T_4) which was followed by litchi orchard based agroforestry systems (T_5). Similarly, the lowest AGCS (78.09kg) was recorded from mahogany cropland based agroforestry systems (T_3) which was followed by homestead agroforestry systems (T_1). Baral *et al.* (2009) also reported that according to forest types, age and its geographical location there was considerable variation in the above ground carbon stock and rate of carbon sequestration rate.

4.2.2 Belowground carbon stock (kg/tree) of different agroforestry systems

The belowground carbon stock (BGCS) was also varied due to different agroforestry systems (Table 4.2). The highest BGCS (48.11kg) was recorded from mango orchard based agroforestry systems (T_4) which was followed by litchi orchard based agroforestry systems (T_5). Similarly, the lowest BGCS (20.30kg) was also found from mahogany cropland based agroforestry systems (T_3) which was followed by homestead agroforestry systems (T_1).

4.2.3 Total tree carbon stock (kgC/tree) of different agroforestry systems

The total tree carbon stock (TTCS) was also influenced significantly by different agroforestry systems (Table 4.2). The highest TTCS (233.16 kg C) was recorded from mango orchard based agroforestry systems (T_4) which was followed by litchi orchard based agroforestry systems (T_5) and the lowest TTCS (98.39kgC) was found from mahogany cropland based agroforestry systems (T_3) which was followed by homestead agroforestry systems (T_1). The above results thus have indicated that biomass components viz., aboveground biomass, belowground biomass and total biomass produced by particular agroforestry practices was influenced by variation in biomass allocation pattern and might be attributed due to the divergence in these agroforestry practices or wide range of habit or bushy nature of growth and age variations. Thus we can say that the rate of carbon stock depend upon the nature of the crop, intensity of the management and soil types. Similar finding were reported by Rajput (2010).

4.2.4 Leaf litter, herb, grass (kg/m^2 C) of different agroforestry systems

Leaf litter, herb, grass (LHG) was also influenced by different agroforestry systems (Table 4.2). The highest LHG (0.71kg) was observed from homestead homestead agroforestry systems (T_1) followed by litchi orchard based agroforestry systems (T_5). Whereas, the lowest LHG (0.24kg) was also observed from mango orchard based agroforestry systems (T_4) which was followed by eucalyptus cropland based agroforestry systems (T_2). The variation in LHGCS might be due to biomass accumulations under the systems. The systems was influenced by two major activities, aboveground litter decomposition and belowground root activity (Lemma *et al.*2007). Systems with high tree density, it is likely that they would have more leaf litters, herbs and grasses and high carbon stocking ability compared to sole rice biomass.

Table 4.2: Main effect of different agroforestry systems on carbon stock

Agroforestry systems	AGCS (kg/tree)	BGCS (kg/tree)	TTCS (kg/tree)	LHG/RCS (kg/m^2)
Homestead	106.62 c	27.72 c	134.34 c	0.71 a
Cropland (E)	110.74 c	28.79 c	139.54 c	0.27 cd
Cropland (M)	78.09 d	20.30 d	98.39 d	0.28 bc
Orchard (Ma)	185.05 a	48.11 a	233.16 a	0.24 d
Orchard (L)	147.31 b	38.30 b	185.60 b	0.31 b
CV (%)	11.18	11.18	11.18	7.88

In a column, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per Tukey HSD test).

4.2.5 Total tree carbon stock per hectare (t/ha C) of different agroforestry systems

The total tree carbon stock (TTCS) was significantly varied in respect of different agroforestry systems (Table 4.3). The highest TTCS (138.38 t C) was recorded from homestead agroforestry systems (T_1) which was followed by mango orchard based agroforestry systems (T_4). Again, the lowest TTCS (11.61 t C) was also recorded from mahogany cropland based agroforestry systems (T_3) followed by eucalyptus cropland based agroforestry systems (T_2). Prasad *et al.* (2010) reported that total dry biomass of some agroforestry tree species varied from species to species. Khaki and Wani (2011) analysed maximum carbon density in pure *Shorea robusta* forest (81.60 C t/ha), followed by agrisilviculture systems (20.70 t/ha) and lowest in natural grassland (2.01 C t/ha). Rajput (2010) also reported similar results for maximum rate of carbon stock (8.40 t/ha) in the Orchard +Cereal-Cereal agroforestry systems, which was found to be 4-5 times higher over the other agroforestry systems. Charles *et al.* (2014) recorded higher stock of carbon density in woodlots (57 C Mg/ha) which was followed by home gardens (18.5 C Mg/ha) and parkland/simple agroforestry systems (10.7 C Mg/ha). Firdaus *et al.* (2010) estimated13.0 Mg/ha carbon in 32 month old *J. curcas.*

4.2.6 Leaf litter, herb, grass carbon stock per hectare (t/ha C) of different agroforestry systems

Leaf litter, herb, grass or rice carbon stock (LHGCS) was also influenced by different agroforestry systems (Table 4.3). The maximum

LHGCS (15.06 t/ha C) was obtained from homestead agroforestry systems (T_1) which was followed by litchi orchard based agroforestry systems (T_5). Again, the minimum LHGCS (5.18 t/ha C) was also obtained from mango orchard based agroforestry systems (T_4) which was followed by eucalyptus cropland based agroforestry systems (T_2). The variations in leaf litter carbon stock rates may be due to the conversion of total biomass into carbon, high abscission, variation in phonology and structure of leaf, age and crown architecture of tree species, genetic characteristics of the species in general.

4.2.7 Total tree carbon sequestration per hectare (t/ha) of different agroforestry systems

Total tree carbon sequestration (TTCseq) was varied significantly in respect of agroforestry systems (Table 4.3). The result indicate that homestead agroforestry systems (T_1) got the highest TTCseq (507.86 t/ha C) which was followed by mango orchard based agroforestry systems (T_4). The lowest TTCseq (42.61 t/ha C) was observed from mahogany cropland based agroforestry systems (T_3) which was followed by eucalyptus cropland based agroforestry systems (T_2).

4.2.8 Leaf litter, herb, grass carbon sequestration per hectare (t/ha) of different agroforestry systems

Leaf litter, herb, grass carbon sequestration (LHGCseq) was also influenced by different agroforestry systems (Table 4.3). It was observed that the highest LHGCseq (48.51 t/ha C) was recorded from vegetations under homestead agroforestry systems (T_1) followed by litchi orchard based agroforestry systems (T_5). On the other hand, the lowest LHGCseq (19.02 t/ha C) was observed rice biomass under mango orchard based agroforestry systems (T_4) which is also followed by mahogany cropland based agroforestry systems (T_3).

4.2.9 Total agroforestry systems carbon sequestration (t/ha) without soil

The study also found thatthe total agroforestry systems carbon sequestrations (TASCseq) was highly influenced by the effects of different agroforestry systems (Table 4.3). The highest TASCseq (563.12 t/ha C) was recorded from homestead agroforestry systems (T_1) which was followed by mango (T_4) and litchi orchard based agroforestry systems (T_5). However, the lowest TASCseq (64.66 t/ha C) was recorded from mahogany cropland based agroforestry systems (T_3) followed by eucalyptus cropland based agroforestry systems (T_2). Several studies have been conducted to explore the effects of agroforestry systems on Carbon sequestration and other biophysical factors that affect the systems (Lal *R.*2007). Such practices in cropland are tillage, plant residue management, and manure and fertilizer application have been identified to affect C sequestration (FAO, 1988).

Table 4.3: Main effect of agroforestry systems on carbon sequestration

Agroforestry systems	NT/ha	TTCS (tC/ha)	LHG (tC/ha)	TTCseq (t/ha)	LHGCseq (t/ha)	TLUCseq (t/ha)
Homestead	1026.2	138.38	15.06	507.86	55.26 a	563.12 a
Cropland (E)	174.5 c	23.86 c	5.74 cd	87.58 c	21.07 cd	108.65 c
Cropland (M)	115.8 c	11.61 c	6.01 bc	42.61 c	22.05 bc	64.66 c
Orchard (Ma)	281.0 b	66.39 b	5.18 d	243.66 b	19.02 d	262.68 b
Orchard (L)	319.7 b	59.10 b	6.63 b	216.90 b	24.34 b	241.24 b
CV (%)	19.66	20.05	7.88	20.05	7.88	27.86

In a column, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per Tukey HSD test).

4.3 Main effect of different agroforestry systems on soil carbon sequestration

4.3.1 Carbon Sequestration (t/ha) of soil (0-15cm) of different agroforestry systems

The study showed that different agroforestry systems had different capacity to sequestrate carbon in the soil depth of 0-15 cm. (Table 4.4). Eucalyptus cropland based agroforestry systems (T_2) had the highest capacity (15.87t/ha) to sequestrate carbon which was followed by mahogany cropland based agroforestry systems (T_3). Again, mango orchard based agroforestry systems (T_4) had the lowest capacity (12.75 t/ha) to sequestrate carbon which was followed by homestead agroforestry systems (T_1). In case of 0-15 cm layer of soil, eucalyptus cropland based agroforestry systems gave the highest sequestration ability of CO_2 due to its high biomass stand density and mango orchard based agroforestry systems gave the lowest sequestration ability of CO_2 because its canopy size was large and maximum herbs or shrubs did not get proper sunlight and nutrients.

4.3.2 Carbon sequestration (t/ha) of soil (16-30cm) of different agroforestry systems

The study revealed that the layer of 16-30 cm of soil had also different capacity to sequestrate carbon due to different agroforestry systems (Table 4.4). Here, homestead agroforestry systems (T_1) had the highest capacity (14.53 t/ha) to sequestrate carbon followed by eucalyptus cropland based agroforestry systems (T_2). Again, litchi orchard based agroforestry systems (T_5) had the lowest capacity (12.70 t/ha) to sequestrate carbon followed by mango orchard based agroforestry systems (T_4). In case of 16-30 cm layer of soil, homestead agroforestry system sequestrated more CO_2 because a homestead had different varieties and canopy sizes of trees and these trees had the capacity for deeper root penetration. Otherwise, litchi orchard based agroforestry systems sequestrated lower amount of carbon because it had only one type of trees and little biomass were grown due to lack of sufficient amount of rainfall cause the data were taken in autumn season.

4.3.3 Carbon sequestration (t/ha) of soil (0-30cm) of different agroforestry systems

The study showed that the sum of two layer of soil i.e. (0-15 cm) and (16-30cm) had a little bit difference to sequestrate carbon due to the different agroforestry systems .(Table 4.4). Here, eucalyptus cropland based agroforestry systems (T_2) had the highest capacity (29.92 t/ha) to sequestrate carbon followed by homestead agroforestry systems (T_1). Again, mango orchard based agroforestry systems (T_4) had the lowest capacity (25.67 t/ha) to sequestrate carbon followed by litchi orchard based agroforestry systems (T_5). Here, eucalyptus cropland based agroforestry systems with both sub-soil and deep soil roots could store a moderate amount of CO_2 due to its maximum capacity to soil root penetration.

Table 4.4: Soil carbon sequestration of different agroforestry systems

Treatments	Carbon seq. 0-15 cm soil profile (t/ha)	Carbon seq. 16-30 cm soil profile(t/ha)	Carbon seq. 0-30 cm soil profile(t/ha)
Homestead	13.52	14.53	28.05
Cropland (E)	15.87	14.05	29.92

Cropland (M)	14.47	13.35	27.82
Orchard (Ma)	12.75	12.92	25.67
Orchard (L)	13.58	12.70	26.28
CV (%)	16.42	18.55	17.61

4.4 Total carbon sequestration (t/ha) by different agroforestry systems considering soil

The bar showed that total carbon sequestration was significantly influenced by the different agroforestry systems considering soil. The highest total carbon sequestration (591.17 t/ha) was recorded from homestead agroforestry systems (T_1) which was followed by mango orchard based agroforestry systems (T_4) and litchi orchard based agroforestry systems (T_5). On the other hand, mahogany cropland based agroforestry systems (T_3) sequestrated the lowest amount (92.48 t/ha) of carbon which was followed by eucalyptus cropland based agroforestry systems (T_2). Here, homestead agroforestry systems (T_1) sequestrated the highest amount of carbon because a homestead had different varieties and sizes of trees.

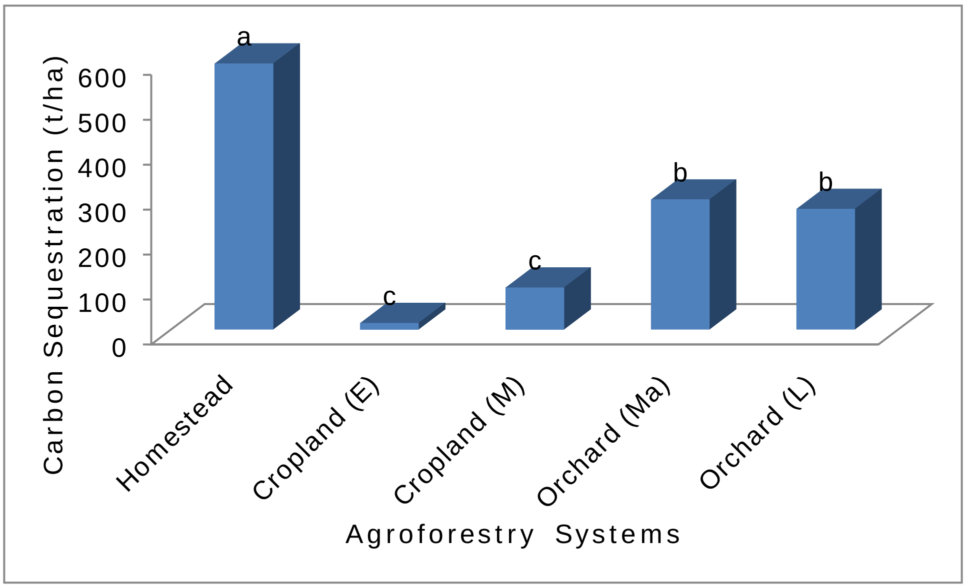


Fig 4.1: Carbon sequestration by different agroforestry systems considering biomass and soil

In a bar, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per Tukey HSD test).

4.5 Main effect of agro-ecological zones (AEZ) on biomass accumulation

4.5.1 Tree height (m) in different AEZs

The study showed that tree height was not affected by the differences in Agro-ecological zones (Table 4.5). The tallest tree height (11.71m) was recorded from AEZ 25 (S_3) which was followed by AEZ 1 (S_1) and the lowest tree height (9.37m) was recorded from AEZ 3 (S_2). It could be due to variability in rainfall, temperature and other climatic factors. Mean annual rainfall is about 1600mm, 15000mm and 2000mm in AEZ 1, AEZ 3 and AEZ 25, respectively (Study on the characterization of the agro-ecological, National Consultant Bangladesh).

4.5.2 Diameter at breast height (cm) in different AEZs

The diameter at breast height (DBH) was significantly influenced by different Agro-ecological zones (Table 4.5). The widest DBH (24.89 cm) was recorded from AEZ 25 (S_3) which was followed by AEZ 1 (S_1) and the smallest DBH (19.67 cm) was recorded from AEZ 3 (S_2). This might be due to stand density which influenced by climatic variation within the AEZ. Diameter measurements had been consistently shown to be the strongest predictors of aboveground tree biomass across a range of species and stand conditions (Chave *et al.* 2005).

4.5.3 Aboveground biomass (kg/tree) in different AEZs

The aboveground biomass (ABG) was also significantly influenced by different Agro-ecological zones (Table 4.5). The highest ABG (337.46 kg) was recorded from AEZ 25 (S_3) which was followed by AEZ 1 (S_1) and the lowest ABG (166.81 kg) was recorded from AEZ 3 (S_2). Species varied considerably in their growth which was primarily controlled by factors such as growth habit, climatic attributes and management practices in different AEZ. Deshmukh (1998) reported that management practices also affect the biomass production of tree grown under different agroforestry systems.

4.5.4 Belowground biomass (kg/tree) in different AEZs

The belowground biomass (BGB) was also significantly influenced by different Agro-ecological zones (Table 4.5). The highest BGB (87.74 kg) was found from AEZ 25 (S_3) which was followed by AEZ 1 (S_1) and the lowest BGB (43.37 kg) was recorded from AEZ 3 (S_2). This might be due to stand density which influenced by climatic variation within the AEZ.

4.5.5 Total tree biomass (kg/tree) in different AEZs

The total tree biomass (TTB) was also significantly influenced by different Agro-ecological zones (Table 4.5). The highest TTB (425.20 kg) was recorded from AEZ 25 (S_3) which was followed by AEZ 1 (S_1) and the lowest TTB (210.18 kg) was recorded from AEZ 3 (S_2). Maximum biomass produced by AZE 25 was influenced by variation in biomass allocation pattern might be attributed due to stand density and wide range of habitat variation and soil condition habit of growth. The similar findings were confronted with Patel (2012).

4.5.6 Leaf litter, herbs, grass biomass (kg/m^2) in different AEZs

The leaf litter, herb, grass biomass (LHGB) was also varied by different Agro-ecological zones (Table 4.5). The highest LHGB (0.84 kg) was recorded from AEZ 1 (S_1) which was followed by AEZ 25 (S_3). On the other hand, the lowest LHGB (0.70 kg) was recorded from AEZ 3 (S_2).

Table 4.5: Main effect of AEZs on biomass accumulation

Name of AEZs	Tree height (m)	DBH (cm)	AGB (kg/tree)	BGB (kg/tree)	TTB (kg/tree)	LHGB (kg/m^2)
AEZ 1	10.89 b	22.38 b	249.10 b	64.77 b	313.86 b	0.84 a
AEZ 3	9.37 c	19.67 c	166.81 c	43.37 c	210.18 c	0.70 c
AEZ 25	11.71 a	24.89 a	337.46 a	87.74 a	425.20 a	0.78 b
CV (%)	7.69	3.65	11.18	11.18	11.18	7.88

In a column, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per Tukey HSD test).

4.6 Main effect of different AEZs on carbon stock

4.6.1 Aboveground carbon stock (kg/tree) in different AEZs

The aboveground carbon stock (AGCS) was significantly varied according to different agro-ecological zones (Table 4.6). The highest AGCS (168.73 kg) was recorded from AEZ 25 (S_3) which was followed by AEZ 1 (S_1). Again the lowest AGCS (83.41 kg) was recorded from AEZ 3 (S_2). This might be due to stand density which influenced by climatic variation within the AEZ. The carbon storage capacity in agroforestry varies across species and geography (Newaj and Dhyani, 2008).

4.6.2 Belowground carbon stock (kg/tree) in different AEZs

The belowground carbon stock (BGCS) was significantly varied according to different in agro-ecological zones (Table 4.6). The highest (43.87 kg) was recorded from AEZ 25 (S_3) which was followed by AEZ 1 (S_1). Also the lowest (21.69 kg) was recorded from AEZ 3 (S_2). This might be due to stand density which influenced by climatic variation within the AEZ.

4.6.3 Total tree carbon stock (C kg/tree) in different AEZs

The total tree carbon stock (TTCS) was significantly influenced by different Agro-ecological zones (Table 4.6). The highest (212.60 kg C) was recorded from AEZ 25 (S_3) which was followed by AEZ 1 (S_1). Similarly, the lowest (105.09 kg C) was recorded from AEZ 3 (S_2). This might be due to stand density, number and intensity of management which are all influenced by climatic variation within the AEZ. The amount of carbon in any agroforestry systems depends on the structure and function of different components within the systems put into practice (Schroeder, 1993; Albrecht and Kandji, 2003).

4.6.4 Leaf litter, herb, grass carbon stock (kg/m^2) in different AEZs

The Leaf litter, herb, grass carbon stock (LHGCS) was also varied by different Agro-ecological zones (Table 4.6). The highest LHGCS (0.39 kg C) was observed from AEZ 1 (S_1) which was followed by AEZ 25 (S_3) and the lowest LHGCS (0.33 kg C) was observed from AEZ 3 (S_2). However, broad leaved trees had higher litter fall production. Rainfall and different climatic condition (temperature, water availability, wind speed, air humidity etc.) directly influence litter production dynamics (Mahmood and Hoque, 2008).

Table 4.6: Main effect of AEZs on carbon stock

Name of AEZs	AGCS (kg/tree)	BGCS (kg/tree)	TTCS (kg/tree)	LHGCS (kg/m^2)
AEZ 1	124.55 b	32.38 b	156.93 b	0.39 a
AEZ 3	83.41 c	21.69 c	105.09 c	0.33 c
AEZ 25	168.73 a	43.87 a	212.60 a	0.37 b
CV (%)	11.18	11.18	11.18	7.88

In a column, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per Tukey HSD test).

4.6.5 Number of trees (no/ha) in different AEZs

The number of trees (NT) was significantly varied according to different in Agro-ecological zones (Table 4.7). The highest number of trees (398.0/ha) was recorded from AEZ 1 (S_1) which was followed by AEZ 25 (S_3) and the lowest number of trees (365.70/ha) was recorded from AEZ 3 (S_2). This might be due to stand density which influenced by climatic variation within the AEZ.

4.6.6 Total tree carbon stock (t/ha C) in different AEZs

The total tree carbon stock (TTCS) was significantly influenced by different Agro-ecological zones (Table 4.7). The highest TTCS (76.0 t/ha C) was recorded from AEZ 25 (S_3) which was followed by AEZ 1 (S_1) and lowest TTCS (36.50 t/ha C) was recorded from AEZ 3 (S_2). This might be due to stand density which influenced by climatic variation within the AEZ. In temperate zones, experiment was conducted under fruit based agroforestry systems and examined the biomass carbon storage (60 t/ha) by Kursten and Burschel (1993). Kraenzel *et al.* (2003) estimated large *T. grandis* tree carbon storage at the plantation level at *Penas blancas* (141 C t/ha), while the smallest was found at the *Aguas claras* Plantation (100 C t/ha).

4.6.7 Leaf litter, herb, grass carbon stock (t/ha C) in different AEZs

The leaf litter, herb, grass carbon stock (LHGCS) was also varied by different Agro-ecological zones (Table 4.7). The largest LHGCS (8.36 t C) was recorded from AEZ 1 (S_1) which was followed by AEZ 25 (S_3) and the lowest LHGCS (7.02 t C) was recorded from AEZ 3 (S_2).

4.6.8 Total tree carbon sequestration (t/ha) in different AEZs

The total tree carbon sequestration (TTCseq) was significantly influenced by different agro-ecological zones (Table 4.7). The highest TTCseq (278.93 t/ha) was recorded from AEZ 25 (S_3) which was followed by AEZ 1 (S_1). Similarly, the lowest TTCseq (133.94 t/ha) was recorded from AEZ 3 (S_2). This might be due to stand density which influenced by climatic variation within the AEZ. Based on these standing woody biomass, carbon sequestration rate of trees (t/ha) were calculated (Amit and Prabhakar 2016).

4.6.9 Leaf Litter, herb, grass carbon sequestration (t/ha) in different AEZs

The Leaf litter, herb, grass carbon sequestration (LHGCseq) was also varied by different Agro-ecological zones (Table 4.7). The highest LHGCseq (30.68 t/ha) carbon sequestration was found from AEZ 1 (S_1) which was followed by AEZ 25 (S_3) and the lowest LHGCseq (25.75 t/ha) was observed from AEZ 3 (S_2).

4.6.10 Total carbon sequestration (t/ha) in different AEZs

The total carbon sequestration (TASCseq) was significantly influenced by different agro-ecological zones (Table 4.7). The highest TASCseq (307.56 t/ha) was recorded from AEZ 25 (S_3) which was followed by AEZ 1 (S_1). On the other hand, the lowest TASCseq (159.68 t/ha) was recorded from AEZ 3 (S_2). However, AEZ 25 (S_3) have more potentials in sequestering carbon due to high tree stand density which influenced by high mean annual rainfall. Tree crop sequestered carbon at a higher rate than those containing only annual crops or grass lands (Brakas and Aune, 2011). It can be showed that variability in the carbon dioxide sequestration potential under various Agro-ecological zones depends primarily on climatic factors as rainfall, temperature and soil, which influenced the stand density and finally carbon sequestration ability. Rajput (2010) reported similar result with mean maximum rate of CO_2 sequestration potential (30.86 t/ha/yr) by orchard + cereal agroforestry systems followed by pure orchard. Hence, tree plantation sequestrate more carbon and are better option for reducing atmospheric carbon, they cannot be extended to large areas due to population pressure and high demand of land for agriculture purposes. Therefore, agroforestry systems seem to be a better option and simultaneously harness the opportunity for biodiversity conservation and economic benefits to different agro-ecological zones of Dinajpur and Bangladesh at large.

Table 4.7: Main effect of AEZs on carbon sequestration

Name of AEZs	NT/ha	TTCS (t/ha)	LHGCS (t/ha)	TTCseq (t/ha)	LHGCseq (t/ha)	TASCseq (t/ha)
AEZ 1	398.00	67.11	8.36 a	246.29	30.68 a	276.97 a
AEZ 3	365.70	36.50	7.02 c	133.94	25.75 c	159.68 b
AEZ 25	386.60	76.00	7.80 b	278.93	28.63 b	307.56 a
CV (%)	19.66	20.05	7.88	20.05	7.88	27.86

In a column, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per Tukey HSD test).

4.7 Main effect of different AEZs in soil carbon sequestration

4.7.1 Carbon sequestration (t/ha) of soil (0-15cm) of three AEZs

The carbon sequestration capacity of the soil layer of 0-15 cm was significantly varied due to different agro-ecological zones (Table 4.8). AEZ 1 i.e. Old Himalayan Piedmont Plain sequestrated the highest amount of soil carbon (14.87 t/ha) followed by AEZ 25 i.e. Level Barind Tract. On the other hand, AEZ 3 i.e. Tista Meander Floodplain sequestrated lowest amount of carbon (12.93 t/ha). The sequence of the carbon sequestration capacity of three AEZs within 0-15 cm soil layer was AEZ 1>AEZ 25>AEZ 3.

4.7.2 Carbon sequestration (t/ha) of soil (16-30 cm) of three AEZs

The carbon sequestration within soil layer of 16-30 cm was also significantly varied due to different agro-ecological zones (Table 4.8). Here, AEZ 25 i.e. Level Barind Tract sequestrated the highest amount of carbon (14.33 t/ha) followed by AEZ 1 i.e. Old Himalayan Piedmont Plain. And AEZ 3 i.e. Tista Meander Floodplain sequestrated the lowest amount of carbon (12.16 t/ha). The sequence of three AEZs of sequestrating carbon within the soil layer of 16-30 cm was AEZ 25 > AEZ 1 > AEZ 3.

4.7.3 Carbon sequestration (t/ha) of soil (0-30cm) of three AEZs

The layer of 0-30 cm is the total of 0-15 cm and 16-30 cm soil layer (Table 4.8). It was also significantly varied and there was a little bit difference of sequestrating carbon in these three AEZs. Here, we found that AEZ 1 i.e. Old Himalayan Piedmont Plain sequestrated highest amount of carbon (28.97 t/ha) followed by AEZ 25. And AEZ 3 i.e. Tista Meander Floodplain sequestrated lowest amount of carbon (25.09 t/ha). So, the sequence was AEZ 1 > AEZ 25 > AEZ 3.

Table 4.8: Soil carbon sequestration in the selected three AEZs

AEZs	Carbon seq. 0-15 cm soil profile(t/ha)	Carbon seq. 16-30 cm soil profile(t/ha)	Carbon seq. 0-30 cm soil profile(t/ha)
AEZ 1	14.87	14.04	28.97
AEZ 3	12.93	12.16	25.09
AEZ 25	14.25	14.33	28.58
CV (%)	16.42	18.55	17.61

4.8 Total carbon sequestration (t/ha) by three AEZs considering soil

The bar showed that total carbon sequestration was significantly influenced by the three AEZs considering soil. The highest (336.14 t/ha) carbon sequestration was recorded from AEZ 25 i.e. Level Barind Tract which was followed by AEZ 1 i.e. Old Himalayan Piedmont Plain. The lowest (184.77 t/ha) carbon sequestration was recorded from AEZ 3 i.e. Tista Meander Floodplain.

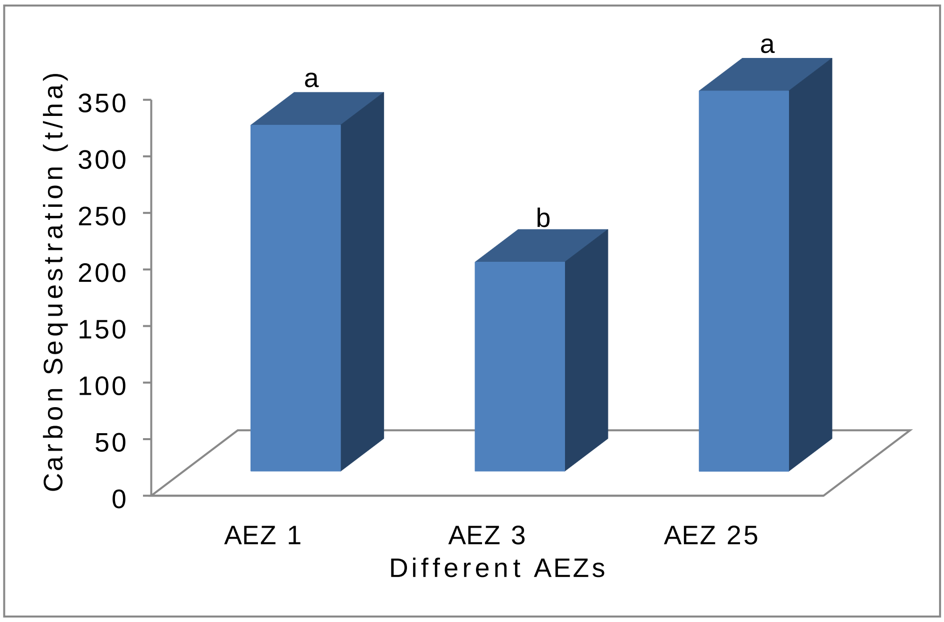


Fig 4.2: Carbon sequestration by different AEZs considering biomass and soil

In a bar, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per Tukey HSD test).

4.9 Interaction effects of different agroforestry systems and AEZs on biomass accumulation

4.9.1 Tree height (m) in interaction between different agroforestry systems and AEZs

Tree height affected the interaction effect of AEZ and agroforestry systems (Table 4.9). The tallest tree height (17.50m) was recorded in S_3T_2 (AEZ 25 + eucalyptus cropland based agroforestry systems) which was followed by S_1T_2 (AEZ 1 + eucalyptus cropland based agroforestry systems) and S_3T_3 (AEZ 25 + mahogany cropland based agroforestry systems). On the other hand, the shortest tree height (5.75m) was recorded in S_2T_5 (AEZ 3 + litchi orchard based agroforestry systems) which was followed by S_2T_4 (AEZ 3 + mango orchard based agroforestry systems) and S_1T_5 (AEZ 1 + litchi orchard based agroforestry systems).

4.9.2 Diameter at breast height (cm) in interaction between different agroforestry systems and AEZs

The DBH was also observed significantly by the interaction effect of AEZ and agroforestry systems (Table 4.9). The widest DBH (33.06cm) was recorded in S_3T_4 (AEZ 25 + mango orchard based agroforestry systems) which was followed by S_1T_4 (AEZ 1 + mango orchard based agroforestry systems) and S_1T_5 (AEZ 1 + litchi orchard based agroforestry systems). Similarly, the smallest DBH (3.11cm) was recorded in S_3T_5 (AEZ 25 + litchi orchard based agroforestry systems) which was followed by S_2T_3 (AEZ 3 + mahogany cropland based agroforestry systems) and S_1T_3 (AEZ 1 + mahogany cropland based agroforestry systems).

4.9.3 Aboveground biomass (kg/tree) in interaction between different agroforestry systems and AEZs

The aboveground biomass (AGB) was also influenced by the interaction effect of AEZ and agroforestry systems (Table 4.9). The highest AGB (453.71kg) was observed in S_3T_4 (AEZ 25 + mango orchard based agroforestry systems) which was followed by S_3T_5 (AEZ 25 + litchi orchard based agroforestry systems) and S_1T_4 (AEZ 1 + mango orchard based agroforestry systems). Again, the lowest AGB (94.96 kg) was similarly observed in S_2T_3 (AEZ 3 + mahogany cropland based agroforestry systems) which was followed by S_1T_3 (AEZ 1 + mahogany cropland based agroforestry systems) and S_2T_1 (AEZ 3 + homestead agroforestry systems).

4.9.4 Belowground biomass (kg/tree) in interaction between different agroforestry systems and AEZs

The belowground biomass (BGB) was also significantly influenced by the interaction effect of AEZ and agroforestry systems (Table 4.9). The highest BGB (117.97 kg) was recorded in S_3T_4 (AEZ 25 + mango orchard based agroforestry systems) which was followed by S_1T_4 (AEZ 1 + mango orchard based agroforestry systems) and S_3T_5 (AEZ 25 + litchi orchard based agroforestry systems). On the other hand, the lowest BGB (24.69kg) was recorded in S_2T_3 (AEZ 3 + mahogany cropland based agroforestry systems) which was followed by S_1T_3 (AEZ 1 + mahogany cropland based agroforestry systems) and S_2T_1 (AEZ 3 + homestead agroforestry systems).

4.9.5 Total tree biomass (kg/tree) in interaction between different agroforestry systems and AEZs

The total tree biomass (TTB) was also found insignificant by the effect of interaction between AEZ and agroforestry systems (Table 4.9). The highest TTB (571.68 kg) was recorded in S_3T_4 (AEZ 25 + mango orchard based agroforestry systems) which was followed by S_1T_4 (AEZ 1 + mango orchard based agroforestry systems) and S_3T_5 (AEZ 25 + litchi orchard based agroforestry systems). Also, the lowest TTB (119.65 kg) was recorded in S_2T_3 (AEZ 3 + mahogany cropland based agroforestry systems) which was followed by S_1T_3 (AEZ 1 + mahogany cropland based agroforestry systems) and S_2T_1 (AEZ 3 + homestead agroforestry systems).

4.9.6 Leaf litter, herbs, grass biomass (kg/m^2) in interaction between different agroforestry systems and AEZs

The leaf litter, herbs, grass biomass (LHGB) was similarly varied by the interaction effect of AEZ and agroforestry systems (Table 4.9). The highest LHGB (1.61 kg) was observed in S_1T_1 (AEZ 1 + homestead agroforestry systems) which was followed by S_3T_1 (AEZ 25 + homestead agroforestry systems) and S_2T_1 (AEZ 3 + homestead agroforestry systems). On the other hand, the lowest LHGB (0.44 kg) was also observed in S_3T_2 (AEZ 25 + eucalyptus cropland based agroforestry systems) which was followed by S_2T_4 (AEZ 3 + mango orchard based agroforestry systems) and S_1T_4 (AEZ 1 + mango orchard based agroforestry systems).

Table 4.9: Interaction effect of different agroforestry systems and AEZs on biomass accumulation

Interactions	Tree height (m)	DBH (cm)	AGB (kg/tree)	BGB (kg/tree)	TTB (kg/tree)	LHGB (kg/m^2)
S_1T_1	12.32 cde	20.33 ef	256.43 de	66.67 de	323.10 de	1.61 a
S_1T_2	15.25 b	15.42 gh	183.06 fg	47.60 fg	230.66 fg	0.70 c
S_1T_3	13.00 cd	13.88 hi	125.96 gh	32.75 gh	158.71 gh	0.67 cd
S_1T_4	7.38 hi	32.00 ab	379.98 b	98.79 b	478.77 b	0.51 ef
S_1T_5	6.50 hi	30.26 bc	300.05 cd	78.01 cd	378.06 cd	0.70 c
S_2T_1	9.95 fg	15.96 g	128.44 gh	33.40 gh	161.84 gh	1.37 b
S_2T_2	12.88 cd	14.08 ghi	128.57 gh	33.43 gh	162.00 gh	0.58 cdef
S_2T_3	11.75 def	12.63 i	94.96 h	24.69 h	119.65 h	0.52 def
S_2T_4	6.50 hi	29.06 c	276.62 de	71.92 de	348.54 de	0.46 f
S_2T_5	5.750 i	26.63 d	205.46 ef	53.42 ef	258.89 ef	0.59 cdef
S_3T_1	10.67 ef	21.76 e	254.84 de	66.26 de	321.10 de	1.55 a
S_3T_2	17.50 a	19.98 ef	352.84 bc	91.74 bc	444.58 bc	0.44 f
S_3T_3	14.38 bc	18.50 f	247.60 def	64.38 def	311.97 def	0.62 cde
S_3T_4	8.25 gh	33.06	453.71 a	117.97 a	571.68	0.59

		a				cdef
S_3T_5	7.750 HI	3.11 abc	378.31 b	98.36 b	476.68 b	0.71 c
CV (%)	7.69	3.65	11.18	11.18	11.18	7.88

In a column, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per Tukey HSD test).

Where, S_1T_1= Homestead in AEZ 1; S_1T_2 = Cropland (E) in AEZ 1; S_1T_3=cropland (M) in AEZ 1; S_1T_4=Orchard (Ma) in AEZ 1; S_1T_5=Orchard (L) in AEZ 1; S_2T_1=Homestead in AEZ 3; S_2T_2=Cropland in AEZ 3; S_2T_3= Cropland in AEZ 3; S_2T_4= Orchard in AEZ 3; S_2T_5= Orchard in AEZ 3; S_3T_1=Homestead in AEZ 25; S_3T_2=Cropland in AEZ 25; S_3T_3=Cropland in AEZ 25; S_3T_4=Orchard in AEZ 25; S_3T_5=Orchard in AEZ 25

4.10 Interaction effect of different agroforestry systems and AEZs on carbon stock

4.10.1 Aboveground carbon stock (kg/tree) in interaction between different agroforestry systems and AEZs

Aboveground carbon stock (AGCS) was influenced by the interaction effect of AEZ and agroforestry systems (Table 4.10). The highest AGCS (226.86 kg) was recorded in S_3T_4 (AEZ 25 + mango orchard based agroforestry systems) which was followed by S_1T_4 (AEZ 1 + mango orchard based agroforestry systems) and S_3T_5 (AEZ 25 + litchi orchard based agroforestry systems). On the other hand, the lowest AGCS (47.48 kg) was recorded in S_2T_3 (AEZ 3 + mahogany cropland based agroforestry systems) which was followed by S_1T_3 (AEZ 1 + mahogany cropland based agroforestry systems) and S_2T_1 (AEZ 3 + homestead agroforestry systems).

4.10.2 Belowground carbon stock (kg/tree) in interaction between different agroforestry systems and AEZs

The belowground carbon stock (BGCS) was also found insignificant by the interaction effect of AEZ and agroforestry systems (Table 4.10). The highest BGCS (58.98 kg) was observed in S_34_2 (AEZ 25 + mango orchard based agroforestry systems) which was followed by S_1T_4 (AEZ 1 + mango orchard based agroforestry systems) and S_3T_5 (AEZ 25 + litchi orchard based agroforestry systems). On the other hand, the lowest BGCS (12.35 kg) was observed in S_2T_3 (AEZ 3 + mahogany cropland based agroforestry systems) which was followed by S_1T_3 (AEZ 1 + mahogany cropland based agroforestry systems) and S_2T_1 (AEZ 3 + homestead agroforestry systems).

4.10.3 Total tree carbon stock (kg/tree C) in interaction between different agroforestry systems and AEZs

The total tree carbon stock (TTCS) was also found insignificant by the interaction effect of AEZ and agroforestry systems (Table 4.8). The highest tree carbon stock (285.84 kg) was recorded in S_3T_4 (AEZ 25 + mango orchard based agroforestry systems) which was followed by S_1T_4 (AEZ 1 + mango orchard based agroforestry systems) and S_3T_5 (AEZ 25 + litchi orchard based agroforestry systems). On the other hand, the lowest tree carbon stock (59.83 kg) was recorded in S_2T_3 (AEZ 3 + mahogany cropland based agroforestry systems) which was followed by S_1T_3 (AEZ 1 + mahogany cropland based agroforestry systems) and S_2T_1 (AEZ 3 + homestead agroforestry systems).

4.10.4 Leaf litter, herb, grass carbon stock (C kg/m^2) in interaction between different agroforestry systems and AEZs

The leaf litter, herb, grass carbon stock (LHGCS) was also significantly influenced by the interaction effect of AEZ and agroforestry systems (Table 4.8). The highest LHGCS (0.76 kg C) was observed in S_1T_1 (AEZ 1 + homestead agroforestry systems) which was followed by S_3T_1 (AEZ 25 + homestead agroforestry systems) and S_2T_1 (AEZ 3 + homestead agroforestry systems). On the other hand, the lowest LHGCS (0.21 kg C) was observed in S_2T_4 (AEZ 3 + mango orchard based agroforestry systems) and S_3T_2 (AEZ 25 + eucalyptus cropland based agroforestry systems) which was followed by S_1T_3 (AEZ 1 + mahogany cropland based agroforestry systems) and S_1T_4 (AEZ 1 + mango orchard based agroforestry systems).

Table 4.10: Interaction effect of different agroforestry systems and AEZs on carbon stock

Interactions	AGCS (kg/tree)	BGCS (kg/tree)	TTCS (kg/tree)	LHGCS (kg/m^2)
S_1T_1	128.21 de	33.34 de	161.55 de	0.76 a
S_1T_2	91.53 fg	23.80 fg	115.33 fg	0.33 c
S_1T_3	62.98 gh	16.37 gh	79.35 gh	0.31 cd
S_1T_4	189.99 b	49.40 b	239.39 b	0.24 ef
S_1T_5	150.03 cd	39.01 cd	189.03 cd	0.33 c
S_2T_1	64.22 gh	16.70 gh	80.92 gh	0.64 b
S_2T_2	64.28 gh	16.71 gh	81.00 gh	0.27 cdef
S_2T_3	47.48 h	12.35 h	59.83 h	0.24 def
S_2T_4	138.31 de	35.96 de	174.27 de	0.21 f
S_2T_5	102.73 ef	26.71 ef	129.44 ef	0.28 cdef
S_3T_1	127.42 de	33.13 de	160.55 de	0.73 a
S_3T_2	176.42 bc	45.87 bc	222.29 bc	0.21 f
S_3T_3	123.80 def	32.19 def	155.99 def	0.29 cde
S_3T_4	226.86 a	58.98 a	285.84 a	0.28 cdef
S_3T_5	189.16 b	49.18b	238.34 b	0.33 c
CV (%)	11.18	11.18	11.18	7.88

In a column, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per Tukey HSD test).

Where, S_1T_1= Homestead in AEZ 1; S_1T_2 = Cropland (E) in AEZ 1; S_1T_3=cropland (M) in AEZ 1; S_1T_4=Orchard (Ma) in AEZ 1; S_1T_5=Orchard (L) in AEZ 1; S_2T_1=Homestead in AEZ 3; S_2T_2=Cropland in AEZ 3; S_2T_3= Cropland in AEZ 3; S_2T_4= Orchard in AEZ 3; S_2T_5= Orchard in AEZ 3; S_3T_1=Homestead in AEZ 25; S_3T_2=Cropland in AEZ 25; S_3T_3=Cropland in AEZ 25; S_3T_4=Orchard in AEZ 25; S_3T_5=Orchard in AEZ 25.

4.10.5 Number of trees (no/ha) in interaction between different agroforestry systems and AEZs

The interaction effect of AEZ and agroforestry systems was significantly varied with the number of tree per hectors in each agroforestry systems (Table 4.9). The maximum number of trees (1048/ha) was recorded in S_1T_1 (AEZ 1 + homestead agroforestry systems) which was followed by S_3T_1 (AEZ 25 + homestead agroforestry systems) and S_2T_1 (AEZ 3 + homestead agroforestry systems). On the other hand, the minimum number of trees (111.5/ha) was recorded in S_2T_3 (AEZ 3 + mahogany cropland based agroforestry systems) which was followed by S_1T_3 (AEZ 1 + mahogany cropland based agroforestry systems) and S_3T_3 (AEZ 25 + mahogany cropland based agroforestry systems).

4.10.6 Total tree carbon stock (t/ha C) in interaction between different agroforestry systems and AEZs

The total tree carbon stock (TTCS) was also varied significantly with the interaction effects of AEZ and agroforestry systems (Table 4.9). The highest tree carbon stock (168.20 C t/ha) was recorded in S_1T_1 (AEZ 1 + homestead agroforestry systems) which was followed by S_3T_1 (AEZ 25 + homestead agroforestry systems). Similarly, the lowest tree carbon stock (6.75 C t/ha) was recorded in S_2T_3 (AEZ 3 + mahogany cropland based agroforestry systems) which was followed by S_1T_3 (AEZ 1 + mahogany cropland based agroforestry systems) and S_2T_2 (AEZ 3 + eucalyptus cropland based agroforestry systems).

4.10.7 Leaf litter, herb, grass carbon stock (t/ha C) in interaction between different agroforestry systems and AEZs

The leaf litter, herb, grass carbon stock (LHGCS) was also influenced by the interaction effect of AEZ and agroforestry systems (Table 4.9). The highest LHGCS (16.08 kg) was observed in S_1T_1 (AEZ 1 + homestead agroforestry systems) which was significantly followed by S_3T_1 (AEZ 25 + homestead agroforestry systems). On the other hand, the lowest LHGCS (4.43 kg) was observed in S_3T_2 (AEZ 25 + eucalyptus cropland based agroforestry systems) which was followed by S_2T_4 (AEZ 3 + mango orchard based agroforestry systems) and S_1T_4 (AEZ 1 + mango orchard based agroforestry systems).

4.10.8 Tree carbon sequestration (t/ha) in interaction between different agroforestry systems and AEZs

The total tree carbon sequestration (TTCseq) was also influenced by the interaction effect of AEZ and agroforestry systems (Table 4.9). The highest tree carbon sequestration (617.28 t/ha) was recorded in S_1T_1 (AEZ 1 + homestead agroforestry systems) which was followed by S_3T_1

(AEZ 25 + homestead agroforestry systems). On the other hand, the lowest tree carbon sequestration (24.78 t/ha) was recorded in S_2T_3 (AEZ 3 + mahogany cropland based agroforestry systems) which was followed by S_1T_3 (AEZ 1 + mahogany cropland based agroforestry systems).

4.10.9 Leaf litter, herb, grass carbon sequestration (t/ha) in interaction between different agroforestry systems and AEZs

The leaf litter, herb, grass carbon sequestration (LHGCseq) was also significant by the interaction effects of AEZ and agroforestry systems (Table 4.9). The highest LHGCseq (59.0 t/ha) was observed in S_1T_1 (AEZ 1 + homestead agroforestry systems) which was followed by S_3T_1 (AEZ 25 + homestead agroforestry systems). Again, the lowest LHGCseq (16.24 t/ha) was observed in S_3T_2 (AEZ 25 + eucalyptus cropland based agroforestry systems) which was followed by S_2T_4 (AEZ 3 + mango orchard based agroforestry systems) and S_1T_4 (AEZ 1 + mango orchard based agroforestry systems).

4.10.10 Total carbon sequestration (t/ha) in interaction between different agroforestry systems and AEZs

The total carbon sequestration (TASCseq) was significantly varied by the interactions effects of AEZ and agroforestry systems (Table 4.9). The highest total agroforestry systems carbon sequestration (676.27 t/ha) was recorded in S_1T_1 (AEZ 1 + homestead agroforestry systems) which was followed by S_3T_1 (AEZ 25 + homestead agroforestry systems).The lowest total agroforestry systems carbon sequestration (43.87 t/ha) was recorded in S_2T_3 (AEZ 3 + mahogany cropland based agroforestry systems) which was followed by S_1T_3 (AEZ 1 + mahogany cropland based agroforestry systems).

Table 4.11: Interactions effect of different agroforestry systems and AEZs on carbon sequestration

Interactions	NT/ha	TTCS (t/ha C)	LHGCS (t/ha C)	TTCseq (t/ha)	LHGCseq (t/ha)	TASCseq (t/ha)
S_1T_1	1048.5 a	168.20 A	16.08 a	617.28 a	59.00 a	676.27 a
S_1T_2	164.0 bcd	18.89 efg	6.98 c	69.33 efg	25.60 c	94.92 efg
S_1T_3	114.0 d	9.03 fg	6.68 cd	33.12 fg	24.50 cd	57.62 fg
S_1T_4	308.0 bc	72.61 b	5.08 ef	266.46 b	18.63 ef	285.09 b
S_1T_5	355.5 b	66.83 bcd	7.00 c	245.27 bcd	25.69 c	270.96 bcd
S_2T_1	989.5 a	80.52 b	13.65 b	295.50 b	50.10 b	345.60 b
S_2T_2	188.0 bcd	15.09 efg	5.83 cdef	55.39 efg	21.38 cdef	76.77 efg
S_2T_3	111.5 d	6.75 g	5.20 def	24.78 g	19.08 def	43.87 g
S_2T_4	226.0	39.29	4.55 f	144.18	16.70 f	160.88
S_2T_5	313.5 bc	40.83 cde	5.85 cdef	149.84 cde	21.47 cdef	171.31 cde
S_3T_1	1040.5 a	166.43 a	15.45 a	610.80 a	56.70 a	667.50 a
S_3T_2	171.5 bcd	37.61 def	4.43 f	138.02 def	16.24 f	154.26 efg
S_3T_3	122.0 cd	19.05 efg	6.15 cde	69.92 efg	22.57 cde	92.49 efg
S_3T_4	309.0 bc	87.29 b	5.93 cdef	320.34 b	21.75 cdef	342.08 b
S_3T_5	290.0 bcd	69.64 bc	7.05 c	255.59 bc	25.87 c	281.46 bc
CV (%)	19.66	20.05	7.88	20.05	7.88	27.86

In a column, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per Tukey HSD test).

Where, S_1T_1= Homestead in AEZ 1; S_1T_2 = Cropland (E) in AEZ 1; S_1T_3=cropland (M) in AEZ 1; S_1T_4=Orchard (Ma) in AEZ 1; S_1T_5=Orchard (L) in AEZ 1; S_2T_1=Homestead in AEZ 3; S_2T_2=Cropland in AEZ 3; S_2T_3= Cropland in AEZ 3; S_2T_4= Orchard in AEZ 3; S_2T_5= Orchard in AEZ 3; S_3T_1=Homestead in AEZ 25; S_3T_2=Cropland in AEZ 25; S_3T_3=Cropland in AEZ 25; S_3T_4=Orchard in AEZ 25; S_3T_5=Orchard in AEZ 25.

4.11 Interaction effect of different agroforestry systems and AEZs on soil carbon sequestration

4.11.1 Interaction effect of different agroforestry systems and AEZs of 0-15 cm soil layer

The interaction effect of AEZ and agroforestry systems was varied by the soil layer of 0-15 cm. Here, S_1T_2 (AEZ 1 + eucalyptus cropland based agroforestry systems) sequestrated highest amount of carbon (17.70 t/ha) which was followed byS_1T_3 (AEZ 1 + mahogany cropland based agroforestry systems).On the other hand, S_2T_4 (AEZ 3 + mango orchard based agroforestry systems) sequestrated lowest amount of carbon (12.30 t/ha) which was followed by S_2T_3 (AEZ3 + mahogany cropland based agroforestry systems).

4.11.2Interaction effect of different agroforestry systems and AEZs of 16-30 cm soil layer

The interaction effect of AEZ and agroforestry systems was also varied by the soil layer of 16-30 cm. Here, S_1T_2 (AEZ 1 + eucalyptus cropland based agroforestry systems) sequestrated highest amount of carbon (16.35 t/ha) which was followed byS_3T_5 (AEZ 25 + litchi orchard based agroforestry systems). On the other hand, S_2T_4 (AEZ 3 + mango orchard based agroforestry systems) sequestrated lowest amount of carbon (10.20 t/ha) which was followed by S_2T_5 (AEZ 3 + litchi orchard based agroforestry systems).

4.11.3 Interaction effect of different agroforestry systems and AEZs of 0-30 cm soil layer

The interaction of AEZ and five agroforestry systems was also affected by the soil layer of 0-30 cm. Here, S_1T_2 (AEZ 1 + eucalyptus cropland based agroforestry systems) sequestrated highest amount of carbon (34.05 t/ha) which was followed byS_1T_3 (AEZ 1 + mahogany cropland based agroforestry systems). Again, S_2T_4 (AEZ 3 + mango orchard based agroforestry systems) sequestrated lowest amount of carbon

(22.50 t/ha) which was followed by S_2T_5 (AEZ 3 + litchi orchard based agroforestry systems).

Table 4.12: Interaction effect of soil carbon sequestration in different agroforestry systems and AEZs

Interactions	Carbon seq. upto 0-15 cm soil profile	Carbon seq. upto 16-30 cm soil profile	Carbon seq. upto 0-30 cm soil profile
S_1T_1	13.30	14.75	28.05
S_1T_2	17.70	16.35	34.05
S_1T_3	16.85	13.95	30.80
S_1T_4	12.40	13.50	25.90
S_1T_5	14.40	11.65	26.05
S_2T_1	12.65	14.25	26.90
S_2T_2	14.35	12.00	26.35
S_2T_3	12.35	13.50	25.85
S_2T_4	12.30	10.20	22.50
S_2T_5	13.00	10.85	23.85
S_3T_1	14.60	14.60	29.20
S_3T_2	15.55	13.80	29.35
S_3T_3	14.20	12.60	26.80
S_3T_4	13.55	15.05	28.60
S_3T_5	13.35	15.60	28.95
CV (%)	16.42	18.55	17.61

Where, S_1T_1= Homestead in AEZ 1; S_1T_2 = Cropland (E) in AEZ 1; S_1T_3=cropland (M) in AEZ 1; S_1T_4=Orchard (Ma) in AEZ 1; S_1T_5=Orchard (L) in AEZ 1; S_2T_1=Homestead in AEZ 3; S_2T_2=Cropland in AEZ 3; S_2T_3= Cropland in AEZ 3; S_2T_4= Orchard in AEZ 3; S_2T_5= Orchard in AEZ 3; S_3T_1=Homestead in AEZ 25; S_3T_2=Cropland in AEZ 25; S_3T_3=Cropland in AEZ 25; S_3T_4=Orchard in AEZ 25; S_3T_5=Orchard in AEZ 25.

4.12 Interaction effect of different agroforestry systems and AEZs considering soil

The total carbon sequestration was significantly influenced by the different agroforestry systems and AEZs considering soil. The highest (704.32 t/ha) total carbon sequestration was recorded from S_1T_1 (AEZ 1 + homestead agroforestry systems) which was followed by S_3T_1 (AEZ

25 + homestead agroforestry systems).The lowest total carbon sequestration (69.72 t/ha) was recorded in S_2T_3 (AEZ 3 + mahogany cropland based agroforestry systems) which was followed by S_1T_3 (AEZ 1 + mahogany cropland based agroforestry systems) and S_2T_2 (AEZ 3 + eucalyptus cropland based agroforestry systems).

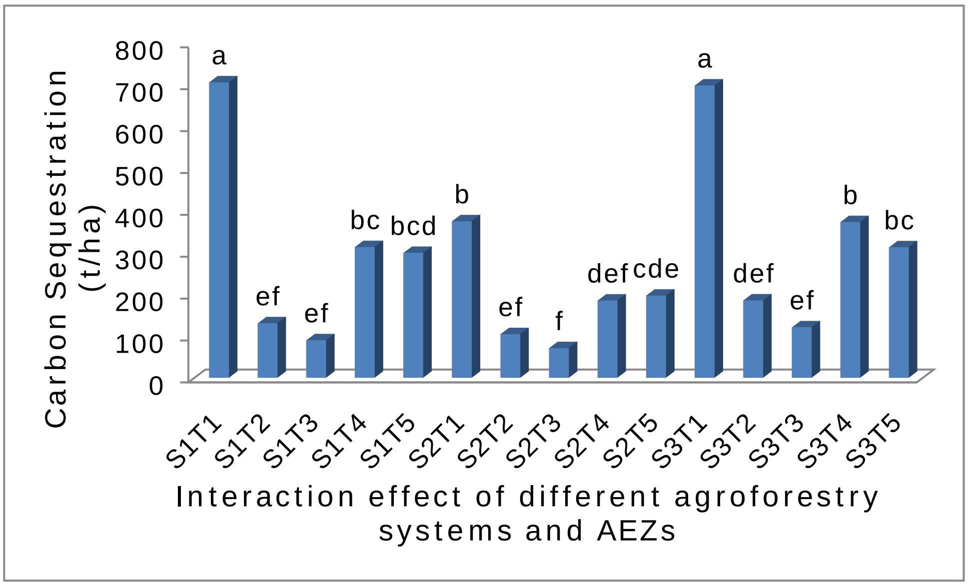


Fig 4.3: Interaction effect of different agroforestry systems and AEZs considering biomass and soil

In a bar, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per Tukey HSD test).

4.13 Economic value of carbon sequestration (US $/ha) by different agroforestry systems and three AEZs

The economic value of carbon sequestration provides market for GHG reduction on monetary value (Fig 11). According to Anonymous, (2019) 1 ton of carbon was sold at US $ 50. So, the highest carbon price 29558.5 $/ha) was recorded from homestead agroforestry systems (T_1) which was followed by mango based agroforestry systems (T_4). On the other hand, the lowest carbon price (4624 $/ha) was obtained from mahogany cropland based agroforestry systems (T_3) which was followed by eucalyptus cropland based agroforestry systems (T_2).

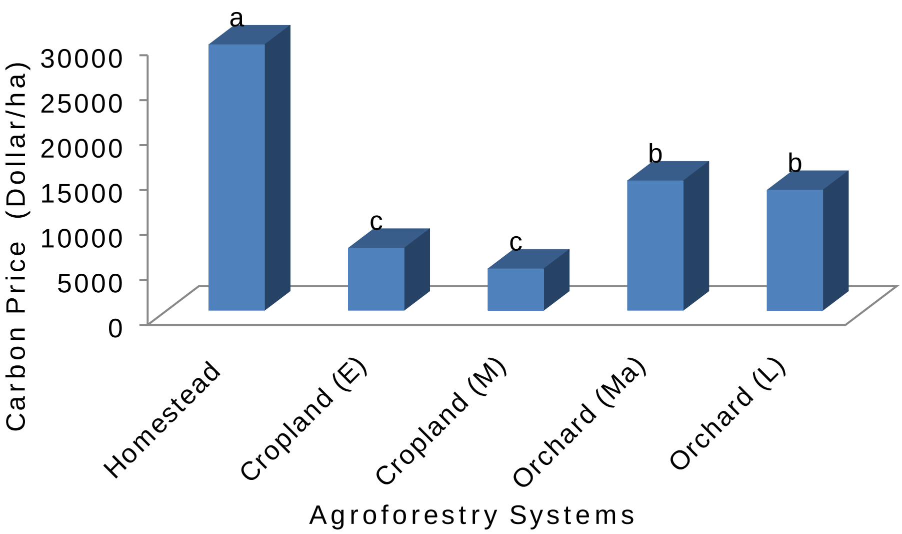


Fig 4.4: Carbon price by different agroforestry systems considering biomass and soil

In a bar, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per Tukey HSD test).

In case of agro-ecological zones, AEZ 25 i.e. level barind tract gave the highest amount of carbon price (16807 $/ha) because the people of AEZ 25 that means Dinajpur Sadar upazila were well educated and conscious about environmental change. They were more connected to the upazila agricultural officer or workers. On the other hand, AEZ 3 i.e. tista meander floodplain gave the lowest amount of carbon price (9238.5 $/ha) because the people of Parbotipur upazila were not connected to the agriculture office and they were not conscious about environmental factors. So, the sequence of carbon price of agro-ecological zones were AEZ 25 > AEZ 1 > AEZ 3.

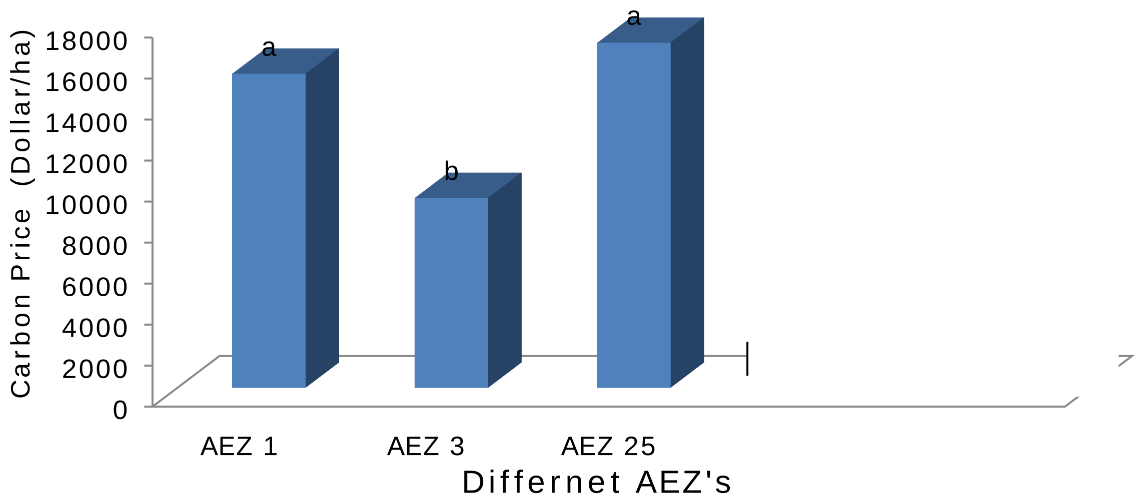


Fig 4.5: Carbon Price by different AEZ’s considering trees, biomass and soil

In a bar, figure having similar letter(s) do not differ significantly whereas figures bearing different letter(s) differ significantly (as per Tukey HSD test).

CHAPTER V

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

The study was carried out on "Carbon Sequestration Potentiality in three agro-ecological zones of Bangladesh under different agroforestry systems ", Dinajpur districts during the year 2018. The experiment comprised of five agroforestry systems viz., T_1=homestead agroforestry System, T_2 = eucalyptus cropland based agroforestry system + litter and shrubs, T_3= mahogany cropland based agroforestry system+ litter and shrubs, T_4= mango orchard based agroforestry system + litter and shrubs, T_5= litchi orchard based agroforestry system+ leaf litter. In case of T_1, all types of trees was selected, for T_2 and T_3 eight years aged eucalyptus and mahogany tree were selected as the main tree component. Similarly, in T_4 and T_5tenyears aged mango and litchi respectively, were also selected. The experiment was laid out in three agro-ecological zones viz. AEZ 1- Old Himalayan piedmont plain (Birganj), AEZ 3- Tista meander flood plain (Parbotipur) and AEZ 25- Level barind tract (Dinajpur sadar). Experimental plots were selected randomly in different locations from each experimental unit (AEZ), in a randomized complete block design (RCBD) with fifteen treatments and four replications. The parameters recorded was tree height (TH) and diameter at breast height (DBH) of trees which used to calculate aboveground, belowground and total biomass as per the formula used by (Chave *et al.,* 2005) of all the agroforestry systems. Litter, shrubs and or rice biomass was estimated using 1 square meter sample plots. The data were analyzed statistically and means were adjusted by Statistics-10 software (Tukey HSD test).

The major effect of different agroforestry systems on biomass production and estimation for carbon sequestration, the results were found in respect of tree height (m), diameter at breath height (cm), aboveground biomass (kg/tree), belowground biomass (kg/tree), total tree biomass (kg/tree) and leaf litter, herbs, grass biomass (kg/m^2) were significantly different. The tallest tree stand (15.21 m) was recorded from Eucalyptus cropland based agroforestry systems (T_2) whereas the shortest tree stand (6.67 m) was obtained from mango orchard based agroforestry system (T_4). The widest DBH (31.38 cm) was observed from the litchi orchard based agroforestry system (T_5) and the smallest DBH (15.0 cm) was observed from the mahogany cropland based agroforestry system (T_3). The highest ABG (116.75kg) was recorded from the mango orchard based agroforestry system (T_4) and the lowest AGB was recorded from the mahogany cropland based agroforestry system (T_4). The highest BGB (96.23 kg) was recorded from the litchi orchard based agroforestry systems (T_5) and the lowest (40.61 kg) was recorded from mahogany cropland based agroforestry system (T_3). The highest total tree biomass (466.33 kg) was recorded from mango orchard based agroforestry systems (T_4) and the lowest total tree biomass (196.78 kg) was recorded from mahogany cropland based agroforestry systems (T_3). The highest LHGB (1.51 kg) was obtained from vegetations under litchi orchard based agroforestry systems (T_5) and the smallest (0.52 kg) was obtained from biomass under mango orchard based agroforestry system (T_4).

Again, the result of this study showed that the main effect of different agroforestry systems on biomass accumulations were found significantly different according to aboveground carbon stock (kg/tree), belowground carbon stock (kg/tree), total tree carbon stock (kg/tree) and leaf litter, herb, grass carbon stock (kg/m^2) due to different in agroforestry systems. The highest AGCS (185.05 kgC) was obtained from Mango orchard based agroforestry systems (T_4) and the lowest AGCS (78.09 kgC) was observed from mahogany cropland based agroforestry systems (T_3). The highest BGCS (48.11 kgC) was obtained from mango orchard based agroforestry system (T_4) and the lowest BGCS (20.30 kgC) was also observed from mahogany cropland based agroforestry systems (T_3). The highest TTCS (233.16 kgC) was recorded from mango orchard based agroforestry systems (T_4) whereas the lowest TTCS (98.39 kgC) was from mahogany cropland based agroforestry system (T_3). The highest LHGCS (0.71 kg C) obtained from homestead agroforestry systems (T_1) and the lowest LHGCS (0.24 kgC) was obtained from mango orchard based agroforestry systems (T_4).

Again, the result of this study also showed that the main effect of different agroforestry system on carbon sequestrations were also significantly varied in number of trees (ha), total tree carbon stock (t/ha C), leaf litter, herb, grass carbon stock (t/ha C), tree carbon sequestration (t/ha), leaf litter, herb, grass carbon sequestration (t/ha) and total agroforestry systems carbon sequestration (t/ha) due to variations in agroforestry system. The maximum tree stand (1026.2/ha) per hectors was recorded from homestead agroforestry system (T_1) whereas the minimum tree stand (115.8/ha) per hectors was recorded from mahogany cropland based agroforestry systems (T_3). The highest total tree carbon stock (138.38 tC) was obtained from homestead agroforestry system (T_1) while, the lowest total tree carbon stock (11.61 tC) was also recorded from mahogany cropland based agroforestry system (T_3). The maximum LHGCS (15.06 tC) was obtained from Homestead agroforestry systems (T_1) and the minimum LHGCS (5.18 tC) was obtained from mango orchard based agroforestry systems (T_4).

The highest total tree carbon sequestrations (507.86t/ha) was recorded from homestead agroforestry system (T_1) and the lowest total tree carbon sequestrations (42.61t/ha) was obtained from mahogany cropland based agroforestry system (T_3). The highest LHGCseq (55.26 t/ha) was observed from homestead agroforestry systems (T_1). On the other hand, the lowest LHGCseq (19.02 t/ha) was recorded from biomass under mango orchard based agroforestry system (T_4). The highest total agroforestry system carbon sequestrations (563.12 t/ha) was recorded from homestead agroforestry system (T_1) whereas the lowest (64.66 t/ha) was obtained from mahogany cropland based agroforestry system (T_3).

The study showed that different layers of soil have different capacity to sequestrate carbon by the three agro-ecological zones. In case of 0-15 cm of soil, eucalyptus cropland based agroforestry system (T_2) had the highest capacity (15.87t/ha) to sequestrate carbon which was followed by mahogany cropland based agroforestry system (T_3). Again, mango orchard based agroforestry system (T_4) had the lowest capacity (12.75 t/ha) to sequestrate carbon which was followed by homestead agroforestry system (T_1). In case of 16-30 cm of soil, homestead agroforestry systems (T_1) had the highest capacity (14.53 t/ha) to sequestrate carbon followed by eucalyptus cropland based agroforestry system (T_2). Again, litchi orchard based agroforestry system (T_5) had the lowest capacity (12.70 t/ha) to sequestrate carbon followed by mango orchard based agroforestry system (T_4). Again, the study also showed that the sum of two layer of soil such as (0-15 cm) and (16-30cm) had a little bit difference to sequestrate carbon. Here, eucalyptus cropland based agroforestry system (T_2) had the highest capacity (29.92 t/ha) to sequestrate carbon followed by homestead agroforestry system (T_1) and mango orchard based agroforestry system (T_4) had the lowest capacity (25.67 t/ha) to sequestrate carbon followed by litchi orchard based agroforestry system (T_5).

On other hand, the main effect of agro-ecological zones (AEZ) on biomass production and estimation for carbon sequestration, the results were found that, tree height (m), the diameter at breath height (cm), aboveground biomass (kg/tree), belowground biomass (kg/tree), total tree biomass (kg/tree) and leaf litter, herbs, grass biomass (kg/m^2) were all significantly different. The tallest tree height (11.71 m) was recorded from AEZ 25 (S_3) and the lowest tree height (9.37) was recorded from AEZ 3 (S_2). The widest DBH (24.89cm) was recorded from AEZ 25 (S_3) and the smallest DBH (19.67 cm) was obtained from AEZ 3 (S_2). The highest ABG (337.46 kg) was recorded from AEZ 25 (S_3) and the lowest ABG (166.81 kg) was recorded from AEZ 3 (S_2). The highest BGB (87.74 kg) was obtained from AEZ 25 (S_3) and the lowest BGB (43.37 kg) was obtained from AEZ 3 (S_2). The highest TTB (425.20 kg) was obtained from AEZ 25 (S_3) whereas lowest TTB (210.18 kg) was recorded from AEZ 3 (S_2). The highest LHGB (0.84 kg) was obtained from AEZ 1 (S_1) and the lowest (0.70 kg) was recorded from AEZ 3 (S_2).

Again, the result similarly showed that the main effect of agro-ecological zones (AEZ) on biomass allocation and accumulations were significant different in aboveground carbon stock (kg/tree), belowground carbon stock (kg/tree), total tree carbon stock (kg/tree C) and leaf litter, herb, grass carbon stock (kg/m^2 C) due to differences in ecological zones. The highest AGCS (168.73 kg/tree C) was recorded from AEZ 25 (S_3) and the lowest AGCS (83.41 kg/tree C) was recorded from AEZ 3 (S_2). The highest BGCS (43.87 kg/tree C) was recorded from AEZ 25 (S_3) whereas the lowest (21.69 kg/tree C) was recorded from AEZ 3 (S_2). The highest TTC (212.60 kg/tree C) was obtained from AEZ 25 (S_3) whereas the lowest (105.09 kg/tree C) was recorded from AEZ 3 (S_2). The highest LHG/RCS (0.39 kg/m^2 C) was recorded from AEZ 1 (S_1) and the lowest (0.33 kg/m^2C) was recorded from AEZ 3 (S_2).

Again, the study also showed the main effect of carbon sequestration on the agro-ecological zones (AEZ) which were also significantly varied in number of trees (ha), total tree carbon stock (t/ha C), leaf litter, herb, grass carbon stock (t/ha C), tree carbon sequestration (t/ha), leaf litter, herb, grass carbon sequestration (t/ha) and total agroforestry systems carbon sequestration (t/ha) due to variations in agro-ecological zones. The maximum number of tree (398.0/ha) was recorded from AEZ 1 (S_1) and the minimum number of trees (365.70/ha) was recorded from AEZ 3 (S_2). The highest TTCS (76.0 t/ha C) was recorded from AEZ 25 (S_3). On the hand the lowest TTCS (36.50 t/ha C) was obtained from AEZ 3 (S_2). The highest LHGCS (8.36

t/ha C) was observed from AEZ 1 (S_1) and the lowest (7.02 t/ha C) was observed from AEZ 3 (S_2). The highest TTCseq (278.93 t/ha) was obtained from AEZ 25 (S_3) and the lowest TTCseq (133.94 t/ha) was recorded from AEZ 3 (S_2). The highest LHGCseq (30.68 t/ha) was observed from AEZ 1 (S_1) whereas the lowest LHGCseq (25.75 t/ha) was observed from AEZ 3 (S_2). The highest TASCseq (307.56 t/ha) was obtained from AEZ 25 (S_3). On the other hand lowest TASCseq (159.68t/ha) was recorded from AEZ 3 (S_2).). However, AEZ 25 (S_3) have more potentials in sequestering carbon due to high tree stand density which influenced by high Mean annual rainfall of about 1600mm, 15000mm and 2000mm of AEZ 1, AEZ 3, AEZ 25 respectively (Study on the characterization of the agro-ecological, National Consultant Bangladesh).

The soil layerof 0-15 cm of the three AEZ sequestrated carbon.AEZ 1 i.e. Old Himalayan Piedmont Plain sequestrated highest amount of carbon (14.87 t/ha) followed by AEZ 25. AEZ 3 i.e. Tista Meander Floodplain sequestrated lowest amount of carbon (12.93 t/ha). The sequence of three AEZs of sequestrating carbon in respect of 0-15 cm soil layer was AEZ 1>AEZ 25>AEZ 3. In case of 16-30 cm soil layer, AEZ 25 i.e. Level Barind Tract sequestrated highest amount of carbon (14.33 t/ha) followed by AEZ 1 i.e. Old Himalayan Piedmont Plain. And AEZ 3 i.e. Tista Meander Floodplain sequestrated lowest amount of carbon (12.16 t/ha). The sequence of three AEZs of sequestrating carbon in respect of 16-30 cm soil layer was AEZ 25 > AEZ 1 > AEZ 3. The layer of 0-30 cm was also significantly varied and there was a little bit difference of sequestrating carbon in these three AEZs. Here, we found that AEZ 1 i.e. Old Himalayan Piedmont Plain sequestrated highest amount of carbon (28.97 t/ha) followed by AEZ 25. And AEZ 3 i.e. Tista Meander Floodplain sequestrated lowest amount of carbon (25.09 t/ha). So, the sequence was AEZ 1 > AEZ 25 > AEZ 3.

Interaction effect of AEZ and agroforestry systems on biomass production and estimation for Carbon sequestrations were also found that the tree height (m), diameter at breath height DBH (cm), aboveground biomass (kg/tree), belowground biomass (kg/tree), total tree biomass (kg/tree) and leaf litter, herbs, grass biomass (kg/m^2) were significantly influenced by the interaction effects. The tallest tree height (17.50 m) was recorded from the treatment combination of S_3T_2 (AEZ 25 + eucalyptus cropland based agroforestry systems). On the other hand, the shortest tree height (5.75 m) was recorded in S_2T_5 (AEZ 3 + litchi orchard based agroforestry systems). The widest DBH (33.06 cm) was recorded in S_3T_4 (AEZ 25 + mango orchard based agroforestry system) whereas the smallest DBH (3.11 cm) was recorded in S_3T_5 (AEZ 25 + litchi orchard based agroforestry systems). The highest AGB (453.71 kg) was observed in S_3T_4 (AEZ 25 + mango orchard based agroforestry system). On the other hand, the lowest AGB (94.96 kg) was recorded in S_2T_3 (AEZ 3 + mahogany cropland based agroforestry system). The highest BGB (117.97 kg) was recorded in S_3T_4 (AEZ 25 + mango orchard based agroforestry system). On the other hand, the lowest BGB (24.69 kg) was obtained in S_2T_3 (AEZ 3 + mahogany cropland based agroforestry systems). The highest TTB (571.68 kg) was recorded in S_3T_4 (AEZ 25 + mango orchard based agroforestry system). On the other hand, the lowest TTB (119.65 kg) was recorded in S_2T_3 (AEZ 3 + mahogany cropland based agroforestry systems). The highest LHGB (1.61 kg) was observed in S_1T_1 (AEZ 1 + homestead agroforestry systems). On the other hand, the lowest LHGB (0.44 kg) was also observed in S_3T_2 (AEZ 25 + eucalyptus cropland based agroforestry system).

Again, the result also showed that the interaction effect of AEZ and agroforestry systems on biomass allocation and accumulations for carbon sequestrations in aboveground carbon stock (kg/tree C), belowground carbon stock (kg/tree C), total tree carbon stock (kg/tree C) and leaf litter, herb, grass carbon stock (kg/m^2 C) were also significant by the interaction effect. The highest AGCS (226.86 kg) was recorded in S_3T_4 (AEZ 25 + mango orchard based agroforestry system). On the other hand, the lowest AGCS (47.48 kg) was recorded in S_2T_3 (AEZ 3 + mahogany cropland based agroforestry system). The highest BGCS (58.98 kg) was observed in S_3T_4 (AEZ 25 + mango orchard based agroforestry system). On the other hand, the lowest BGCS (12.35 kg) was observed in S_2T_3 (AEZ 3 + mahogany cropland based agroforestry system). The highest TTCS (285.84 kg) was recorded in S_3T_4 (AEZ 25 + mango orchard based agroforestry system). On the other hand, the lowest TTCS (59.83 kg) was recorded in S_2T_3 (AEZ 3 + mahogany cropland based agroforestry system). The highest LHGCS (0.76 kg) was observed in S_1T_1 (AEZ 1 + homestead agroforestry system). On the other hand, the lowest LHGCS (0.21 kg) was observed in S_2T_4 (AEZ 3 + mango orchard based agroforestry system) and S_3T_2 (AEZ 25 + eucalyptus cropland based agroforestry system).

Finally, the study on interaction effect of AEZ and agroforestry systems on carbon sequestration found that there was significant difference in respect of number of trees (/ha), total tree carbon stock (t/ha), total tree carbon sequestration (t/ha), total agroforestry systems carbon sequestration (t/ha) respectively; but no significant variations in leaf litter, herb, grass carbon stock (t/ha C) and leaf litter, herb, grass carbon sequestrations (t/ha). The maximum number of trees (1048/ha) was recorded in S_1T_1 (AEZ 1 + homestead agroforestry system). On the other hand, the minimum number of trees (111.5/ha) was recorded in S_2T_3 (AEZ 3 + mahogany cropland based agroforestry system). The highest TTCS (168.20 t/ha C) was recorded in S_1T_1 (AEZ 1 + homestead agroforestry system) whereas the lowest TTCS (6.75 t/ha C) was recorded in S_2T_3 (AEZ 3 + mahogany cropland based agroforestry system). The highest LHGCS (16.08 kg) was observed in S_1T_1 (AEZ 1 + homestead agroforestry system). On the other hand, the lowest LHGCS (4.43 kg) was observed in S_3T_2 (AEZ 25 + eucalyptus cropland based agroforestry system). The highest TTCseq (617.28 t/ha) was recorded in S_1T_1 (AEZ 1 + homestead agroforestry system). On the other hand, the lowest TTCseq (24.78 t/ha) was recorded in S_2T_3 (AEZ 3 + mahogany cropland based agroforestry system). The highest LHGCseq

(59.0 t/ha) was observed in S_1T_1 (AEZ 1 + homestead agroforestry system). Also, the lowest LHGCseq (16.24 t/ha) was observed in S_3T_2 (AEZ 25 + eucalyptus cropland based agroforestry system). The highest TASCseq (676.27 t/ha) was recorded in S_1T_1 (AEZ 1 + homestead agroforestry system). On the other hand, the lowest TASCseq (43.87 t/ha) was recorded in S_2T_3 (AEZ 3 + mahogany cropland based agroforestry system).

The interaction effect of AEZ and agroforestry systems was varied by the soil layer of 0-15 cm. Here, S_1T_2 (AEZ 1 + Eucalyptus cropland based agroforestry system) sequestrated highest amount of carbon (17.70 t/ha) which was followed byS_1T_3 (AEZ 1 + mahogany cropland based agroforestry system). On the other hand, S_2T_4 (AEZ 3 + mango orchard based agroforestry system) sequestrated lowest amount of carbon (12.30 t/ha) which was followed by S_2T_3 (AEZ 3 + mahogany cropland based agroforestry system). In case of the soil layer of 16-30 cm, S_1T_2 (AEZ 1 + eucalyptus cropland based agroforestry system) sequestrated highest amount of carbon (16.35 t/ha) which was followed byS_3T_5 (AEZ 25 + litchi orchard based agroforestry system). On the other hand, S_2T_4 (AEZ 3 + mango orchard based agroforestry system) sequestrated lowest amount of carbon (10.20 t/ha) which was followed by S_2T_5 (AEZ 3 + litchi orchard based agroforestry system). In case of 0-30 cm soil layer, S_1T_2 (AEZ 1 + eucalyptus cropland based agroforestry system) sequestrated highest amount of carbon (34.05 t/ha) which was followed byS_1T_3 (AEZ 1 + mahogany cropland based agroforestry system). Again, S_2T_4 (AEZ 3 + mango orchard based agroforestry system) sequestrated lowest amount of carbon (22.50 t/ha) which was followed by S_2T_5 (AEZ 3 + litchi orchard based agroforestry system).

5.2 Conclusions

The findings of the study concluded that among the five agroforestry systems, homestead agroforestry system gave the highest biomass and carbon storage capacity than the other agroforestry systems. On the other hand, mahogany cropland based agroforestry system gave minimum biomass and carbon storage capacity. It may be ranked according to the performance of carbon storage capacity by different agroforestry systems, i.e. homestead agroforestry system > mango orchard based agroforestry system > litchi orchard based agroforestry system > eucalyptus cropland based agroforestry system > mahogany cropland based agroforestry system.

In case of AEZs, the AEZ 25 sequestrated the highest carbon than the other two AEZs. Indeed, AEZ 25 has greater ability for carbon sequestration due to climatic influence and more awareness of farmers in tree management practices. The economic value of carbon sequestration provides monetary value for GHG reduction. So, the highest carbon price was obtained from homestead agroforestry system and the lowest from mahogany cropland based agroforestry system.

However, homestead and orchard based agroforestry system sequestrated more carbon and a better option for reducing atmospheric CO_2but they cannot be extended to many large areas of Bangladesh due to high population pressure and demand of agricultural land. Therefore, homestead and orchard agroforestry system should be maintained for larger tree plantation coverage, reduction in GHGs effects and for more carbon sequestration capacity.

5.3 Recommendations

Based on the results of the study carried out, the following recommendations are made.

1. Farmers and forest department should consider eucalyptus and mahogany cropland based agroforestry systems for more carbon sequestration.
2. In this research, quantification of carbon was done by non-destructive method. A study on destructive method should be done for better quality research.
3. Public awareness should be raised about the impact of climate change and the role of agroforestry in mitigating climate change effect.
4. Mango orchard based agroforestry system sequestrates more carbon than litchi orchard based agroforestry system. So, for better environment, mango orchard based agroforestry system should be expanded.
5. Homestead agroforestry systems had a better opportunity for large tree plantation coverage, reduction in GHGs effects and to sequestrate more carbon. So, it should be well maintained.

REFERENCES

Abbas, M., Nizami, S. M., Saleem, A., Gulzar, S. and Khan, I. A. (2011).Biomass expansion factors of *Olea ferruginea* (Royle) in sub-tropical forests of Pakistan. African J. Biotechnology, 10 (9): 1586-1592.

Albrecht, A. and Kandji, S.T., (2003). Carbon sequestration in tropical agroforestry systems. Agriculture, Ecosystems and Environment. Institut de Recherche pour le Development (IRD), c/o International Centre for Research in Agroforestry (ICRAF), Nairobi, Kenya. 99: 15-27.

Amundson, R. (2001). The carbon budget in soils.*Annual Review of Earth Planetary Sciences* 29: 535-62.

Anderson, K. and Bows A., (2011). 'Beyond 'dangerous' climate change: emission scenarios for a new world'. Philosophical Transactions A of the Royal Society, No.369, pp. 20-44.

Andre, B., Job, K., Bernard, V., Boaz, W. and Joseph, K. (2011).Soil organic carbon dynamics, functions and management in West African agro-ecosystems. Science Direct.4: 3-4.

Anonymous, (2004). Forest Carbon Sequestration: CATALYST the magazine of the union of concerned scientists 3:1-4

Anonymous, (2019). The true cost of carbon pollution. Environmental Defence Fuel (www.edf.org).

Avery, T.E. and Burkhart, H.E. (2001). Forest Measurements (fifth edition). New York: McGraw-Hill, 456 pp.

BBS (Bangladesh Bureau of Statistics), (2014).Bangladesh Population and Housing Census 2011. Community Report: Dinajpur.

Barua, S. K. and Haque, S. M. S. (2013). Soil Characteristics and Carbon Sequestration Potentials of Vegetation In Degraded Hills of Chittagong, Bangladesh. Land Degrad. Dev., 24: 63-71.doi: 10.1002/ldr.1107

Brakas, S.G. and Aune, J. B.(2011). Biomass and Carbon Accumulation in Land Use Systems of Claveria, the Philippines. In: Kumar BM, Nair PKR (eds.) Carbon sequestration potential of agroforestry Systems: opportunities and challenges. Springer, Dordrecht, pp 163-175.

Brown, K. and Pearce, D., (1994). The Economic Value of Non Timber Benefits of Tropical Forests: Carbon Storage. In Weiss, J., (ed.).The Economics of Project Appraisal and the Environment; New Horizons in Environment Economics. Chelttenham (UK): Edward Elgar, Aldershot Publishing.

Brown, S., Delaney, M. and Shoch, D., (2001).Carbon monitoring, analysis, and status report for the Rio Bravo Carbon Sequestration Pilot Project. In: Report to the Programme for Belize. Report to the Programme for Belize, Winrock International, Arlington, VA, USA.

Chauhan, S.K., Sharma, S.C., Beri, V., Yadav, S. and Gupta, N. (2010). Yield and carbon sequestration potential of wheat (Triticum aestivum) -poplar (Populus deltoides) based agri-silvicultural systems Indian. Journal of Agricultural Sciences 80: 129-35.

Chavan, B. L. and Rasal, G. B. (2010).Sequestered standing carbon stock in selective tree species grown in University campus at Aurangabad, Maharashtra, India. International Journal of Engineering Science and Technology. 2(7): 3003-3007.

Chavan, B. L. and Rasal, G. B. (2011). Potentiality of carbon sequestration in six year ages young plant from University campus of Aurangabad. Global Journal of Research in Engineering Chemical Engineering. 11(7): 15-20.

Chave, J., Andalo, C., Brown, S., Cairns, M. A., Chambers, J. Q., Eamus, D., Folster, H., Fromard, F., Higuchi, N., Kira, T., Lescure, J. P., Puig, H., Riera, B. and Yamakura, T. (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia 145: 87-99.

Clyde, P., (2012). Importance-of-carbon-trading-in-the-global-market, slide share, available at, http://www.slideshare.net/Patricia291/importance-of-carbon-trading-in-the-global-market.

Danesh, M., Yong S. M. and Masao K., (2011). Carbon Sequestration in the Forests of Bangladesh. Environmental Science and Engineering, pp. 55-79.

Denissen, A. K. (2012). Climate Change and its Impacts on Bangladesh. http:www.ncdo.nl/artikel/climate-change-its-impacts-Bangladesh.

Dhyani, S.K., Newaj, R. and Sharma, A.R. (2009). Agroforestry: its relation with agronomy, Challenges and opportunities. Indian Journal of Agronomy 54: 249- 266.

Dixon, R.K. (1995). Agroforestry systems: sources or sinks of greenhouse gases? Agroforestry Systems 31: 99-116.

Dossa, E. L., Fernandes, E. C. M., Reid, W. S. and Ezui, K. (2008).Above and below ground biomass, nutrient and carbon stocks contrasting an open grown and a shaded coffee plantation.Agroforestry Systems. 72: 103-115.

Doygun, H. and Alphan, H., (2006). Monitoring urbanization of Iskenderun Turkey, and its negative implications. Environmental Monitoring and Assessment. 114: 145-155.

EIA, (2002). Emissions of Greenhouse Gases in the United States. Energy Information Administration, U.S. Department of Energy.

Report Number DOE/EIA-0573(2002). ftp://ftp.eia.doe.gov/pub/oiaf/1605/cdrom/pdf/ggrpt/057302.pdf.

FAO, (2000). Carbon Sequestration Options Under the Clean Development Mechanism to Address Land Degradation. World Soil Resources Reports 92. FAO and IFAD, Rome.

FAO, (2008). Climate change and food security.

FAO/UNDP, (1988). Agroecological Regions of Bangladesh, Land Resources Appraisal of Bangladesh for Agricultural Development Report 2. Banglapedia - National Encyclopedia of Bangladesh.

Figueroa, J. D., Timothy, F., Sean, P., Howard, M., Rameshwar, D. and Srivastava (2007). Review of Advances in CO_2 capture technology-The U.S. Department of Energy's Carbon Sequestration Program. International Journal of greenhouse gas control 2: 9-20.

Firdaus, M. S., Hanif, A. H. M., Safiee, A. S. and Ismail, M. R. (2010). Carbon sequestration potential in soil and biomass of *Jatropha curcas*. 19th World Congress of Soil Science, Soil Solutions for a Changing World.1-6 August Brisbane, Australia. Published on DVD.

Garg, V. K. (1998). Interaction of tree crops with a sodic soil environment: Potential for rehabilitation of degraded environments. Land Degradation and Development 9: 81-93.

Gladstone, W.T. and Ledig, F.T. (1990). Reducing pressure on natural forests through high yield forestry. Forest Ecology and Management 35: 69-78.

Gomez and Kwanchai A. (1984) Statistical procedures for agricultural research.

Hangarge, L. M., Kulkarni, D. K., Gaikwad, V. B., Mahajan D. M. and 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, vol. 3(7):3426-3429.

Hanif, M. A., Bari, M. S, and Rahman, M. A. (2015). Potentiality of carbon sequestration by agroforestry species in Bangladesh, Res. on Crops, 16(3): 562-567.

Hellings, B. F., Romijn, H. A. and Franken, Y. J.(2012). Carbon storage in *Jatropha curcas* trees in Northern Tanzania. 6 February, Version 1. www.fact-foundation.com

Hooda, N., Gera, M., Andrasko, K., Sathaye, J. and Gupta, M.K.(2007). Community and farm forestry climate mitigation projects: case studies from Uttaranchal, India. Mitigation and Adaptation Strategies for Global Change 12: 1099-1130.

Houghton, R.A., (2005). The contemporary carbon cycle. In Schlesinger, W. H. (ed.) Biogeochemistry. Elsevier Science. pp. 473-513.

IPCC, (Intergovernmental Panel on Climate Change) (2001). Climate Change 2001: Impacts, Adaptation and Vulnerability. IPCC Third Assessment Report. Intergovernmental Panel on Climate Change. IPCC Secretariat, c/o World Meteorological Organisation, Geneva, Switzerland.

IPCC (2007). Climate Change 2000: The Scientific Basis. Oxford Univ. Press, Oxford, UK.

IPCC, (2000). IPCC Special Report on Land Use, Land-Use Change and Forestry.A special report of the Intergovernmental Panel on Climate Change. Approved at IPCC Plenary XVI (Montreal, 1-8 May, 2000).IPCC Secretariat, c/o World Meteorological Organization, Geneva, Switzerland.

IPCC, (2006). Agriculture, forestry and other land use. In: Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K. (ed.). IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme. IGES, Japan.

IPCC, (2007). Climate Change (2007): Synthesis report - Summary for policymakers. An assessment of the Intergovernmental Panel on Climate Change.

IPCC, (2013). Climate Change (2013): The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T. F., Qin, D., Plattner, G.K., Tignor, M., Allen, S, K., Boschung, J., Nauels, A., Xia, Y., Bex, V. and Midgley, P.M. (ed.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 1535.

ISDR (International Strategy for Disaster Reduction)(2008).Climate Change and Disaster Risk Reduction.

Jacoby, H. D., Prinn, R. G. and Schmalensee, R. (1998)."Kyoto's Unfinished Business." Foreign Affairs 77 (4): 54-66.

Jaman, (2016). Quantification of Carbon Stock and Tree Diversity of Home gardens in Rangpur District, Bangladesh. International Journal of Agriculture and Forestry, 6(5): 169-180.

James, M., Roshetko, M. S., Delos, A. and Katherine, W. (2002). Smallholder Agroforestry Systems as a Strategy for Carbon Storage: A Paper presented at International Symposium on Forest Carbon Sequestration and Monitoring, November 11-15, 2002, Taipei, Taiwan.

Jose, S. (2009). Agroforestry for ecosystem services and environmental benefits: an overview. Agroforestry Systems 76: 1-10.

Kabir, M. E., Webb, E. L. and Dhar, T. K. (2010). Are home gardens managed properly in Bangladesh? *Asia Pacific Journal of Rural Development.* 20(2): 47–68.

Kandji, S.T., Verchot, L.V., Mackensen, J., Boye, A. and Van, N.M.(2006). Opportunities for linking climate change adaptation and mitigation through agroforestry systems: World Agroforestry into the Future. Garrity, D.P., Okono, A., Grayson, M. and Parrott, S (ed.): World Agroforestry Centre (ICRAF). Nairobi, Kenya. pp. 113-121.

Karl, T. R. and Trenberth, K. E. (2003).Modern Global Climate Change. Science 302: 1719-1723. http://www.sciencemag.org.

Kirschbaum, M.U.F. (1996). The carbon sequestration potential of tree plantations in Australia. In: Eldridge, K.G., Crowe, M. P., Old, K.M. (ed.), Environmental Management: The Role of Eucalypts and Other Fast Growing Species. CSIRO Forestry and Forest Products. pp. 77-89.

Koul, D. N. and Panwar, P. (2008). Prioritizing land management options for carbon sequestration potential. Current Science. 95(5): 658-663.

Kumar, A.K. (2010). Carbon sequestration: underexplored environmental benefits of Tarai agroforestry. Indian Journal of Soil Conservation 38: 125-131.

Lal, R. (2007). Carbon management in agricultural soils. *Mitigation and Adaptation Strategies for Global Change* 12: 303-22.

Lal, R. (2004). Soil carbon sequestration to mitigate climate change. Geoderma 123: 1-22.

Liu, C. and Li, X.(2012). Carbon storage and sequestration by urban forests in Shenyang, China. *Urban Forestry & Urban Greening*.11, 121– 128.

Lindner, M., Sohngen, B., Joyce, A.L., Price, T.D., Bernier, Y.P. and Karjalainen, T. (2002). Integrated forestry assessments for climate change impacts. Forest Ecology and Management 162: 11 7-136.

Madhusudanan, S. (2011).Tree allometry and carbon sequestration potential in the above ground biomass of selected multipurpose tree species in south Gujarat. M.Sc Thesis, Navsari Agricultural University, Navsari, Gujarat.

Maikhuri, R.K., Semwa, R. L., Rao, K. S., Singh, K. and Saxena, K.G. (2000). Growth and ecological impacts of traditional agroforestry tree species in Central Himalaya, India. Agroforestry Systems 48: 257-272.

Makundi, W. R. and Sathaye, J. A. (2004). GHG mitigation potential and cost in tropical forestry-relative role for agroforestry. Environment, Development and Sustainability 6: 235-260.

Mandal, R. A., Laake, P. and Van (2005).Carbon sequestration in CF: an eligible issue for CDM (A case study of Nanital India). Banko Janakari 15 (2): 64-72.

Mckenzie, N.J., Jacquier, D., Isbell, R. and Brown, K. (2004). *Australian soils* and *landscapes: an illustrated compendium*, CSIRO publishing: Collingwood, Vic. 416.

Mingorance, M., Barahona, E. and Farnandez-Galvez. (2007). Guidelines for improving organic carbon recovery by the wet oxidation method. Chemosphere 68 (3): pp 409-413.

Miah, D., Man, Y. S. and Masao, K. (2010). Carbon Sequestration in the Forests of Bangladesh. Environmental Science and Engineering. Springer Berlin Heidelberg pp. 55-79.

Montagnini, F. and Nair, P. K. R. (2004). Carbon sequestration: An under-exploited environmental benefit of agroforestry systems. Agroforestry Systems 61: 281- 295.

Murthy, I.K., Gupta, M., Tomar, S., Munsi, M. and Tiwari, R. (2013).Carbon Sequestration Potential of Agroforestry Systems in India. Journal of Earth Science, Climate Change 4: 131. doi:10.4172/2157-7617.1000131

Mutuo, P.K., Cadisch, G., Albrecht, P. C.A. and Verchot, L. (2005).Potential of agroforestry for carbon sequestration and mitigation of greenhouse gas from soils in the tropics. Nutrient Cycling in Agro-ecosystems 71: 43-54.

Nair, P. K. R. and Nair, V. D. (2003). Carbon storage in North American Agroforest. Syst.. In: Kimble, J., Heath, L. S., Birdsey, R. A., Lal, R., (editors). The Potential of, U. S., Forest Soils to Sequester Carbon and Mitigate the Greenhouse Effect. CRC Press, Boca Raton, FL, pp. 333 - 346.

Newaj, R. and Dhyani, S. K. (2008). Agroforestry for carbon sequestration: Scope and present status. Indian Journal of Agroforestry 10: 1-9.

Novara, A. (2017). Agricultural land abandonment in Mediterranean environment provides ecosystem services via soil carbon sequestration. *Sci. Total Environment.* 576: 420-429.

Oelbermann, M., Voroney, R. P. and Gordon, A. M. (2004). Carbon sequestration in tropical and temperate agroforestry systems: a review with examples from Costa Rica and southern Canada Agriculture. Ecosystems and Environment 104: 359-377.

Oyedele, D. J., Scatena, M., Sparvoli, E. and Pini, R. (2010). Distribution of organic carbon and total nitrogen in aggregate size fractions in a southern Nigeria Ultisol under different agricultural land use. Proceedings of the 19th World Congress of

Soil Science: Soil solutions for a changing world, Brisbane, Australia, 16 August, Symposium, 312, Farm systems and environment impacts. pp. 52-54.

Patel, S. S. (2012). Morphological variations and carbon sequestration potential of various clones of eucalyptus. M.Sc Thesis, Navsari Agricultural University, Navsari, Gujarat, India.

Pearson, T. R., Brown, S. L. and Birdsey, R. A. (2007). Measurement guidelines for the sequestration of forest carbon, general technical report, USAID forest service.

Phanikumar, D. V., Patra, A. K., Ratnam, M. V. and Sripathi, S. (2009). Planetary scale variability in the low latitude E region field aligned irregularities. Journal of Geophysical Res. 114: 148-227.

Post, W. M., Emmanuel, W. R., Zinke, P. J. and Stagenberger, A. G. (1982).Soil organic pool and world life zones. Nature, 298: 156-159.

Prasad, R., Saroj, N. K., Newaj, R., Venkatesh, A., Dhyanni, S. K. and Dhanai, C.S. (2010). Atmospheric carbon capturing potential of some agroforestry trees from mitigation of warming effect and climatic change. Indian Journal of Agroforestry. 12(2): 37-41.

Rahman, K., Bar, R. and Rouholahnedjad, E., (2014). Climate change and agricultural water resources: A vulnerability assessment of the Black.

Rahman, M. M., (2013). Carbon sequestration in forests of Chittagong and Chittagong hill tracts. An M.S. thesis of the Institute of Forestry and Environmental Sciences, Chittagong University, Chittagong, Bangladesh. p. 58.

Rahman, M. M, Kabir, M. E, Akon, J. U. and Ando, K. (2015). High carbon stocks in roadside plantations under participatory management in Bangladesh. Open access article under Published by Elsevier B.V. Global Ecology and Conservation 3 (2015). pp. 412-423.

Ramachandran, A., Jayakumar, S., Haroon, R. M. and Arockiasamy, D. I. (2007). Carbon sequestration: estimation of carbon stock in natural forests using geospatial technology in the Eastern Ghats of Tamil Nadu, India. Current Science. 92(3): 323-331.

Ravindranath, N. H. and Madelene, O. (2008).Carbon Inventory Methods: Handbook for Greenhouse Gas Inventory, Carbon Mitigation and Round wood Production Projects.

Rizvi, R. H., Dhyani, S. K., Yadav, R. S. and Singh, R. (2011). Biomass production and carbon stock of poplar agroforestry systems in Yamunanagar and Saharanpur districts of north-western India. Current science. 100(5): 736-742.

Roshetko, J. M., Delaney, M., Hairiah, K. and Purnomosidhi, P. (2002). Carbon stocks in Indonesian home garden systems: Can smallholder systems be targeted for increased carbon storage? American Journal of Alternative Agriculture 17: 138- 148.

Ross, W. G. (2009). Carbon Sequestration in Forests, Congressional Research Service,7-5700 www.crs.gov RL 31432.

Saha S. K., Nair P. K. R., Nair V. D. and Kumar, B. M.(2009). Soil carbon stock in relation to plant diversity of home gardens in Kerala, India. Agroforestry Systems 76: 53-65.

Sanderman, J., Hengl, T. and Fiske, G. J. (2017). Soil carbon debt of 12,000 years of human a land use. *Proc. Natl Acad. Sci*, 114: 9575-9580.

Sathaye, J., Shukla, P. R. and Ravindranath, N. H. (2006). Climate change, Sustainable development and India: Global and national concerns. Current Science, 90 (3), 314-325.

Scandrett, J., Oliver, G. and Doyle, R. (2010). Soil carbon depth functions under different land uses in Tasmania. Proceedings of the 19th World-Congress-of-Soil-Science: Soil solutions for a changing world, Brisbane, Australia, 1-6 August 2010 Symposium 421 Soil, energy and food security. pp. 45-48.

Schimel, D. S. (2001). Recent patterns and mechanisms of carbon exchange by terrestrial ecosystems. Nature 414: 169-172.

Scholes, R. J. and Noble, I. R. (2001). Storing carbon on land. Science. 294: 1012-1013.

Schroeder, P. (1993). Agroforestry systems integrated land use to store and conserve carbon. Climate Research 3: 53-60.

Schroeder, P., Ladd, L. (1991). Slowing the increase of atmospheric CO_2: A biological approach. Climate Change 19: 283-290.

Schroth, G. (2011). Linking Carbon, Biodiversity and Livelihoods Near Forest Margins: The Role of Agroforestry. In: Kumar, B. M. and Nair, P. K. R. (ed.) Carbon sequestration potential of agroforestry Systems: opportunities and challenges. Springer, Dordrecht, pp. 181- 200.

Shah, A. (2013). Climate Change and Global Warming Introduction, Global Issues, available at, http://www.globalissues.org/ /article/233/climate-change-and-global-warming-introduction.

Sharma, R., Sharma, E. and Purohit, A. N. (1995). Dry matter production and nutrient cycling in agroforestry systems of mandarin grown in association with *Albizia* and mixed tree species. Agroforestry systems 29: 165-179.

Sharma, R. P. (2003). Relationship between tree dimensions and biomass, sapwood area, leaf area and leaf area index in Alnus nepalensis D. Don in Nepal, Agricultural University of Norway (NLH), Aas.

Shin, M. Y., Miah, M. D. and Lee, K. H. (2007). Potential contribution of the forestry sector in Bangladesh to carbon sequestration. Journal of Environmental Management. 82: 260-276.

Swamy, S. L., Puri, S. and Singh, A. K. (2003). Growth, biomass, carbon storage and nutrient distribution in Gmelina arborea Roxb. Stands on red lateritic soils in Central India. Bio resource Technology 90: 109-126.

Takimoto, A., Nair, P. K. R. and Nair, V. D. (2008). Carbon stock and sequestration potential of traditional and improved agroforestry systems in the West African Sahel. Agriculture, Ecosystems and Environment 125: 159-166.

Tengnas, B. (1994). Agroforestry extension manual for Kenya. Nairobi: International Centre for Research in Agroforestry.

TEEIC, (Tribal Energy and Environment Information), (2017).Environmental resources for tribal energy development. Office of Indian energy and economic development. https://teeic.indianaffairs.gov/er/carbon/carboninfor/cycle

USEPA, (2003). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2001. U.S. Environmental Protection Agency. EPA 430-R-03-004.

Verma, K. S., Zegeye, M. W. and Kaushal, R. (2002). Growth and yield performance of wheat in agri-horti-silvicultural systems of agroforestry in mid-hills of Himachal Himalayas. Indian Journal of Agroforestry. 4(1): 1-7.

Wang, Z.P., Han, X.G. and Li, L.H. (2005).Effects of grassland conversion to croplands on soil organic carbon in the temperate Inner Mongolia.Journal-of-Environmental-Management. 86(3): 529-534.

Weng, Q. and Yang, S., (2006). Urban air pollution patterns, land use, and thermal landscape: an examination of the linkage using GIS. *Environmental Monitoring and Assessment*.117, pp. 463–489.

Wright, D. G., Mullen, R. W., Thomason, W. E. and Raun, W. R. (2001). Estimated land area increase of agricultural ecosystems to sequester excess atmospheric carbon dioxide. Commun. Soil Sci. Plant Anal. 32: 1803-1812.

APPENDICES

Appendix I: Weather data of the experimental site during the period from November 2018 to March 2019

Months	* Air Temperature (^{0}C)			* Minimum Rainfall	* Relative Humidity (%)
	Maximum	Minimum	Average		
November 2018	28.40	16.40	22.40	10.00	80.00
December 2018	25.60	12.20	18.90	3.00	81.00
January 2019	24.40	10.30	17.35	9.00	82.50
February 2019	27.00	12.70	19.85	12.00	75.00
March 2019	31.70	15.90	23.80	26.00	68.00

Note * Monthly average

Source: Bangladesh Meterological Station.

Appendix II: The physical and chemical properties of soil in Birganj upazila under Dinajpur district

Soil characteristics	Physical and chemical properties of soil
pH	5.50-6.52
Organic matter (%)	0.47
Calcium (meq /100 g)	2.72
Magnesium (meq /100 g)	0.89
Potassium (meq /100 g)	0.09
Nitrogen (µg/ g)	42.0
Phosphorus (µg/ g)	61.10
Stannum (µg/ g)	7.0
Boron (µg/ g)	2.93

Copper (µg/ g)	1.60
Iron (µg/ g)	170.0
Manganise (µg/ g)	59.0
Zinc (µg/ g)	2.30

Source: Soil Resources Development Institute, Dinajpur (2018)

Appendix III: The physical and chemical properties of soil in Parbotipur upazila under Dinajpur district

Soil characteristics	Physical and chemical properties of soil
pH	4.2-5.6
Organic matter (%)	1.0
Exchangeable acidity (meq /100 g)	0.29
Calcium (meq /100 g)	1.0
Magnesium (meq /100 g)	0.37

Potassium (meq /100 g)	0.24
Total Nitrogen (%)	0.08
Phosphorus (µg / g)	35.4
Stannum (µg / g)	24.8
Boron (µg / g)	0.37
Copper (µg / g)	1.6
Iron (µg / g)	82.0
Manganise (µg / g)	11.2
Zinc (µg / g)	0.7

Source: Soil Resources Development Institute, Dinajpur (2018)

Appendix IV: The physical and chemical properties of soil Dinajpur Sadar upazila under Dinajpur district

Soil characteristics	Physical and chemical properties of soil
pH	4.8-5.4
Organic matter (%)	1.17
Exchangeable acidity (meq /100	0.08

g)	
Calcium (meq /100 g)	1.3
Magnesium (meq /100 g)	0.89
Potassium (meq /100 g)	0.72
Total Nitrogen (%)	0.06
Phosphorus (µg /g)	101.2
Stannum (µg /g)	16.6
Boron (µg /g)	0.42
Copper (µg /g)	0.85
Iron (µg /g)	77.9
Manganise (µg /g)	73.5
Zinc (µg /g)	1.73

Source: Soil Resources Development Institute, Dinajpur (2018)

Appendix-V: Plates of different activities done in the field for data collection of the experiment

Plate 1 : Measurement of breast height diameter in litchi orchard

Plate 2 : Taking plant height in litchi orchard


Plate 3 : Collection of soil sample under litchi orchard

Plate 4 : Collection of soil sample under mahogany cropland

Plate 5 : Collection of leaf litter, herb, grass under mango orchard

Plate 6: Collection of leaf litter, herb, grass under litchi orchard

Plate 7: Collection of soil sample in homestead

Plate 8: Soil sample test in laboratory

Plate 9 : Measurement of breast height diameter in mango orchard

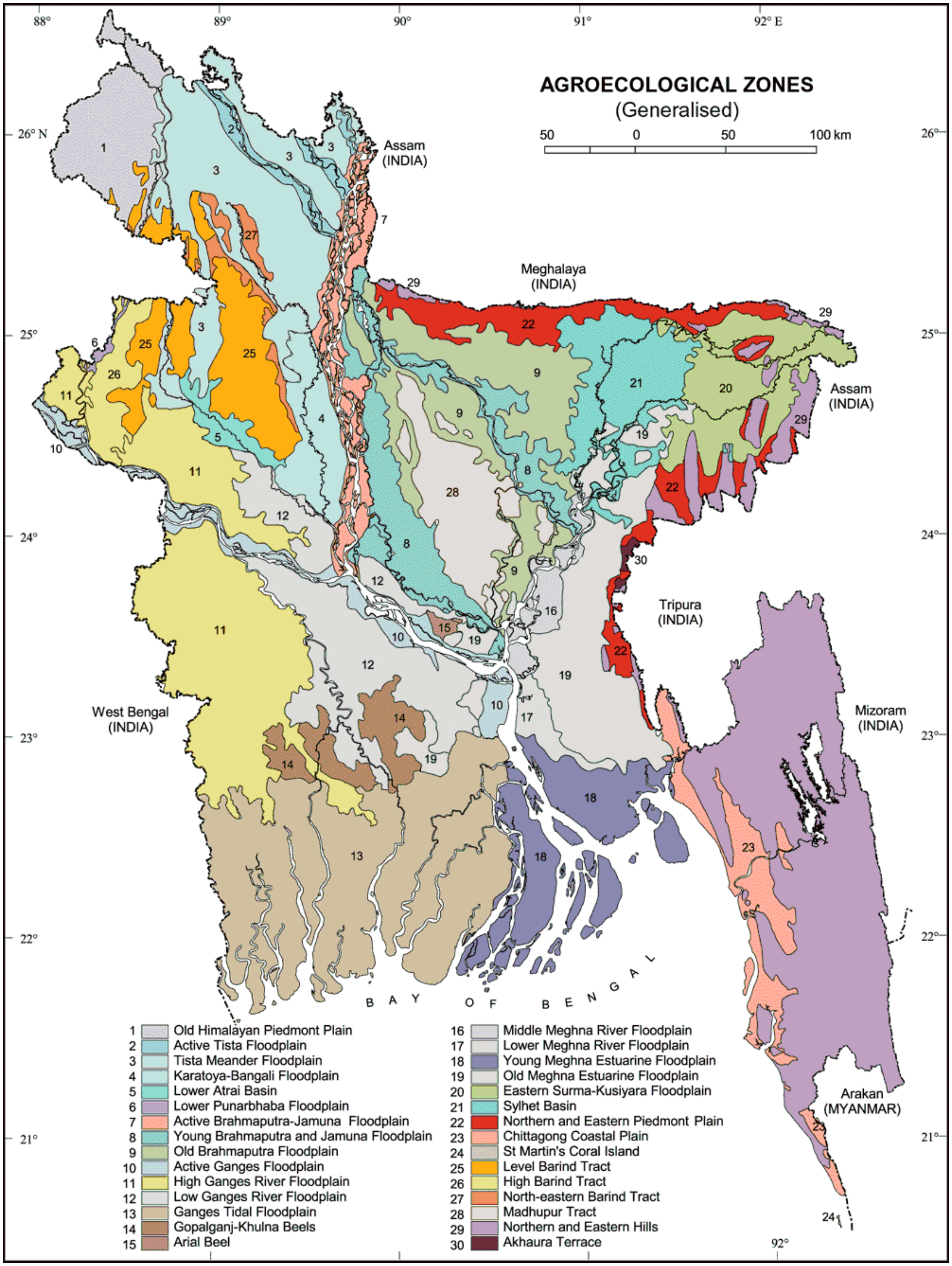
Plate 10 : Taking plant height in mango orchard

Plate 11 : Taking plant height in mahogany cropland

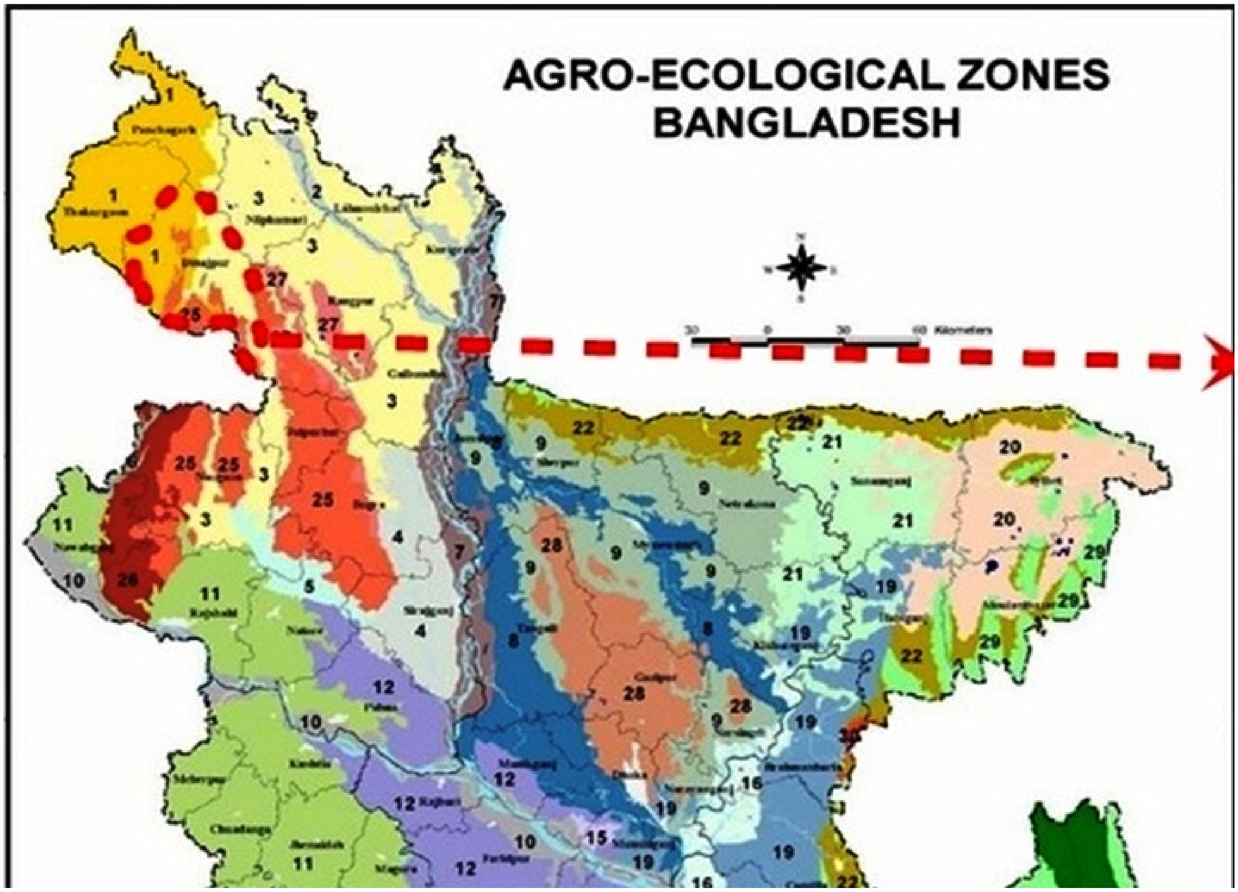
Plate 12: Measurement of breast height diameter in mahogany cropland

Plate 13: Measurement of breast height diameter in eucalyptus cropland

Plate 14 : Measurement of breast height diameter in litchi orchard


AGROECOLOGICAL ZONES
(Generalised)
50 0 50 100 km
88°
89°
90°
91°
92° E
26° N
25°
24°
23°
22°
21°
Assam (INDIA)
Meghalaya (INDIA)
Tripura (INDIA)
Mizoram (INDIA)
West Bengal (INDIA)
Arakan (MYANMAR)
B A Y O F B E N G A L
1 Old Himalayan Piedmont Plain
2 Active Tista Floodplain
3 Tista Meander Floodplain
4 Karatoya-Bangali Floodplain
5 Lower Atrai Basin
6 Lower Punarbhaba Floodplain
7 Active Brahmaputra-Jamuna Floodplain
8 Young Brahmaputra and Jamuna Floodplain
9 Old Brahmaputra Floodplain
10 Active Ganges Floodplain
11 High Ganges River Floodplain
12 Low Ganges River Floodplain
13 Ganges Tidal Floodplain
14 Gopalganj-Khulna Beels
15 Arial Beel
16 Middle Meghna River Floodplain
17 Lower Meghna River Floodplain
18 Young Meghna Estuarine Floodplain
19 Old Meghna Estuarine Floodplain
20 Eastern Surma-Kusiyara Floodplain
21 Sylhet Basin
22 Northern and Eastern Piedmont Plain
23 Chittagong Coastal Plain
24 St Martin's Coral Island
25 Level Barind Tract
26 High Barind Tract
27 North-eastern Barind Tract
28 Madhupur Tract
29 Northern and Eastern Hills
30 Akhaura Terrace

Cooch Behar
Kokrajhar
Baliadangi
Kishanganj
Dinhata
Dhubri
Purnea
Kurigram
Rangpur
Dinajpur
দিনাজপুর
Katihar
Hatsingimari
Phulbari
Tura
Itahar
Sahibganj
Tapan
Birampur
Saghata
Sherpur
Phulpur
Malda
Bogra
Map data ©2017 Google


AGRO-ECOLOGICAL ZONES
BANGLADESH