Study on the Carbon Sequestration Potentiality of Different Cropland Agroforestry Systems in Dinajpur District

A THESIS

BY

MST. NUSRAT JAHAN PAKHOM

Registration No. 1805343

Session: 2018

Thesis Semester: July-December, 2019

MASTER OF SCIENCE (M.S)

IN

AGROFORESTRY AND ENVIRONMENT

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DEPARTMENT OF AGROFORESTRY AND ENVIRONMENT

HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY, DINAJPUR-5200

DECEMBER, 2019

DEDICATED
TO MY
BELOVED PARENTS
&
RESPECTED TEACHERS

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ABSTRACT

A Field experiment was conducted in Kaharole upazila of Dinajpur district of Bangladesh to evaluate the carbon sequestration and climate risk adaptation potentiality in different cropland systems, during October 2018 to September 2019. The experiment was laid out in randomized complete block design (RCBD) with three replications. There were two experiments; experiment 1taking three cropland agroforestry systemsviz:-boundary, composite and scattered cropland while experiment 2 taking nine agroforestry practices viz:-Mahagoni-Maize, Mahagoni-Rice, Eucalyptus-Maize, Mango-Vegetable, Mango-Rice, Lombu-Rice, Eucalyptus-Mahagoni-Maize, Lombu-Mango-Rice, Mahagoni-Jackfruit-Vegetable. So, there were total 36 experimental plots with two experiments. Data were recorded from tree growth parameters (height and diameter at breast height) and under storeyvegetations (herbs, shrubs and crops) in order to estimate the different cropland biomass accumulation. The results revealed that there was significant difference of carbon sequestration potentiality of different cropland systems. In case of identified different cropland systems and agroforestry practices there were 3 cropland systems and 9 agroforestry practices available in Kaharole upazila in Dinajpur district. In case of the effect of different cropland systems and agroforestry practices on carbon sequestration, there were significantly differencesin tree carbon sequestration (t/ha) and total carbon sequestration in leaf litter, herb and grass (t/ha) on different croplands. The highest total cropland carbon sequestration (328.11 t/ha) was recorded from composite cropland agroforestry system and the lowest (81.61 t/ha) was obtain from scattered cropland agroforestry system. In case of effect of different agroforestry practices carbon sequestration also significantly varied in respect of all the considered parameters. The highest carbon sequestration (402.09 t/ha) was recorded from eucalyptus-mahagoni-maize practice and the lowest (9.7533 t/ha) was obtained from mango-vegetable agroforestry practices. Among the three cropland systems, the composite plantation gave the maximum carbon sequestration potentiality. Among the nine agroforestry practices, the eucalyptus-mahagoni-maize practice showed the maximum carbon sequestration potentiality. In case of economic value of carbon sequestration, the composite cropland system gave the maximum (39713.95 $/ha) monitory return. Therefore, composite plantation is better option for cropland agroforestry system to reduce atmospheric carbon and emphasis should be given in composite cropland plantation for mitigating the green house gases and also contribute the climate risk adaptation potentiality.

CONTENTS

CONTENTS (Cont.)

CONTENTS (Cont.)

LIST OF FIGURES

LIST OF FIGURES (Cont.)

LIST OF APPENDIX

LIST OF ABBREVIATION

AFS	= Agroforestry Systems
AGF	= Agroforestry
CSP	= Carbon Sequestration Potential
GHG	= Green House Gases
MPTs	= Multi-purpose trees
IPCC	= Intergovernmental Panel on Climate Change
NAPCC	= National Action Plan on Climate Change
NICRA	=National Initiative on Climate Resilient Agriculture
DBH	= Diameter of Breast Height
AGB	= Aboveground Biomass
AGCS	= Aboveground Carbon Stock
GB	= Belowground Biomass
BGCS	= Belowground Carbon Stock
BGTB	= Belowground Tree Biomass
C	= Carbon
CDM	= Clean Development Mechanisms
CO_2	= Carbon Dioxide
FAO	= Food and Agricultural Organizations
CV%	= Coefficients of variation in percentage
LHG	= Leaf litter, herb and grass
RCBD	= Randomized Complete Block Design

CHAPTER ONE

INTRODUCTION

Agriculture is facing diverse challenges and constraints due to growing demographic pressure, increasing needs of food, feed, pulp, fodder and timber, depletion of natural resources and changing climate. Bangladesh thus, recognizes that for ensuring sustainability in agriculture and country's food security, appropriate mitigation and adaptation strategies have to be developed. The country has initiated timely action to address the problems of climate change. (Dhyani *et al.*, 2013, NRCAF 2013).

Agroforestry is the purposeful growing of trees and crops in interacting combination for a variety of motives. Agroforestry is a collective name for land use systems and technologies where woody perennials (tree, shrubs, palms and bamboos) are deliberately used on the same land management units as agricultural crop and/or animal, in some form of spatial arrangement or temporal sequence. In agroforestry systems, there are both ecological and economical interactions among the different components (Nair, 1990). Cropland Agroforestry (CAF) is a traditional land use system in Bangladesh where tree species like date palm (*Phoenix sylvestris*), palmyra palm (*Borassus flabellifer*), babla (*Acacia nilotica*), mango (*Mangifera indica*), khoer (*Acacia catechu*), mahogany (*Swietenia mahogany*), jackfruit (*Artocarpus heterophyllus*), eucalyptus and sissoo (*Dalbergia sissoo*) grow naturally or planted on agricultural lands and are purposely retained and maintained by the farmers for different household utilities, products and also for cash income (FAO, 2004). Various patterns of cropland agroforestry systems are practiced in different agro-ecological regions of Bangladesh which reflects biophysical and social variations (Shams, 2013). Trees are planted on the borders or within the field, systemically or at irregular intervals, usually with crops such as rice, wheat, pulse, jute, oilseed, sugarcane, vegetables and other crops, and farmers also grow shade-tolerant crops such as turmeric, ginger and aroids when trees (e.g. Jackfruit, Mahagoni) have high canopy coverage (Miah *et al.*, 2002).

The role of land-use systems such as agroforestry as a climate-change mitigation and adaptation strategy has gained considerable importance lately following the realization of the ability of these systems to capture atmospheric carbon dioxide (CO_2) and to store the carbon (C) in plant parts and soil (Sharma *et al.*, 2016; Nair, 2012). Various patterns of cropland agroforestry systems are practiced in different agro-ecological regions of Bangladesh which reflects biophysical and social variations (Shams, 2013).

Carbon sequestration is used to describe both natural and deliberate process by which CO_2 is either remove from the atmosphere or diverted from the emission sources and stored in the ocean, terrestrial environments (vegetation, soil and sediments), and geologic formation. Carbon sequestration is the removal of carbon from the atmosphere by storing it in the biosphere (IPCC, 2007). It is also the capture and storage of carbon that would otherwise be emitted or remained in the atmosphere (FAO, 2004). Carbon is sequestered in the process of plant growth as carbon and captured in plant cell formation and oxygen is released (Altieri *et al.*, 2017). Carbon sequestration potential is one of the hopeful but little-studied characteristics of agroforestry system.

Global climate change is considered to be one of the most serious threats to the environment and it is at the center of scientific and political debate in recent years. Greenhouse gas from deforestation and degradation and the climate change mitigation potential of forested landscapes are well documented (IPCC, 2007).

Agriculture is a significant contributor (10-12%) to global anthropogenic emissions of green house gases (GHGs) (Smith *et al.*, 2012), while IPCC recognized agroforestry with high potential for sequestering carbon under the climate change mitigation strategies (Watson *et al.*, 2000; Chauhan *et al.*, 2009). Agroforestry in developing countries has been attracted increasing attention for both adaptations to climate change and greenhouse gas mitigation. The developing countries are bearing the maximum brunt of global warming and climate change. Agroforestry practices stores more carbon compared to conventional plantations, and thus mitigates GHG emissions (Chauhan *et al.*, 2010a, 2010b Hergoualc'h *et al.*, 2012). Agroforestry, in Bangladeshis practiced in both irrigated and rain-fed conditions where it produces fuel, fodder, timber, fertilizer, fibre, and contributes to food, nutritional and ecological security, sustains livelihoods, alleviates poverty and promotes productive and resilient cropping and farming environments. Agroforestry has been receiving greater attention by researchers, policy-makers and others for its perceived ability to contribute significantly to economic growth, poverty alleviation and environmental quality (Dhyani *et al.*, 2014), and recognized as an important part of the 'evergreen revolution' movement in the country. It is, therefore, important that countries like Bangladesh to take protective steps to contribute in fighting climate change through the role of land use practices to mitigate the climate change.

Bangladesh is one of the developing countries in South Asia with a large population. Most of the people in the country depend on forest and agriculture. The establishment of agroforestry based land use system will help in substantial and productive agriculture and climate change mitigation. However, the amounts of carbon that can be sequestered by this system are unknown. The study was therefore undertaken with the following objectives seeks to establish and compare the amount of carbon sequestered by different agroforestry land use system.

The specific objectives of the study were:

i. To identify the existing cropland system and agroforestry practices in Dinajpur district.
ii. To estimate the biomass and total carbon sequestration by cropland agroforestry systems.
iii. To quantify the economic value of carbon credits in cropland agroforestry systems in Dinajpur district.

CHAPTER TWO

REVIEW OF LITERATURE

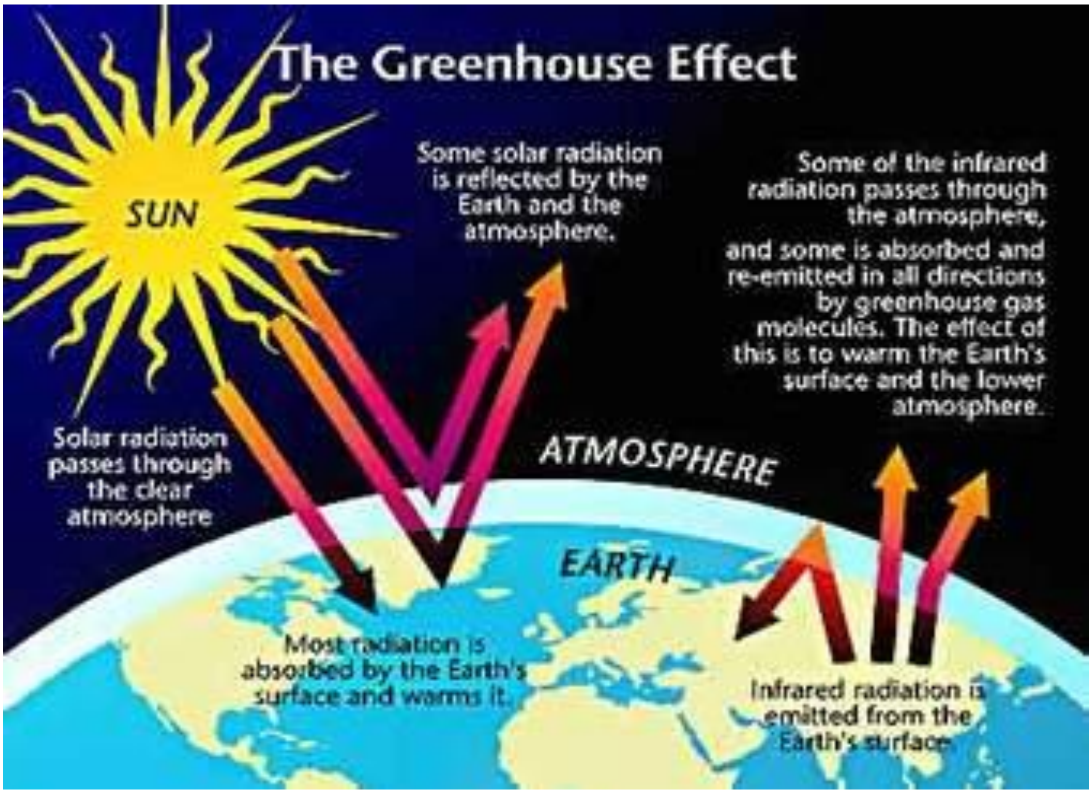
Carbon sequestration is one of the most important environmental issues of this century. The role of agroforestry land use systems on carbon sequestration under cropland agroforestry system was a major concern of this research work. However, in Bangladesh, there is inadequate information especially in regard to quantification of carbon stock in different cropland agroforestry systems. Keeping this in view, an attempt has been made to review finding on carbon sequestration with particular emphasis on above and below ground biomass accumulations, carbon stock and carbon sequestration in some land use systems. This chapter present the available literatures from the source accessible are reviewed under the following heads.

2.1 Greenhouse gases
2.2 Carbon cycle
2.3 Climate change
2.4 Climate change and its impact of Bangladesh
2.5 Carbon sequestration
2.6 Global concept of carbon sequestration in agroforestry
2.7 Carbon sequestration potential of agroforestry systems
2.8 Carbon sequestration in tree biomass
2.9 Carbon sequestration for different crop land
2.10 Different agroforestry practices
2.11 Kyoto protocol in respect of carbon sequestration

2.1 Greenhouse gases

Global awareness of environmental issues has increased on an unprecedented scale. Deforestation, land degradation, desertification, loss of biodiversity, global warming, increase in natural calamities, mean sea level rise, ozone layer depletion, acid rain, disruption of agricultural activities and climate change are some of the environmental issues linked directly to terrestrial ecosystem, 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 system, and conservation and sustainable development of land-use system are critical for meeting those demands sustainably and stabilizing CO_2 concentration in the atmosphere to mitigate global climate change (Ravindranath and Madelene, 2008).

From general point of view, green house is a kind of glass house where plants are grown under controlled temperature. Solar radiation penetrates through the glass and heat is trapped. Natural atmospheric gasses known as green house gasses acts as a glass of this natural globe. Greenhouse gasses absorb some of the infrared energy and radiate it back towards the earth (Jacoby *et al.,* 1998). The main greenhouse gases are water vapor (H_2O), Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), troposphere ozone (O_3), halons and chloroflurocarbons (CFC-11, CFC-12). Out of these gases, water vapour and CO_2 are very important. The actual mechanism by which CO_2 heats the atmosphere is called as greenhouse effect. Most of the energy in solar radiation lies in the visible wavelength of lights which can pass readily through the atmosphere. When the earth surface absorbs solar energy, it heats up and re-radiates infrared light. Water vapour 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 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. 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 are driving the threat of global climate change (Karl and Trenberth, 2003). This means that one molecule of CH_4 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 the basis, CO_2 accounts for 84% of the total amount of greenhouse gas emissions in USA (USEPA, 2003).



(IPPC, 2006)

Fig.2.1: Greenhouse effect

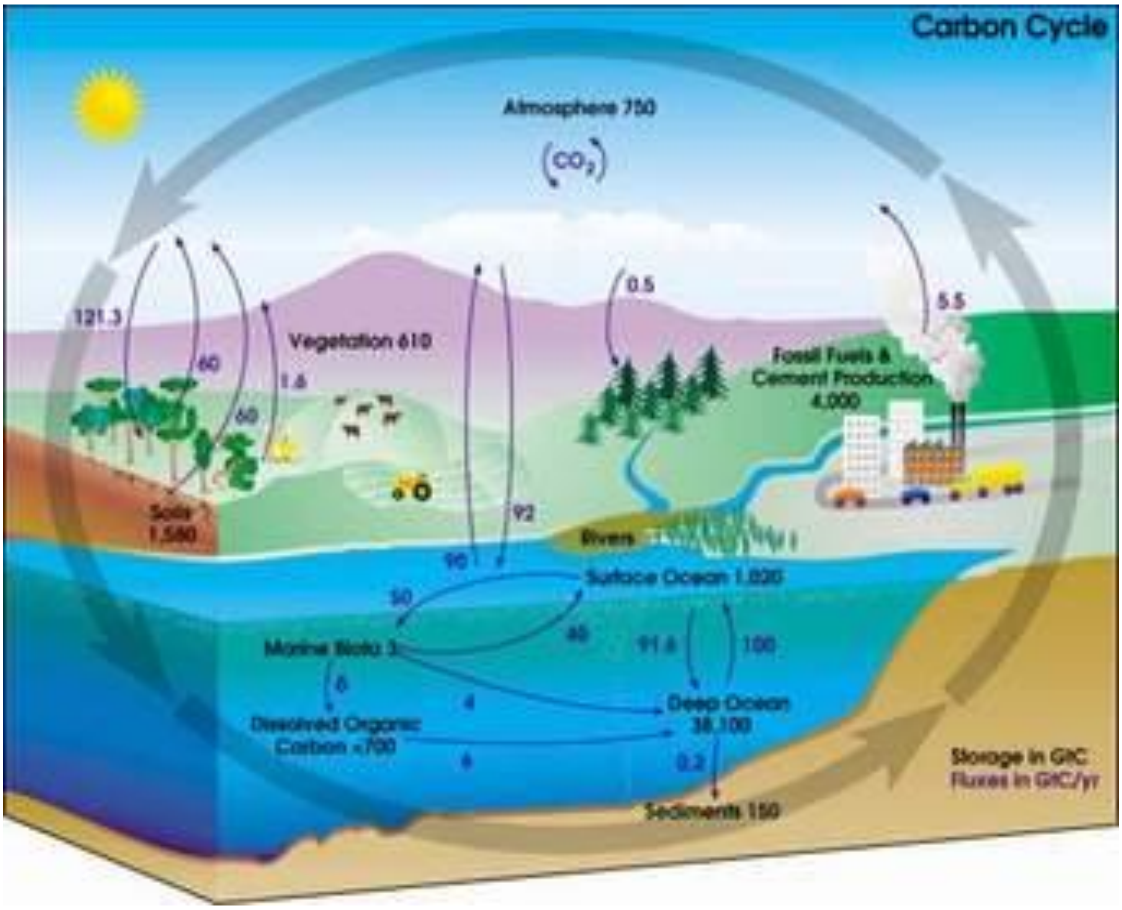
2.2 Carbon cycle

The Carbon cycle is the circulation and transformation of carbon back and forth between living and the environment. The carbon cycle is the biogeochemical cycle by which carbon is exchanged among the biosphere, pedosphere, geosphere, hydrosphere, and atmosphere of the Earth. Carbon is an element, something that cannot be broken down into a simpler substance. Carbon is the main component of biological compounds as well as a major component of many minerals such as limestone. 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 carbon cycle was discovered by Joseph Priestley and Antoine Lavoisier, and popularized by Humphry Davy (Holme, 2008).

The global carbon cycle is now usually divided into the following major reservoirs of carbon interconnected by pathways of exchange (Archer *et al.*, 2010).

1) The atmosphere
2) The terrestrial biosphere
3) The ocean, including dissolved inorganic carbon and living and non-living marine biota
4) The sediments, including fossil fuels, freshwater systems, and non-living organic material.
5) The Earth's interior (mantle and crust). These carbon stores interact with the other components through geological processes.

Carbon in the Earth's atmosphere exists in two main forms: carbon dioxide and methane. Both of these gases absorb and retain heat in the atmosphere and are partially responsible for the greenhouse effect. Methane produces a larger greenhouse effect per volume as compared to CO_2, but it exists in much lower concentrations and is more short-lived than CO_2. Carbon dioxide is removed from the atmosphere primarily through photosynthesis and enters the terrestrial and oceanic biospheres. Carbon dioxide also dissolves directly from the atmosphere into bodies of water (ocean, lakes, etc.), as well as dissolving in precipitation as raindrops fall through the atmosphere. When dissolved in water, carbon dioxide reacts with water molecules and forms carbonic acid, which contributes to ocean acidity. It can then be absorbed by rocks through weathering. It also can acidify other surfaces it touches or be washed into the ocean. Human activities over the past two centuries have significantly increased the amount of carbon in the atmosphere, mainly in the form of CO_2, both by modifying ecosystems' ability to extract CO_2 from the atmosphere and by emitting it directly i.e. by burning fossil fuels and manufacturing concrete (Hansen *et al.*, 2008).



(TEEIC, 2017)

Fig. 2.2: Carbon cycle

2.3 Climate change

Climate change occurs when changes in Earth's climate system result in new weather patterns that remain in place for an extended period of time. This length of time can be as short as a few decades to as long as millions of years. The climate system receives nearly all of its energy from the sun, with a relatively tiny amount from earth's interior. The climate system also gives off energy to outer space. The balance of incoming and outgoing energy, and the passage of the energy through the climate system, determines Earth's energy budget. When the incoming energy is greater than the outgoing energy, earth's energy budget is positive and the climate system is warming. If more energy goes out, the energy budget is negative and earth experiences cooling.

The energy moving through earth's climate system finds expression in weather, varying on geographic scales and time. Long-term averages of weather in a region constitute the region's climate. Climate change is a long-term, sustained trend of change in climate. Such changes can be the result of "internal variability", when natural processes inherent to the various parts of the climate system alter the distribution of energy. Examples include variability in ocean basins such as the Pacific decadal oscillation and Atlantic multidecadal oscillation. Climate change can also result from external forcing, when events outside of the climate system components, nonetheless produce changes within the system. Examples include changes in solar output and volcanism. Human activities can also change climate, and are presently driving climate change through global warming (Vermeulen *et al.*, 2012).

The most general definition of climate change is a change in the statistical properties (principally its mean and spread) of the climate system when considered over long periods of time, regardless of cause. Accordingly, fluctuations over periods shorter than a few decades, such as El Niño, do not represent climate change. The term "climate change" is often used to refer specifically to anthropogenic climate change (also known as global warming). Anthropogenic climate change is caused by human activity, as opposed to change in climate that may have resulted as part of Earth's natural processes. In this sense, especially in the context of environmental policy, the term climate change has become synonymous with anthropogenic global warming. Within scientific journals, global warming refers to surface temperature increases while climate change includes global warming and everything else that increasing greenhouse gas levels affect (Conway *et al.*, 2008).

2.4 Climate change and its impact of Bangladesh

Bangladesh is one of the largest deltas in the world which is highly vulnerable to natural disasters because of its geographical location, flat and low-lying landscape, population density, poverty, illiteracy, lack of institutional setup etc. In other words, 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. The total land area is 147,570 sq. km. consists mostly of floodplains (almost 80%) leaving major part of the country (with the exception of the north-western highlands) prone to flooding during the rainy season. Moreover, the adverse affects of climate change – especially high temperature, sea-level Rise, cyclones and storm surges, salinity intrusion, heavy monsoon downpours etc. has aggravated the overall economic development scenario of the country to a great extent. 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, cyclones and storm surges, salinity intrusion, extreme temperature and drought etc. (Denissen, 2012).

The economy of Bangladesh is based on agriculture mainly, with two thirds of the population engaged (directly or indirectly) on Agricultural activities; although the country is trying to move towards industrialization slowly during the last one and a half decade almost. So, the overall impact of Climate Change on Agricultural production in Bangladesh would be wide spread and devastating for the country's economy. Beside this, other impacts of climate change such as - extreme temperature, drought, and salinity intrusion etc. are also responsible for the declining crop yields in Bangladesh. Temperature and rainfall changes have already affected crop production in many parts of the country and the area of arable land has decreased to a great extent. The salinity intrusion in the coastal area is creating serious implications for the coastal land that were traditionally used for rice production (Asaduzzaman *et al.*, 2010).

2.5 Carbon sequestration

Carbon sequestration is the removal of carbon from the atmosphere by storing it in the biospheret (Albrecht *et al.,* 2003). It is also the capture and storage of carbon that would otherwise be emitted to or remains in the atmosphere.

Carbon sequestration is the process involved in carbon capture and the long-term storage of atmospheric carbon dioxide or other forms of carbon to mitigate or defer global warming. It has been proposed as a way to slow the atmospheric and marine accumulation of greenhouse gases, which are released by burning fossil fuels. Carbon dioxide is naturally captured from the atmosphere through biological, chemical, and physical processes. Artificial processes have been devised to produce similar effects, including large-scale, artificial capture and sequestration of industrially produced CO_2 using subsurface saline aquifers, reservoirs, ocean water, aging oil fields, or other carbon sinks.

Bio-sequestration or carbon sequestration through biological processes affects the global carbon cycle. Examples include major climatic fluctuations, such as the azolla event, which created the current arctic climate. Such processes created fossil fuels, as well as clathrate and limestone. By manipulating such processes, geo-engineers seek to enhance sequestration (ETGS, 2010). Thus forest act contributing approximately 80% of terrestrial aboveground and 40% of terrestrial belowground carbon storage (Phat *et al.*, 2004).

2.6 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 concentration of greenhouse gases (GHG), 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 sequestration in the biosphere is widely accepted as a strategy for reducing the GHG concentration 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 (Albrecht *et al.,* 2003). The IPCC special report on land use, land-use change and forest (LULUCF) shows that net increase in global C stocks are estimated to be 0.026Pg (billion tons) C year-1 for improving agroforestry management and 0.39 Pg C year-1 for agroforestry-related land use changes in 2007 (IPCC, 2007). The proper design and management, agroforestry systems could be effective C sequestration model. Agroforestry would be the only system that could realistically be implemented to mitigation the atmospheric CO_2 through terrestrial C sequestration. In spite of these postulated benefits, the C sequestration potential (CSP) of agroforestry system remains largely unexplored (Nair, 2012).

2.7 Carbon sequestration potential of agroforestry systems

Agroforestry is the practice of introducing trees in the farming system. It has played a significant role in enhancing land production and improving livelihood in both developed and developing countries. Although carbon sequestration through reforestation of degraded natural forest 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 (Murthy *et al.,* 2013). The effectiveness of agroforestry system in storing carbon depends on both environmental and socio-economic factors; in humid tropics, agroforestry systems have the potential to sequester over 70 Mg/ha in the top 20 cm of the soil. The carbon storage capacity in agroforestry varies across species, land type and geography (Murthy *et al.,* 2013).

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 difficult comparisons. Few studies of specific agroforestry practices have proved potential for carbon sequestration (Nair *et al.*, 2009).

2.8 **Carbon sequestration in tree biomass**

Chavan and Rasal (2010) studied the aboveground carbon (AGC), belowground carbon (BGC) and mean organic carbon (MOC) in *Ficus religiosa* in their study and find out 4.27, 0.641 and 4.91 t/tree, respectively and 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 monoperma* (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.

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

Abbas *et al.* (2011) stated that average contribution of stem portion of the *Olea ferruginea* 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 major part of the 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.

2.9 Carbon sequestration for different cropland agroforestry

2.9.1 Boundary cropland agroforestry

Tree growing on farm boundaries is a very common practice, but it requires agreement between the neighbors involved to avoid conflicts. There are different ways of sharing trees planted on a boundary. Sometimes two rows of trees are planted, one on each side of the boundary, and then each farmer grows and manages his own trees. A disadvantage with this system is that it occupies more land than a single row. If trees are grown in a single row, the neighbors can agree on ownership of every second tree for example. In such cases, it is recommended that trees of the same species are grown, although it may be difficult to keep track of which tree belongs to which farmer. If different species are chosen, one species may outcompete the other and one of the two farmers is disadvantaged. Another option is for the neighbors to agree to own trees in different sections of the boundary. This may be easier than owning every second trees, and it is then possible to choose different species for different sections according to the farmers' preferences (Sanginga *et al.,* 2007).

In small-scale farming areas boundary planting is usually enough to reduce wind speed, and there is no need to establish windbreaks. Trees on boundaries which are regularly pollarded can meet most of a family's need for firewood. In addition, other products and services are obtained and the boundary is effectively demarcated. If the trees are not well managed there may be negative effects on crops, and if competitive species are planted root competition may be a problem. Conflicts with neighbors may arise if the sharing arrangements are not well handled.

Some examples; certain species, e.g. *Cordia abyssinica* and *Croton megalocarpus*, have traditionally been used as boundary markers. Grevillea is a very popular tree too. Trees with a short lifespan, e.g. *Sesbania spp*. and *Acrocarpus fraxinifolius,* are less suitable unless they are combined with more permanent trees. Competitive trees such as eucalypts, pines and *Acacia mearnsii* should be avoided. Many other non-competitive trees are suitable. Non-commercial fruit trees, e.g. *Syzygium cuminii, Vitex spp.* and *Annona spp.* can also be suggested.

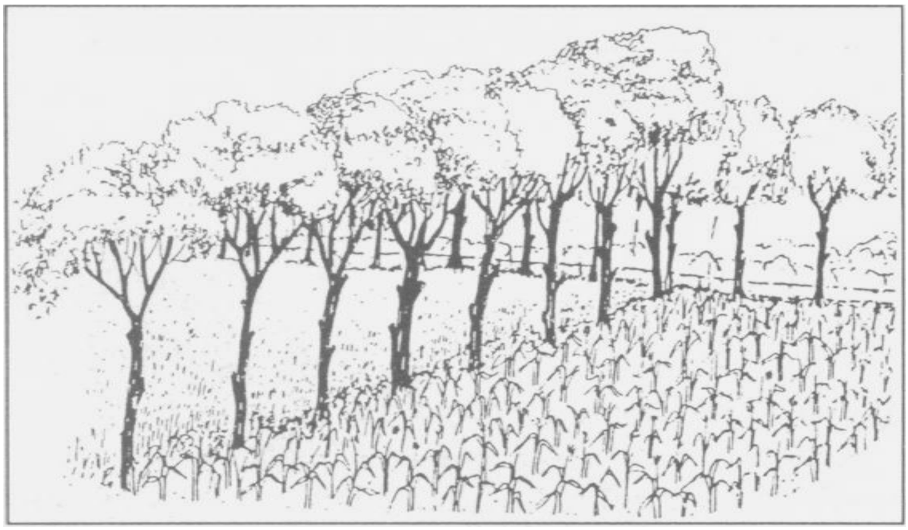


Fig. 2.3: A line of trees along a boundary cropland agroforestry

2.9.2 Composite Cropland agroforestry (Mixture of Species)

Different types of tree species growing on farm boundaries in one or two sites are a very popular practices in cropland agroforestry. The composite cropland one of this kinds of cropland where different (mixture of tree species) species of tree are grown on boundary of cropland. These types of cropland practices having higher carbon sequestration ability than other cropland practices. In this land is getting more than three output at a time (Fig. 2.4).

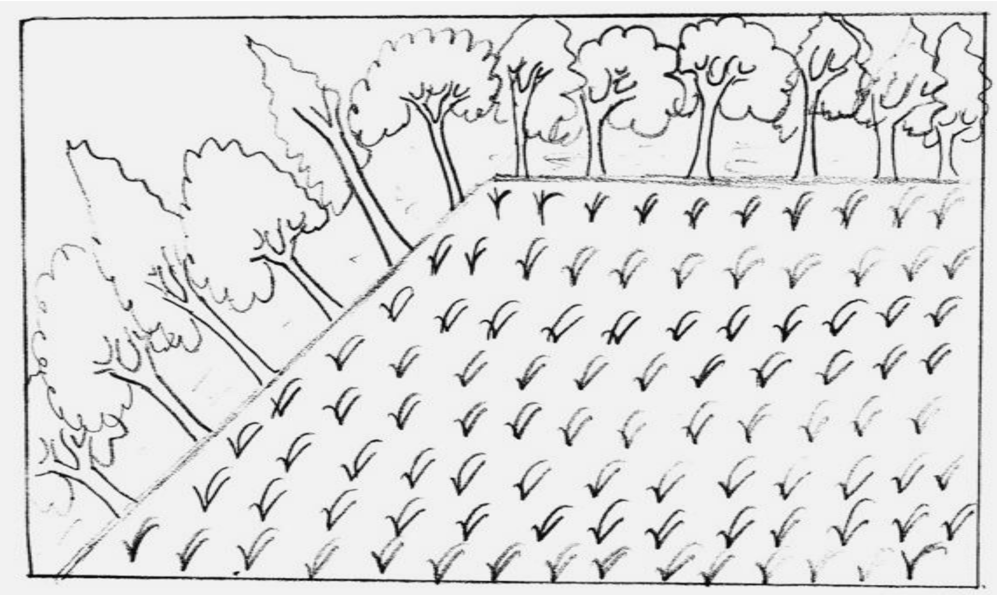


Fig. 2.4: Composite cropland agroforestry system

2.9.3. Scattered cropland agroforestry

Scattered trees support high levels of farmland biodiversity and ecosystem services in agricultural landscapes, but they are threatened by agricultural intensification, urbanization, and land abandonment. Scattered trees are centraland dynamicelements of many agricultural landscapes worldwide. Scattered trees have become an important object of landscape ecological research, as there is growing awareness that these ecological keystone structures govern much of the biodiversity and ecosystem services on farmlands (Plieninger *et al.*, 2015).

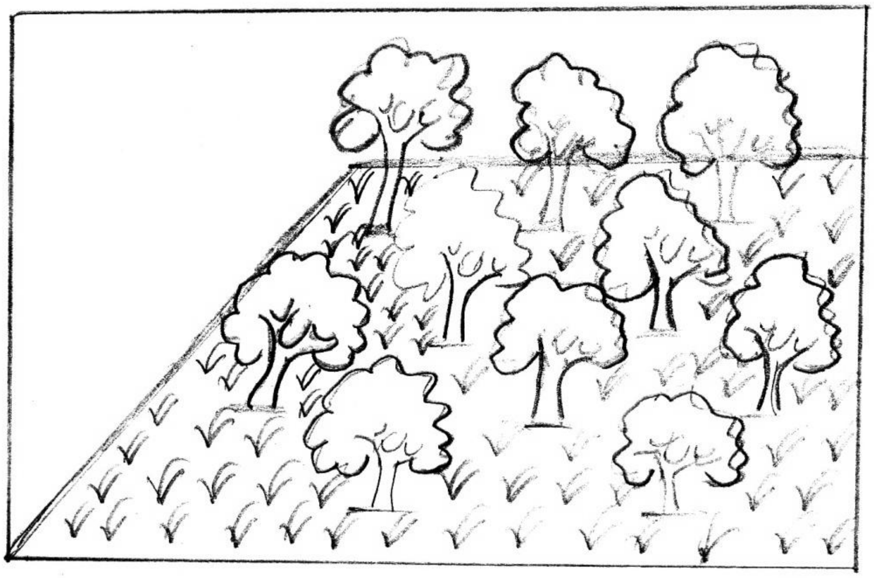


Fig. 2.5: Scattered cropland agroforestry system

2.10 Different agroforestry practices

Bangladesh, our homeland, is mainly an agriculture based country and agriculture play a great role in the national economy of the country. The population of Bangladesh in 2011 was estimated by the BBS at 16.44 Crore. According to the BBS, the annual population growth rate for 2010-11 is 1.4%. This sector is playing a vital role in achieving self-sufficiency in food production. However, the contribution of agriculture to the GDP and incremental employment is likely to diminish day by day. The natural resources are depleting due to constant pressure by the increasing population. To feed the over increasing population appropriate production system should be developed to maximize production without deteriorating the existing resources.

Agro forestry can provide a sound ecological basis for increased crop and animal productivity, more dependable economic returns, and greater diversity in social benefits on a sustained basis In Bangladesh scope of agroforestry is vast (Ahmed, 2004). The main venues of agroforestry are homestead, roadside, cropland, railway side, embankment side, charland, coastal area, deforested area, institutional premises, riverside etc. Among them charland is the most important venue for practicing agroforestry systems. The major char inhabited districts of Bangladesh are Jamalpur, Sirajgonj, Noakhali, Bogra, Rangpur and Mymensingh. In Mymensingh district there are 12 upazilas of which Mymensingh sadar, Ishwargonj, Trishal, Gaffargaon and Gouripur upazila are charinhabited area containing about 584 sq. km charland areas. These five upazilas contained at least 361000 homesteads of which 25% i.e. 90000 homesteads remained in char areas (Ibrahim *et al.*, 2011). A large impact of agroforestry practices on livelihood improvement of the farmers of char Kalibari area of Mymensingh and more number of populations are living in these char areas and maintaining their livelihood through char based farming systems. Therefore, for increasing production, maintaining ecological balance and improving socio-economic condition of the charland people, integrated approach with crop and trees is necessary.

2.11 Kyoto protocol in respect of carbon sequestration

The Kyoto protocol is an international agreement setting targets for industrialized countries to cut their greenhouse gas emission. It contains legally binding commitments, in addition to those included in Annex B of the protocol (most Organization for Economic Cooperation & Development countries and countries with economic in transition) agreed to reduce their anthropogenic greenhouse gas emission (carbon dioxide, methane, nitrous oxide, CFC) 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 concern that human activity increasing the concentration of greenhouse 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 greenhouse gas concentration in the atmosphere at the level that would prevent dangerous anthropogenic interference with the climate system 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).

The Kyoto protocol provides for the involvement of developing countries in an atmospheric greenhouse gas reduction regime under its clean development mechanism (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 project. The paper analyzes the effect of reforestation project on carbon sequestration in Bangladesh, in general, and in the hilly Chittagong region, in particular, and concludes by demonstrating the carbon trading opportunities. Result showed that tree tissue in the forests of Bangladesh stored 92 tons of carbon per hectare (tC/ha), on average. The result also revealed a gross stock of 190 tC/ha in the plantations of 13 tree species, ranging age from 6 to 23 years (Schlamadinger *et al.*, 2007).

CHAPTER THREE

MATERIALS AND METHODS

In this chapter, the materials and methods followed in conducting this study has been discussed with including the study areas, the sampling technique, data collection and procedure followed for estimation of biomass and carbon sequestration.

3.1 Study area

3.1.1 Geographical location of Dinajpur

The district of Dinajpur situated between 25˚23ˈN and 89˚18ˈeast longitudes and district is bounded by Panchagarh and Thakurgaon district on north. On the south it is bounded by Joypurhat, Gaibandha district and India, on the east by Rangpur and Nilphamary district and on the west by the West Bengal, India. The map (Fig. 3.1) shows the boundary area of Thakurgaon, Panchagarh and Dinajpur districts (BBS, 2014).

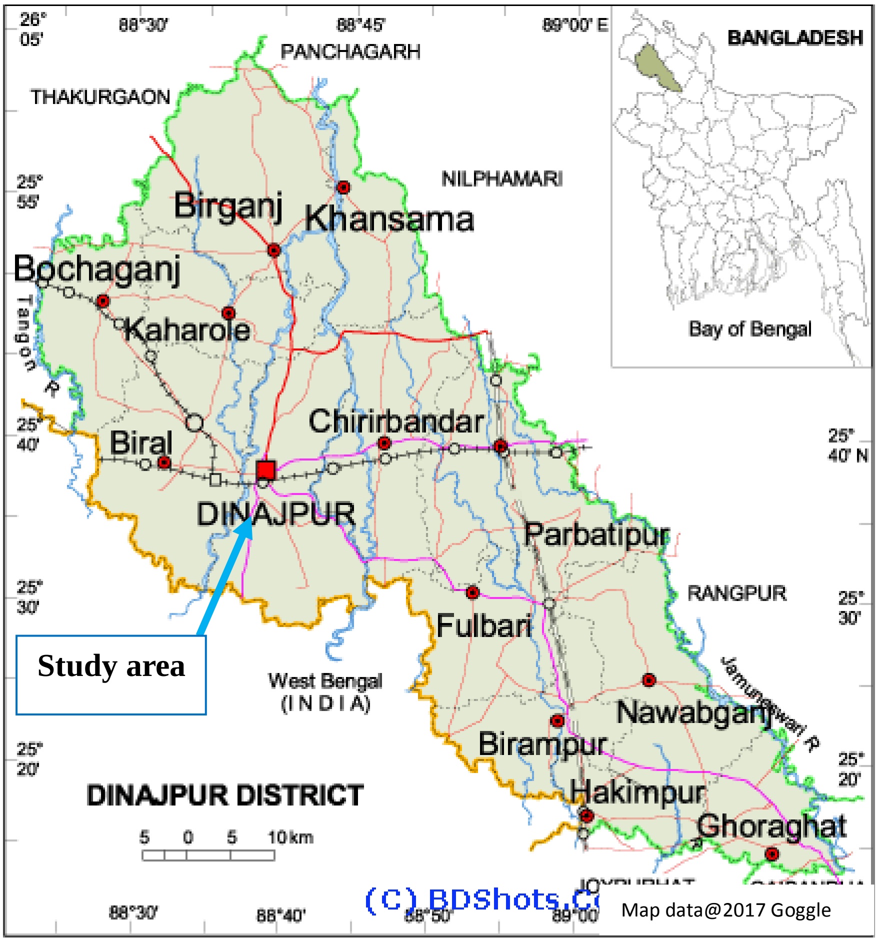


Figure 3.1: Map showing Dinajpur districts

3.1.2 Geographical location of Kaharole upazila in Dinajpur district

Kaharole is an Upazila of Dinajpur District in the Division of Rangpur. It is located at 25.7917˚N and 88.600˚E. It has 22448 households and total area 205.54 km^2. It has 6 unions /words, 153 Mauzas/Mahallas and 152 villages (Hossain, 2012) (Fig. 3.2).

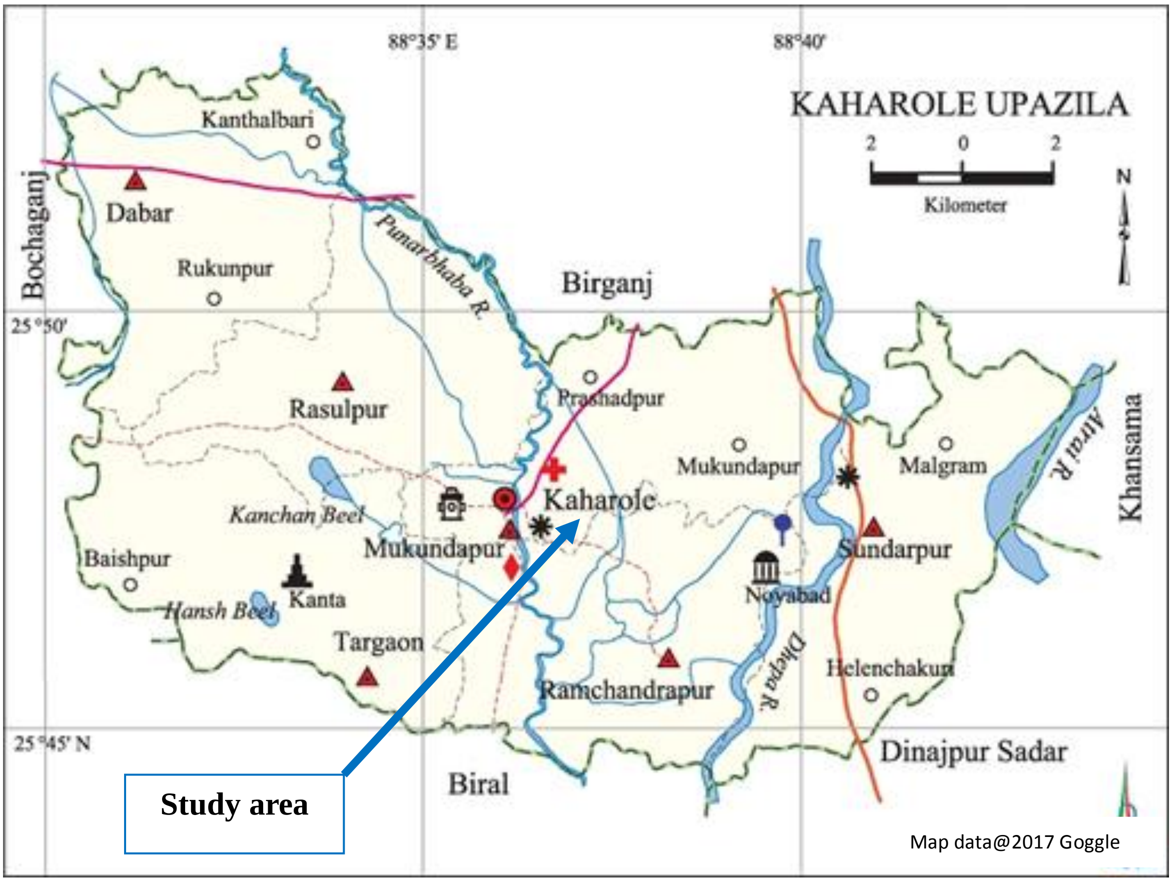


Figure 3.2: Map showing Kaharole upazila of Dinajpur districts

3.1.3 Characteristics of soil in Dinajpur district

The land of Dinajpur District experiences old Himalayan Piedmont Plain in most of its part. Its 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 poil are experienced. The soil of Barind tract in south east region of this district experiences the old alluvium taking the form of mixed beown and grey silty loam and the central part of meander floodplains along the river little Jamuna and the valley of Karotoa river (BBS, 2014).

3.1.4 Climate of Dinajpur

The district of Dinajpur experience temperate and pleasant climate. It shows high temperature, humidity and coldness. The mean temperature of this district ranger from 10.7˚C to 22.8˚C during winter and it varies from 23.4˚C to 34.1˚C 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 experience 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 (BBS, 2014).

3.2 Experimental period

The study period was from October, 2018 to September, 2019.

3.3 Experimental design and treatment

The experiment was laid out in a Randomized Complete Block Design (RCBD) with the three replications in each treatment. The experiment consisted of three cropland agroforestry systems i.e. Boundary, Composite and Scattered (Hanif *et al.,* 2018) and each system consisted of three cropping practices. Therefore, there was two experiments with nine agroforestry practices. In Experiment 1 consisted of three treatments taking cropland agroforestry systems and Experiment 2 consisted of nine treatments taking agroforestry practices. Total number of experimental plot were 36. The two experiment are-

Experiment 1: Different types of cropland agroforestry

T_1= Boundary cropland

T_2= Composite cropland (mixture of species)

T_3= Scattered cropland

Experiment 2: Different cropland agroforestry practices

P_1= Mahagoni-Maize

P_2= Mahagoni-Rice

P_3= Eucalyptus-Maize

P_4= Mango-Vegetable

P_5= Mango-Rice

P_6= Lombu-Rice

P_7= Eucalyptus-Mahagoni-Maize

P_8= Lombu-Mango-Rice

P_9= Mahagoni-Jackfruit-Vegetable

3.4 Sampling

A stratified random sampling method was used in selecting the sampling area (Kaharol Upazila) in Dinajour districts. This upazila were selected from three cropland agroforestry system (boundary, scattered, composite) and nine cropping practices (tree-rice, tree-vegetable, tree-maize). The experiment stratified RCBD with the three replications. It is useful where there is large variation between sampling area and sampling plots and if the sampling plots from the same areas is more similar than different area (Watson, 1947).

3.5 Study locations

The study was conducted in different cropland agroforestry farms of Kaharol upazila under Dinajpur district. It is located at 25.7917˚N and 88.600˚E. It has 22448 households and total area 205.54 km^2. It has 6 unions /words, 153 Mauzas/ Mahallas and 152 villages (Hossain, 2012).

3.6 Sampling plots

The experiments were conducted at the following village/ union/ location; No. 1 Kaharole union, No. 2 Kharole union, No. 3 Kharole union; as showing Fig. 3.2.

3.7 Sampling techniques

The methodology procedure for sampling of this experiment varies due to different cropland agroforestry systems. However, seven years Eucalyptus tree and seven years mahagoni tree was selected as an experimental tree in different cropland agroforestry. Similarly, same age was also considered in other tree species and different cropland agroforestry combinations. Hence, only mature trees with the diameter of breast height greater than 5cm (DBH) 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 dried it at 80˚C for 72 hours. Dry weight was also recorded. The procedure for measuring stand density from different land use is as follows:

3.7.1 Boundary cropland agroforestry

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

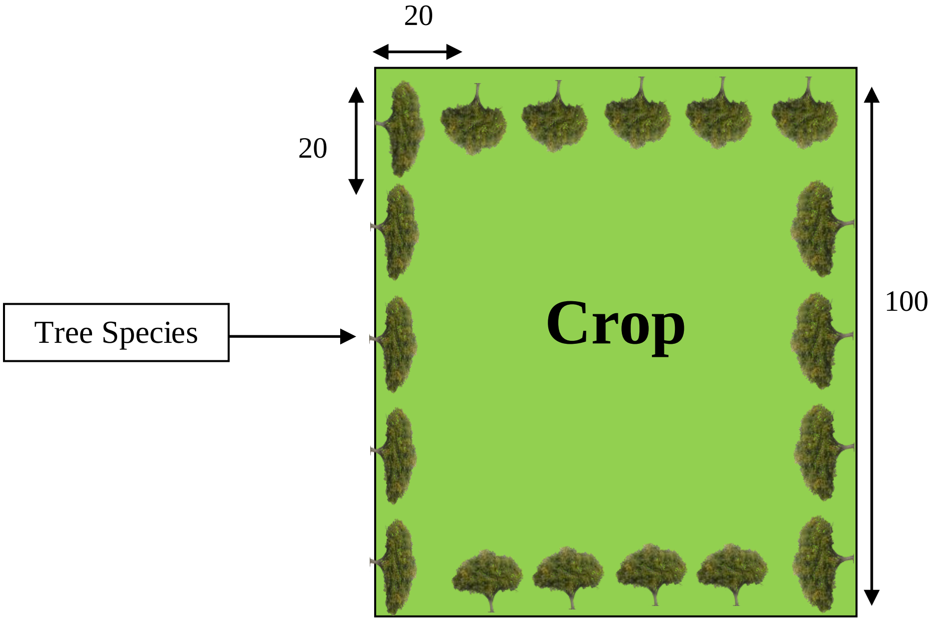


Fig. 3.3: Showing sketch of measurement in boundary cropland agroforestry

3.7.2 Composite cropland agroforestry (mixture of species)

A sample unit of 20m×20m quadrant of both sides of the composite cropland was employed in this case. The diagram below showed the scale of measurement in composite cropland.

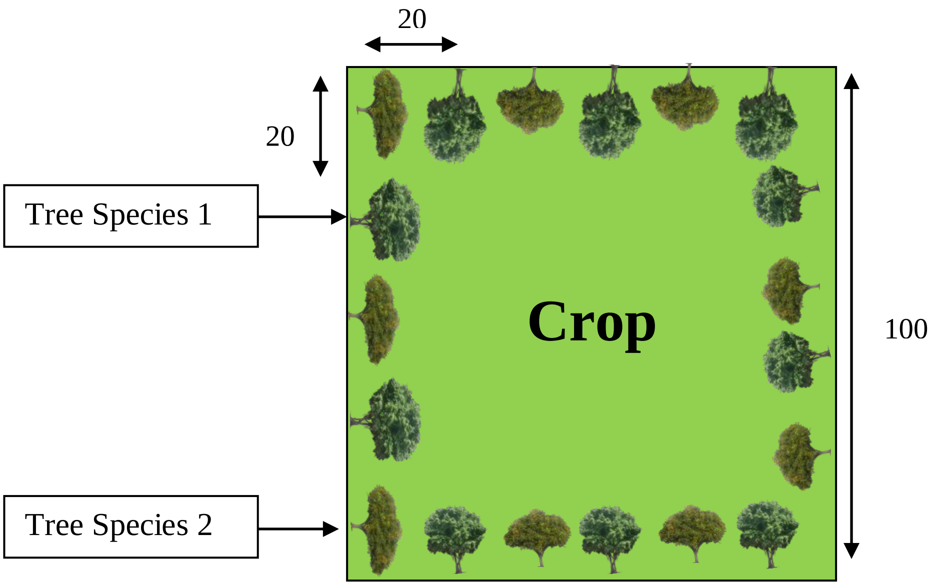


Fig. 3.4: Showing sketch of measurement in composite cropland agroforestry

3.7.3 Scattered cropland agroforestry

Sample of 20m×20m quadrant was employed in this case. The diagram below showed the scale of measurement in scattered cropland.

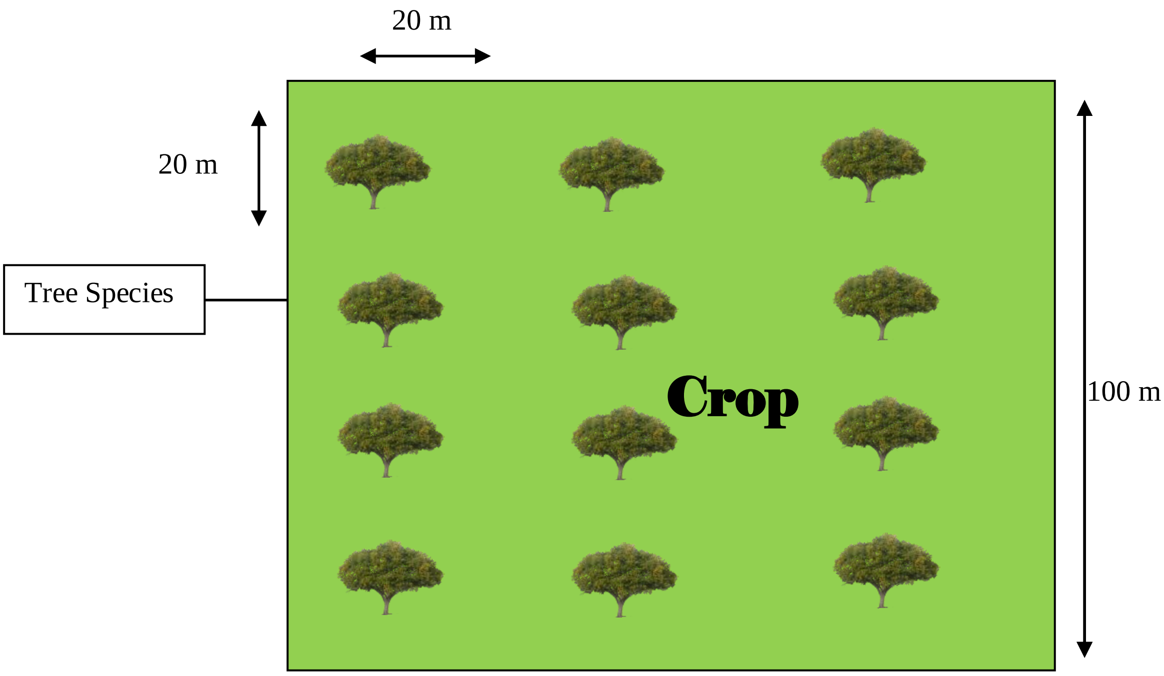


Fig. 3.5: Showing sketch of measurement in scattered cropland agroforestry

3.8 Tree biomass estimation

The estimation of tree biomass is the sum of above ground and below ground biomass content. For accurate measure of tree 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 (Peichl and Arain, 2007).

3.8.1 Tree height (m)

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

Fig. 3.6: Height measurement in cropland (Source: Filed Survey, 2019)

3.8.2 Diameter at breast height (cm)

The Diameter at Breast Height (DBH) of stem of the trees was measured in centimeters (cm) at breast height (1.37 cm from the ground level) with the help of measuring tape. The observation of diameter were taken on all the trees per sample unit per replication and its average was also calculated in each cropland system.

Fig. 3.7: Diameter measurement in cropland (Source: Filed Survey, 2019)

3.8.3 Above ground tree biomass

Above ground tree biomasses are calculated using allometric equations. For above ground tree biomass (AGB) calculation, IPCC recommended methodology was used. In this system, the following allometric equation were used for estimation of biomass (kg/tree) of tree diameter 5-60 cm (Chave *et al.*, 2005) and improve AGB by Chave *et al.* (2014).

AGB = 0.0595× ρD2H (kg/tree) (Chave *et al.*, 2005)

Where,

AGB = Above ground biomass
D = DBH, Diameter of breast height (cm)
H = Tree height (cm)
ρ= Wood specific gravity (mg m^{-3})

3.8.4 Below ground tree biomass

Below ground tree biomass (BGB) of trees was calculated by multiplying the above ground biomass (AGB) with a default value of 0.26, provided by Hangarge *et al.* (2012) as a factor of root: shoot ratio. Average root biomass content of all trees was 26% of aboveground biomass.
Belowground Tree Biomass =Above ground biomass×0.26 (kg/tree)

3.8.5 Total tree biomass

Total tree biomass (TTB) was calculated by summing above ground biomass (AGB) and below ground biomass (BGB).
Total biomass = AGB + BGB (kg/tree)

3.9 Estimation of leaf litter, herb and grass (LHG)

To determine the biomass of leaf litter, herbs, and grass (LHG), samples were taken destructively in the field within a small area of 1 m^2. Fresh samples are weighed in the field and a well-mixed sub-sample is then placed in a marked bag. The sub-sample is used to determine an oven-dry-to-wet mass ratio that is used to convert the total wet mass to oven dry mass. For the cropland floor (herbs, grass, and litter), the amount of biomass per unit area is given below:

$$LGH = \frac{W\ field}{A} \times \frac{W\ subsample\ ,dry}{W\ subsample\ ,wet} \times \frac{1}{10000}\ (kg/m^2)$$ (IPCC, 2006)

Where,

LGH = 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];

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

Generally, for any plant species, 50% of its biomass is considered as carbon storage

Carbon storage = Biomass × 0.5 (tC/ha) (Pearson *et al.*, 2005).

3.11 Estimation of carbon stock in leaf litter, herb and grass (LHG)

The carbon content in under stories biomass (LHG) was calculated by multiplying with default carbon fraction of 0.47

LHG (kg/m^2) = Biomass× 0.47 (tC/ha) (IPCC, 2006)

3.12 Estimation of carbon sequestered (t/ha)

To estimate carbon sequestration of crop and trees the biomass carbon was multiplied with a factor of 3.67 for all species.

Estimated carbon sequestration (t/ha) = Biomass carbon × 3.67 (Rajput, 2010).

Hence, the factor 3.67 was determined from weight of carbon as calculated below:

CO_2 is composed of one molecule of carbon and two molecules of oxygen.

The atomic weight of C is 12.001115

The atomic weight of O_2 is 15.9994

The weight of CO_2 is C + O×2=43.999915

The ratio of CO_2 to C is 43.999915/12.001115=3.6663

Therefore, to estimate the carbon sequestration in tree, multiply the carbon biomass weight by 3.6663.

3.13 Total cropland carbon sequestration

To estimate the total carbon sequestration by a particular cropland system was calculated by summing of total tree carbon dioxide sequestration and total LHG carbon dioxide sequestration(Anup *et al.,* 2013).

Total cropland carbon sequestration = Tree CO_2 sequestration + LHG CO_2 sequestration (t/ha)

3.14 Estimation of economic value of carbon credits

Now-a-days, it has been proved that destruction of ecosystems and deterioration of quality and quantity of services offered by ecosystems has negative effects on the current economic growth. Currently, it is estimated that the amount of carbon dioxide gas (CO_2) has increases in the atmosphere compared with before the industrial revolution and due to its long lifetime, this causes about 60% of global warming (Common and Sigrid, 2005). The economic value of carbon sequestered in agroforestry is important in addressing the risk of global climate change that has presented a profound challenge to the international community. Carbon dioxide is a highly emitted greenhouse gas in the world today. This carbon can be sequestrated by the plants. One ton of net sequestered or mitigated carbon dioxide from plant biomass in a land use is equal to one carbon credit. Therefore, total carbon credit in a land use systems was calculated from CO_2-eq values of retained biomass in respective cropland agroforestry systems. The carbon credit were calculated from the total cropland carbon sequestration from tree and crop biomass using the guidelines of IPCC (2006). It is estimated that the monetary value of one ton of net sequestrated CO_2 equivalent to U$15 Dollars (Jepkemei *et al.,* 2010). As cropland is a promising practice of agroforestry in the northern Bangladesh and it has a good role to play in the carbon circle mitigation processes by sequestering the carbon. In this study, the value of Vivian, (2010) was used.

3.15 Statistical analysis

Data were statistically analyzed using the "Analysis of Variance" (ANOVA) technique with the help of computer package R- language. The means difference were adjusted by Tukey HSD test.

CHAPTER FOUR

RESULTS AND DISCUSSION

The study was conducted to identifying the existing cropland systems and agroforestry practices, estimate the biomass accumulation and carbon sequestration potentiality of different cropland at Kaharole upazila in Dinajpur District of Bangladesh. The result of the study is presented from figure 4.1 to 4.17 in this chapter. The findings of the study and interpretations of the result are discussed under the following sub heading to achieve the objectives of the study.

4.1 Effect of identification of existing cropland agroforestry and agroforestry practices

In this Study identified several cropland agroforestry systems and agroforestry practices, there were three cropland system i.e. boundary cropland agroforestry, composite cropland agroforestry, scattered cropland agroforestry and nine agroforestry practices mahagoni-maize, mahagoni–rice, eucalyptus-maize, mango–vegetable, mango-rice, lombu-rice, eucalyptus-mahagoni-maize, lombu-mango-rice, mahagoni-jackfruit-vegetable.

4.2 Effect of agroforestry practices on carbon sequestration

4.2.1 Leaf litter, herbs and grass biomass

The total biomass of leaf litter, herb and grass (LHG) was significantly varied with the agroforestry practices (Fig. 4.1). The highest biomass of LHG (107.7 t/ha) was found eucalyptus-mahagoni-maize agroforestry practices which was followed by mahagoni-jackfruit-vegetable and Lombu-rice agroforestry practices. On the other hand, the lowest biomass of LHG (2.0 t/ha) was recorded from Mango-Rice agroforestry practices which was followed by Eucalyptus-Maize and mahagoni-rice agroforestry practices. Wide variation of total biomass might be due to heterogeneity of different agroforestry practices. The maximum understory biomass produce by different agroforestry practices might be attributed due to the organic soil condition and habit of growth. Ackermann, (2014) reported that tree shading have great influenced in understory vegetation or crop yield. Moreover, he also explained that changes of incident photosynthetically active radiation (PRA), air temperature and CO_2 concentration were the basic reasons of understory vegetation.

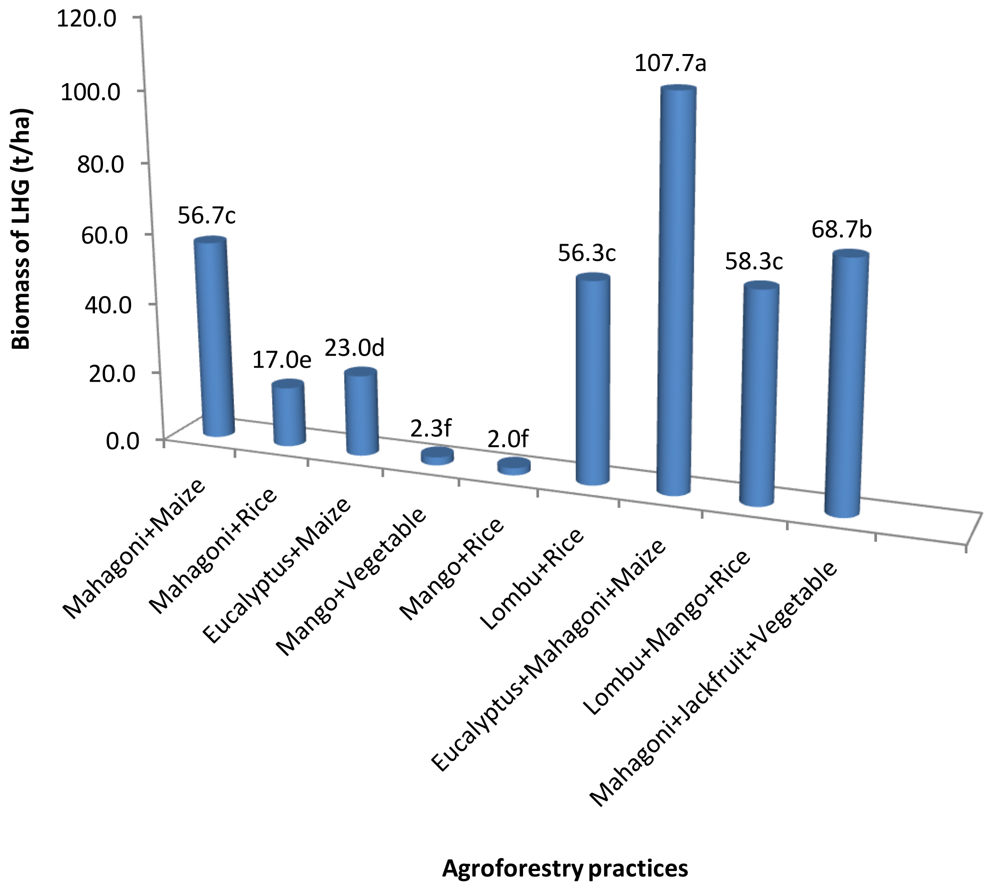


Fig. 4.1: Effect of different agroforestry practices on the LHG biomass estimation (t/ha)
[In a figure, different letter(s) are significantly different at P≤ 0.05 level of significant by Tukey HSD test]

4.2.2 Carbon stock of LHG

Leaf litter, herb and grass carbon stock (LHG) was also influenced by different agroforestry practices (Fig. 4.2). The highest carbon stock of LHG (50.6 t/ha) was observed from eucalyptus-mahagoni-maize agroforestry practices which was followed by mahagoni-jackfruit-vegetable and lombu-rice agroforestry practices. Whereas, the lowest carbon stock of LHG (1.0 t/ha) was also observed from mango-rice agroforestry practices which was followed by eucalyptus-maize and mahagoni-rice agroforestry practices. The variation in LHG might be due to biomass accumulation under the practices. The practices were influence by two major activities, aboveground litter decomposition and belowground root activity (Freschet *et al.*, 2013). 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 under story biomass.

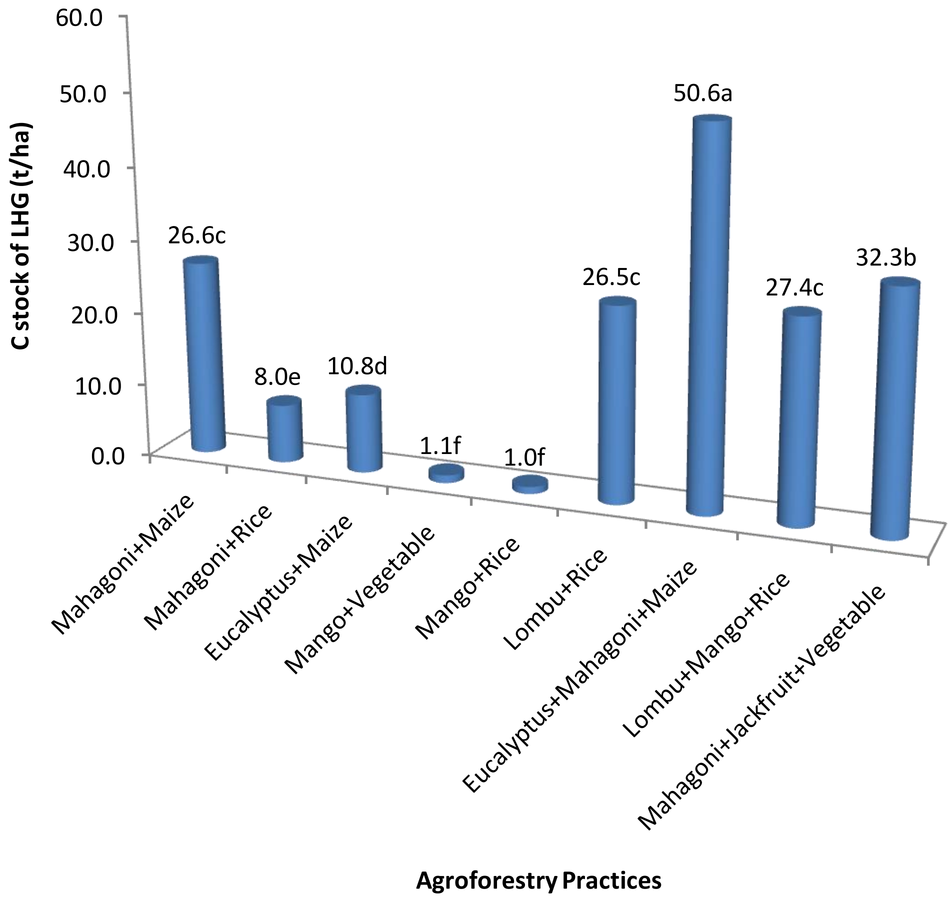


Fig. 4.2: Effect of different agroforestry practices on the LHG carbon stock estimation (t/ha)

[In a figure, different letter(s) are significantly different at P≤ 0.05 level of significant by Tukey HSD test]

4.2.3 Leaf litter, herb and grass carbon sequestration per hectare (t/ha)

The carbon sequestration of LHG was also influenced by different agroforestry practices (Fig. 4.3). The highest carbon sequestration of LHG (185.7 t/ha) was observed from eucalyptus-mahagoni-maize agroforestry practices which was followed by mahagoni-jackfruit-vegetable and lombu-rice agroforestry practices. Whereas, the lowest carbon sequestration of lhg (3.5 t/ha) was also observed from mango-rice agroforestry practices which was followed by eucalyptus-maize and mahagoni-rice agroforestry practices. The variation in LHG might be due to biomass accumulation under the practice. Practice like tillage, plant residue management and manure or fertilizer application have been identified to affect C sequestration in understory biomass (Bhattacharya *et al.*, 2016).

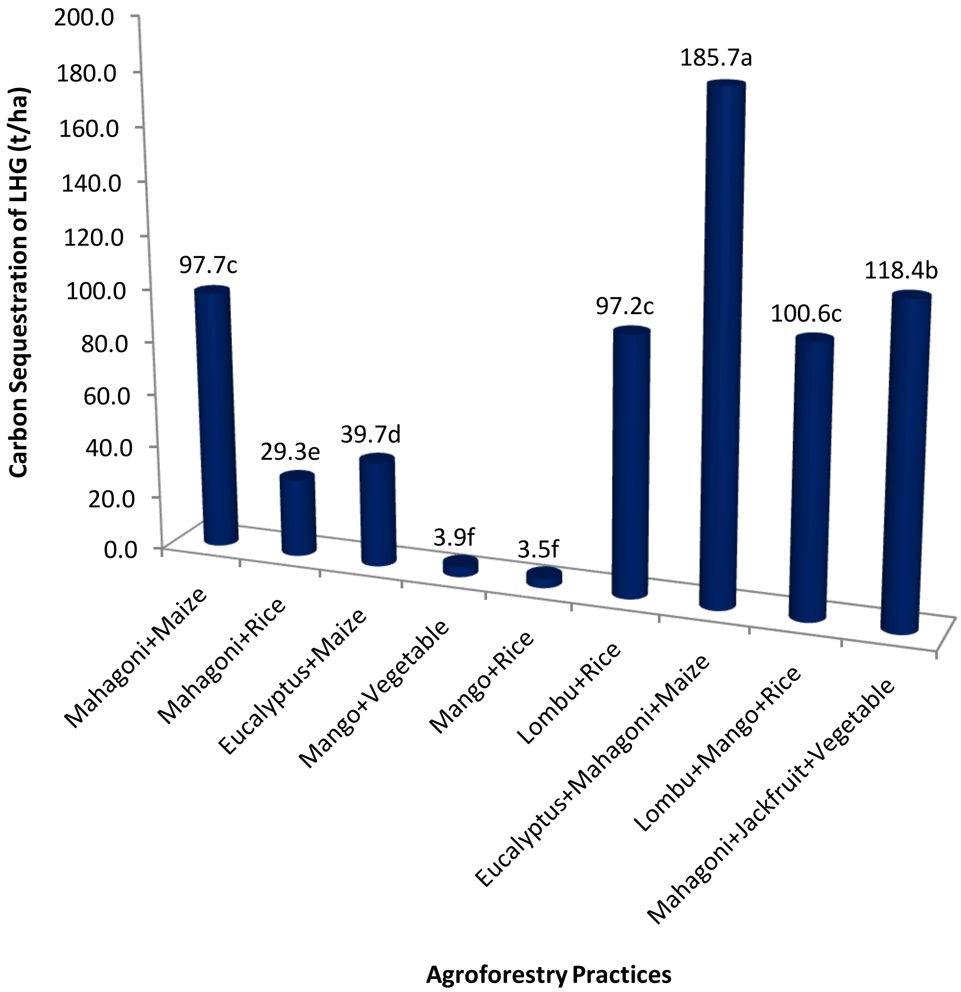


Fig. 4.3: Effect of different agroforestry practices on the LHG carbon sequestration estimation (t/ha) [In a figure, different letter(s) are significantly different at P≤ 0.05 level of significant by Tukey HSD test]

4.2.4 Tree carbon stock per hectares (t/ha)

The tree carbon stock was significantly varied in respect of different agroforestry practices (Fig. 4.4). The highest C stock of tree (58.957 t/ha) was recorded from eucalyptus-mahagoni-maize agroforestry practices which was followed by mahagoni-maize and lombu-rice agroforestry practices. Again, the lowest C stock of tree (1.5867 t/ha) was also recorded from mango-vegetable agroforestry practices which was followed by eucalyptus-maize and mahagoni-rice agroforestry practices. Prasad *et al*, (2010) reported that the total dry biomass of some agroforestry is influenced by tree species to species. The above result indicated that the biomass components viz., above ground biomass, below ground biomass and total biomass produced by particular cropland agroforestry practices were influenced by variation in biomass allocation pattern and might be attributed due to the divergence in this agroforestry practices or wide range of habit or bushy nature of growth and age variations. The rate of carbon stock depends upon the nature of the crop, intensity of the management and soil types. Similar findings were reported by Rajput (2010).

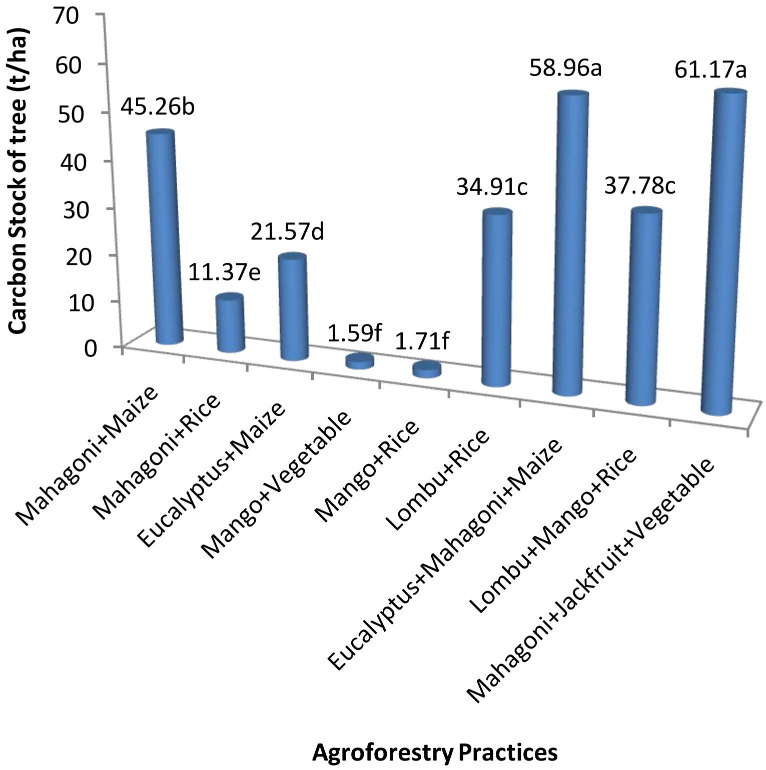


Fig. 4.4: Effect of different agroforestry practices on the tree carbon stock estimation (t/ha)

[In a figure, different letter(s) are significantly different at P≤ 0.05 level of significant by Tukey HSD test]

4.2.5 Tree carbon sequestration per hectare (t/ha)

The total tree carbon sequestration was significantly varied in respect of different agroforestry practices (Fig. 4.5). The highest C sequestration of tree (216.38 t/ha) was recorded from eucalyptus-mahagoni-maize agroforestry practices which was followed by mahagoni-maize and lombu-rice agroforestry practices. Again, the lowest C sequestration of tree (5.82t/ha) was also recorded from mango-vegetable agroforestry practices which was followed by eucalyptus-maize and mahagoni-rice agroforestry practices. Prasad *et al*, (2010) reported that carbon sequestration is also influenced by tree species to species. Based on these standing woody biomass, the carbon sequestration rate of trees (t/ha) was calculated by Rajput (2010).

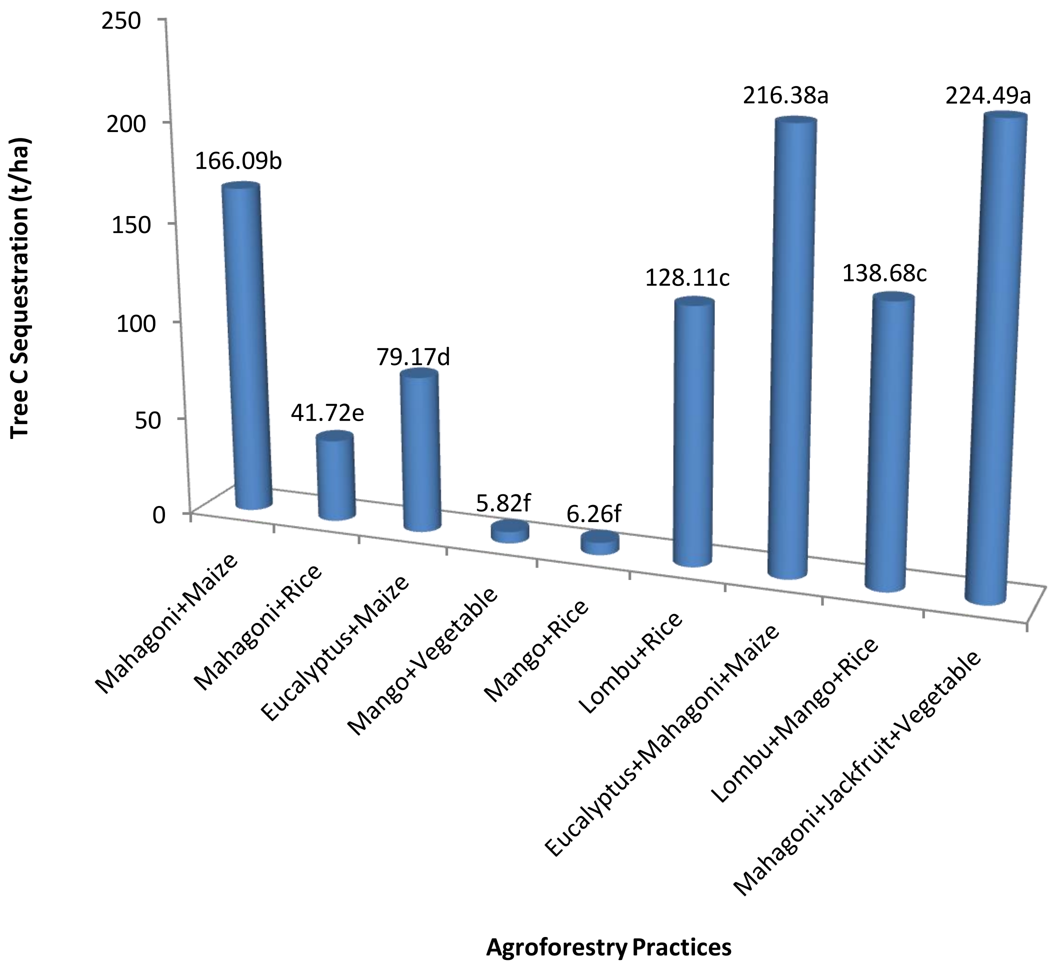


Fig. 4.5: Effect of different agroforestry practices on the tree carbon sequestration estimation (t/ha) [In a figure, different letter(s) are significantly different at P≤ 0.05 level of significant by Tukey HSD test]

4.2.6 Total cropland system carbon stock per hectare (t/ha)

The total cropland carbon stock, tree carbon stock and LHG carbon stock was significantly varied in respect of different agroforestry practices (Fig. 4.6). The highest carbon stock (109.56 t/ha) was recorded from eucalyptus+ mahagoni-maize agroforestry practices which was followed by mahagoni+-maize and lombu-rice agroforestry practices. Again, the lowest carbon stock (2.67 t/ha) was also recorded from mango-rice agroforestry practices which was followed by eucalyptus+ maize and mahagoni-rice agroforestry practices. The above result have indicated that biomass components viz., aboveground biomass, belowground biomass and total biomass produced by particular cropland agroforestry practices were influenced by variation in biomass allocation pattern and might be attributed due to the divergence in this agroforestry practices or wide range of habit or bushy nature of growth and age variations. This might be due to variation in different agroforestry practices in the study area. 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).

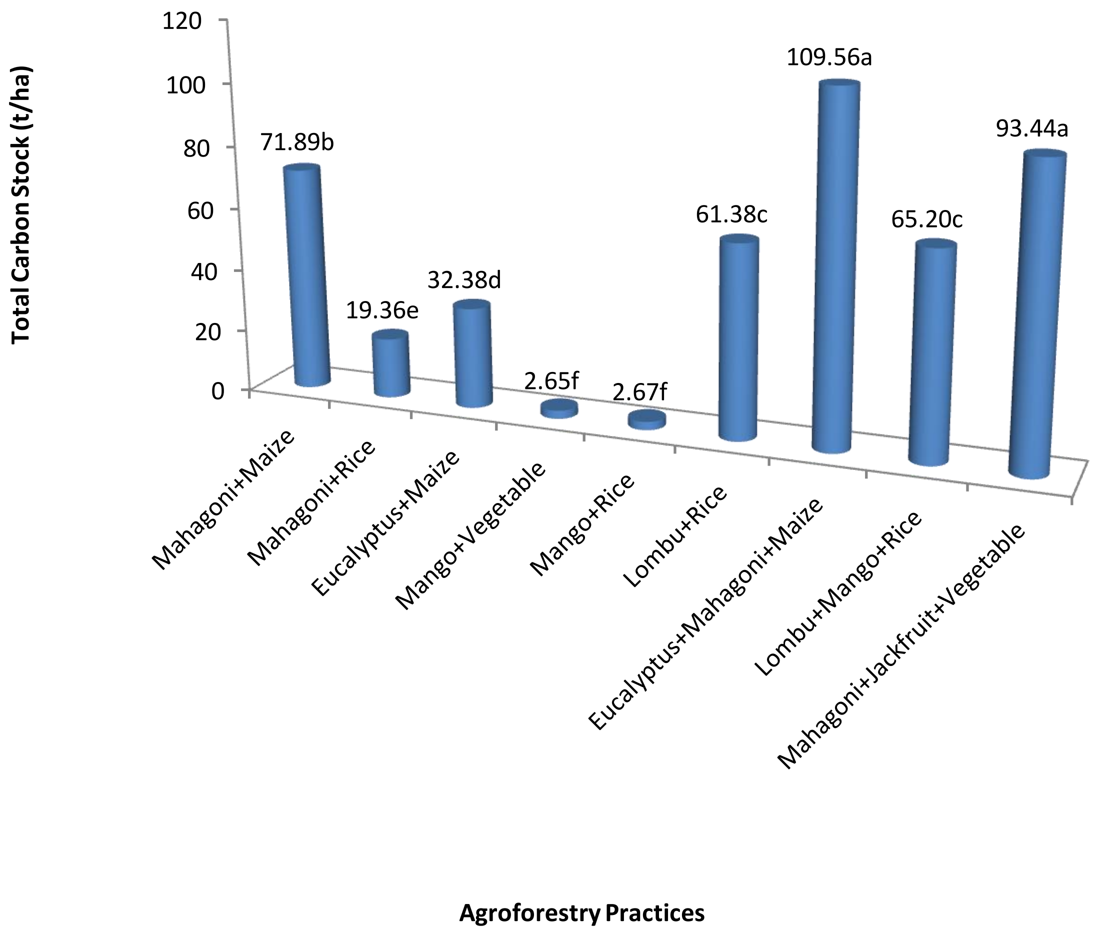


Fig. 4.6: Effect of different agroforestry practices on the total carbon stock estimation (t/ha)
[In a figure, different letter(s) are significantly different at P≤ 0.05 level of significant by Tukey HSD test]

4.2.7 Total agroforestry practices carbon sequestration per hectare (t/ha)

The study also found that, the total cropland system carbon sequestration per hectares was highly influenced by the effects of different agroforestry practices (Fig. 4.7). The highest carbon sequestration (402.09 t/ha) was recorded from eucalyptus-mahagoni-maize agroforestry practices which was followed by mahagoni-maize and lombu-rice agroforestry practices. However, the lowest carbon sequestration (9.7533 t/ha) was recorded from mango-vegetable agroforestry practices which was followed by eucalyptus-maize and mahagoni-rice agroforestry practices. Several studies have been conducted to explore the effect of agroforestry practices on carbon sequestration and other biophysical factors that affect the system (Mbow *et al.,* 2014). Carbon Sequestration is also influenced by tree species (Pérez-Cruzado *et al.,* 2012). It can be shown that variability in the carbon sequestration potential under various agroforestry practices depends primarily on the climatic factores as rainfall, temperature and soil, which influence the stand density and finally carbon sequestration ability. Rajput (2010) reported similar result with mean maximum rate of carbon sequestration ability. He also revealed that the rate of CO_2 sequestration potential was higher in Agrisilviculture land use system, which however remained significantly higher than horticulture land use system and forest.

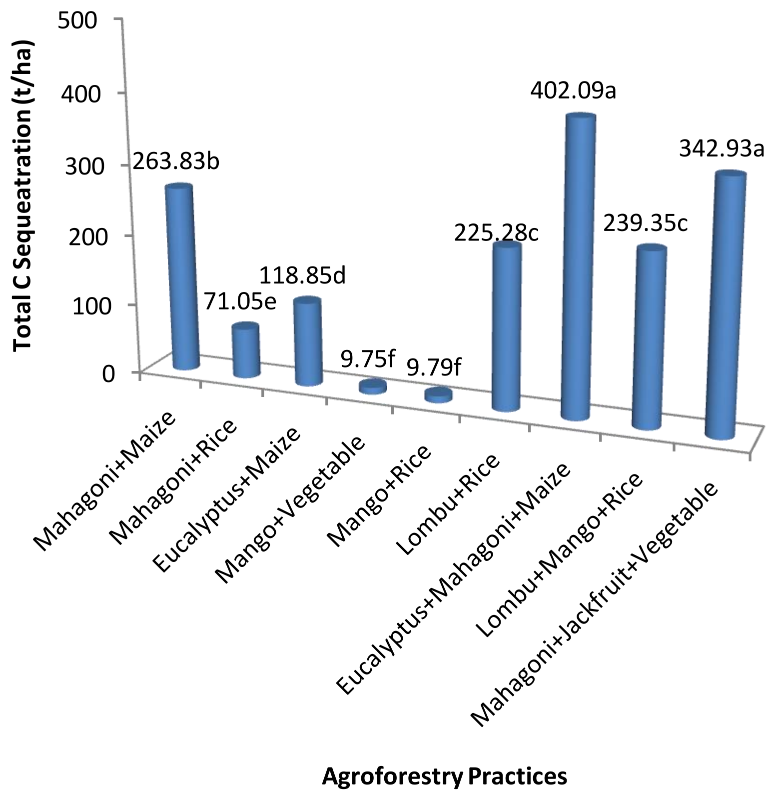


Fig. 4.7: Effect of different agroforestry practices on the total carbon sequestration estimation (t/ha) [In a figure, different letter(s) are significantly different at P≤ 0.05 level of significant by Tukey HSD test]

4.3 Effect of different cropland system on carbon sequestration

4.3.1 Leaf litter, herb and grass (LHG) biomass (t/ha)

The leaf litter, herb and grass (LHG) i.e. understory biomass of trees was also varied in different cropland systems (Fig.4.8) The highest biomass of LHG (78.22 t/ha) was recorded from the composite cropland agroforestry which was followed by boundary and scattered cropland agroforestry . On the other hand, the lowest biomass of LHG (20.22 t/ha) was recorded from the scattered cropland agroforestry which was followed by boundary and composite cropland agroforestry. Ackermann (2014) reported that tree shading have great influenced on understory vegetation or crop yield. Moreover, he also explained that, changes of incident photosynthetically active radiation (PAR), air temperature and CO_2 concentration were the basic reasons of understory vegetation.

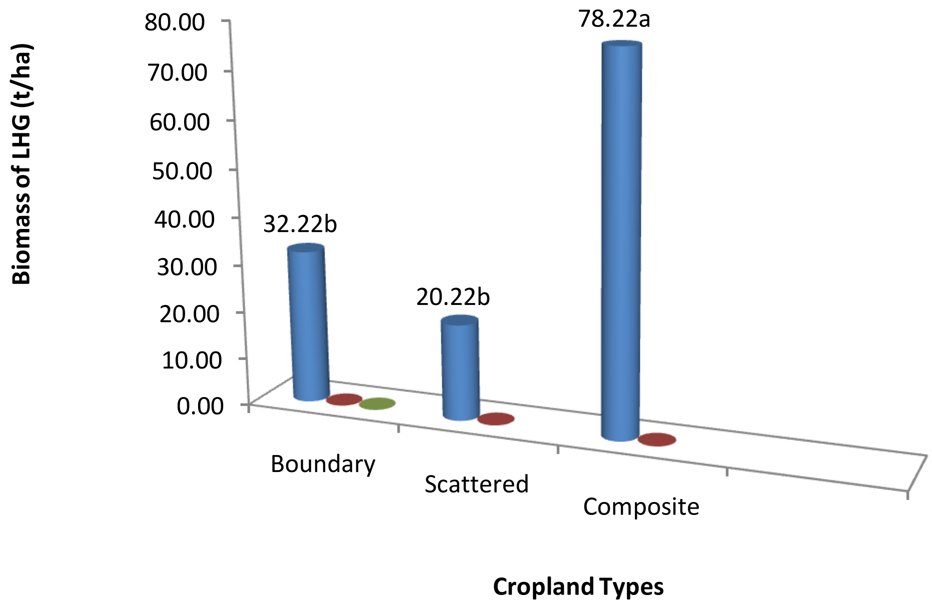


Fig. 4.8: Effect of different cropland system on the biomass of LHG estimation (t/ha) [In a figure, different letter(s) are significantly different at P≤ 0.05 level of significant by Tukey HSD test]

4.3.2 Leaf litter, herb and grass carbon stock (t/ha)

The leaf litter, herb and grass carbon stock (CLHG) was also varied in different cropland systems (Fig. 4.9) the highest CLHG (36.76 t/ha) was recorded from the composite cropland agroforestry which was followed by boundary and scattered cropland agroforestry. On the other hand, the lowest CLHG (9.0533 t/ha) was recorded from scattered cropland agroforestry which was followed by boundary and composite cropland agroforestry. However, broad leaved trees had higher litter fall production. Rainfall and different climate condition (temperature, water availability, wind speed, air humidity etc.) directly influence the litter production dynamics (Barbier *et al.*, 2008).

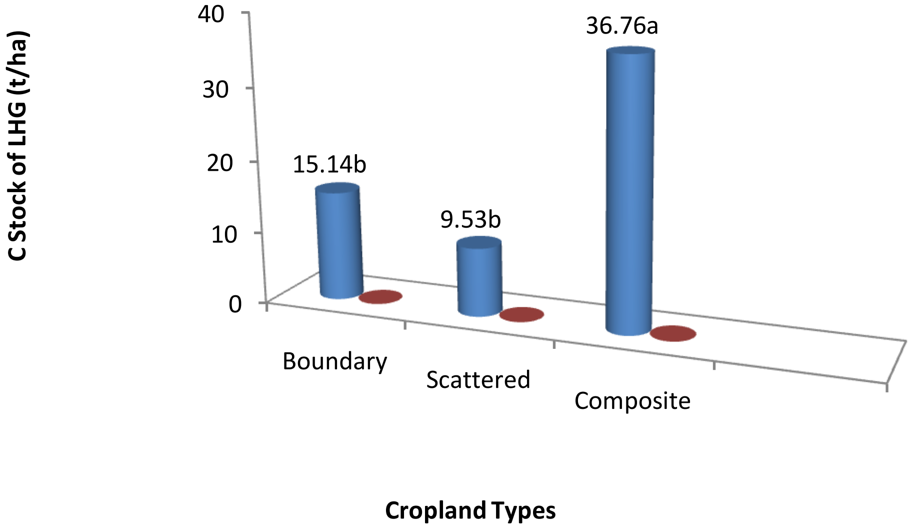


Fig. 4.9: Effect of different cropland system on the LHG carbon stock estimation (t/ha) [In a figure, different letter(s) are significantly different at P≤ 0.05 level of significant by Tukey HSD test]

4.3.3 Leaf litter, herb and grass carbon sequestration (t/ha)

The leaf litter, herb and grass carbon sequestration (CSLHG) was also varied in different cropland systems (Fig.4.10) The highest CSLHG (134.92 t/ha) was recorded from the composite cropland agroforestry which was followed by boundary and scattered cropland agroforestry. On the other hand, the lowest CSLHG (34.876 t/ha) was recorded from the scattered cropland agroforestry which was followed by boundary and composite cropland agroforestry. Management practices like tillage, plant residue management and manure or fertilizer application have been identified to affect C sequestration in understory biomass (Bhattacharya *et al.*, 2016).

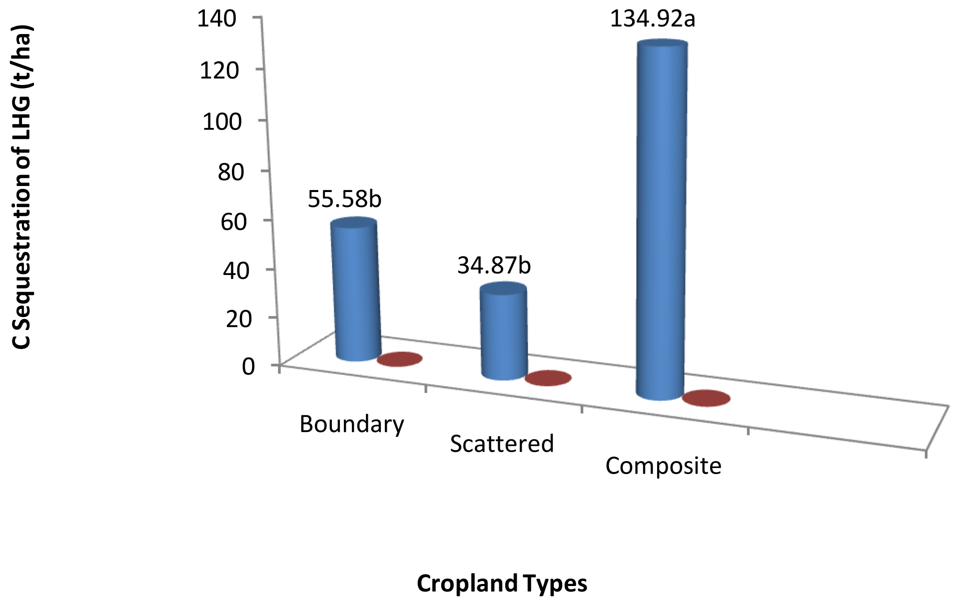


Fig. 4.10: Effect of different cropland system on the LHG carbon sequestration estimation (t/ha) [In a figure, different letter(s) are significantly different at P≤ 0.05 level of significant by Tukey HSD test]

4.3.4 Tree biomass per hectare (t/ha)

Total tree biomass (TB) was significantly influenced by different cropland systems (Fig. 4.11). The highest tree biomass (TB) (105.28 t/ha) was recorded from the composite cropland agroforestry which was followed by boundary and scattered cropland agroforestry. On the other hand, the lowest tree biomass (TB) (20.22 t/ha) was recorded from scattered cropland agroforestry which was followed by boundary and composite cropland agroforestry. The maximum biomass production by composite cropland was influence by variation in biomass allocation pattern, might be attributed due to stand density, wide range of habitat variation, number of tree and soil condition habit of growth. The maximum biomass production by different cropland systems 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 (Lieurance, 2016).

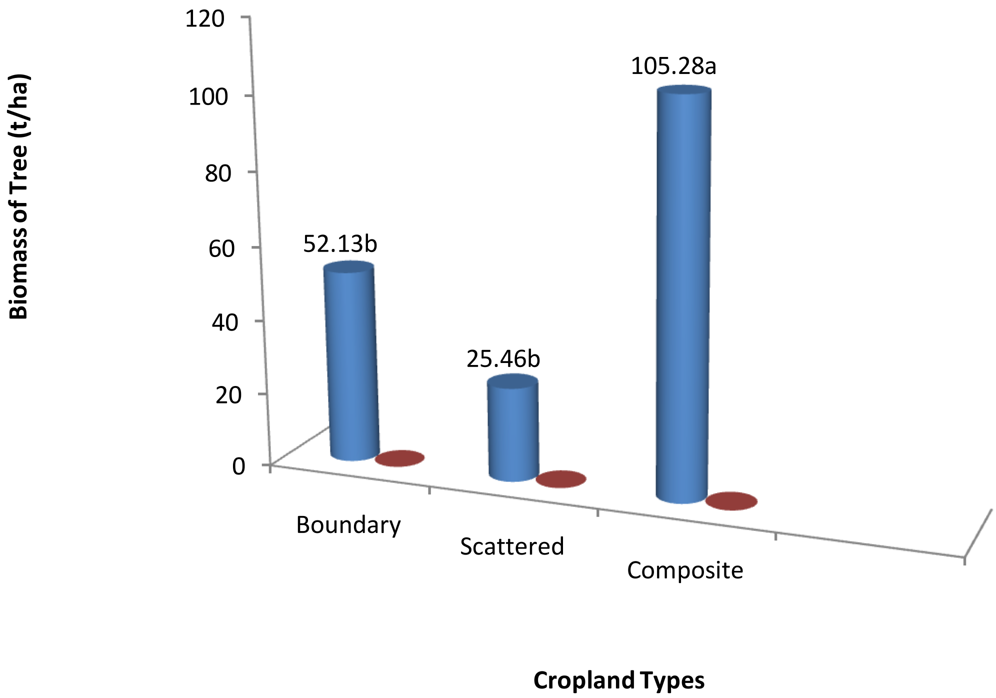


Fig. 4.11: Effect of different cropland system on the tree biomass estimation (t/ha) [In a figure, different letter(s) are significantly different at P≤ 0.05 level of significant by Tukey HSD test]

4.3.5 Tree carbon stock per hectare (t/ha)

Total tree carbon stock (CT) was significantly influenced by different cropland systems (Fig. 4.12). The highest tree carbon stock (52.638 t/ha) was recorded from the Composite cropland agroforestry which was followed by boundary and scattered cropland agroforestry. On the other hand the lowest tree carbon stock (12.73 t/ha) was recorded from scattered cropland agroforestry which was followed by boundary and composite cropland agroforestry. The amount of carbon in any cropland agroforestry systems depends on the structure and function of different components within the systems put into practice (Murthy *et al.*, 2013).

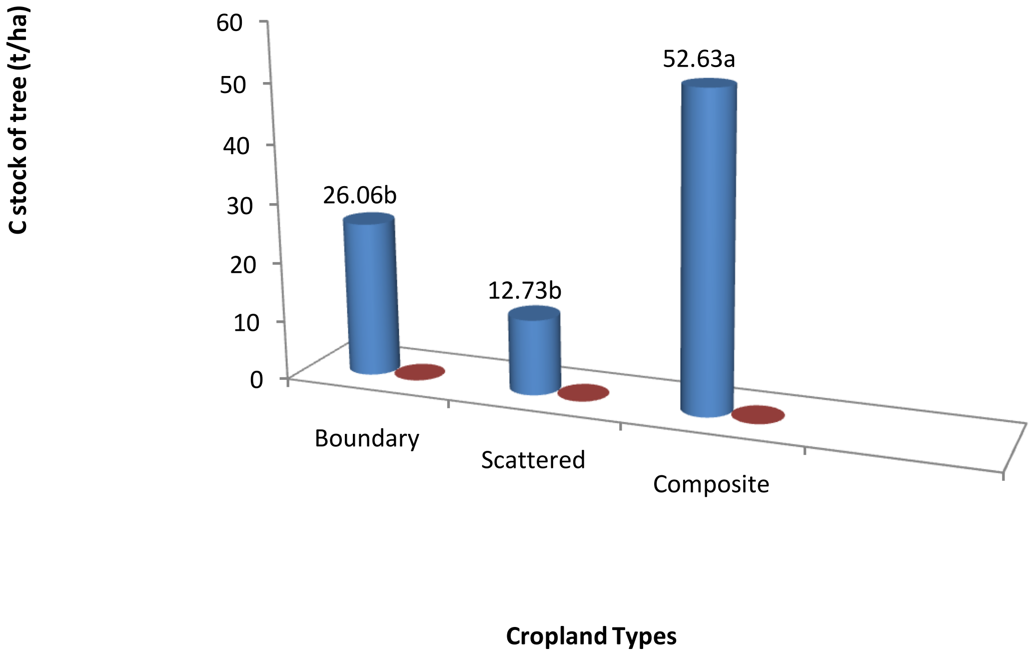


Fig. 4.12: Effect of different cropland system on the tree carbon stock estimation (t/ha) [In a figure, different letter(s) are significantly different at P≤ 0.05 level of significant by Tukey HSD test]

4.3.6 Tree carbon sequestration per hectare (t/ha)

Total tree carbon sequestration (CST) was significantly influenced by different cropland systems (Fig. 4.13). The highest tree carbon sequestration (CST) (193.18 t/ha) was recorded from the Composite cropland agroforestry which was followed by boundary and scattered cropland agroforestry. On the other hand the lowest tree carbon sequestration (CST) (46.733 t/ha) was recorded from scattered cropland agroforestry which was followed by boundary and composite cropland agroforestry. Based on these standing woody biomass, Carbon Sequestration rate of trees (t/ha) were calculated (Kiran, G.S. and Kinnary, S., 2011).

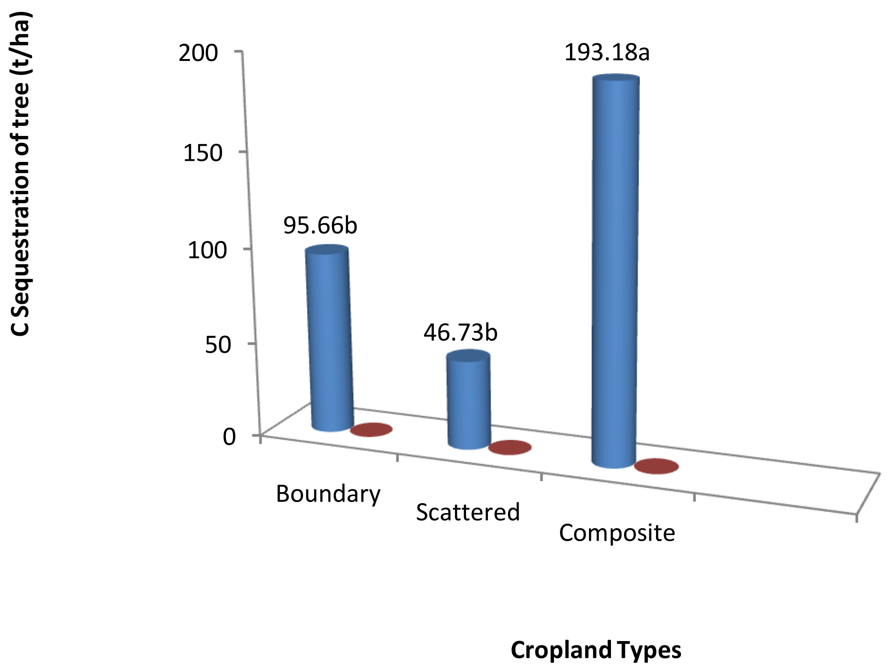


Fig. 4.13: Effect of different cropland system on the tree carbon sequestration estimation (t/ha) [In a figure, different letter(s) are significantly different at P≤ 0.05 level of significant by Tukey HSD test]

4.3.7 Total carbon stock per hectare (t/ha)

Total carbon stock (TC) was significantly influenced by different cropland systems (Fig. 4.14). The highest total carbon stock (TC) (89.402 t/ha) was recorded from the composite cropland agroforestry which was followed by boundary and scattered cropland agroforestry. On the other hand, the lowest total carbon stock (TC) (22.238 t/ha) was recorded from the scattered cropland agroforestry which was followed by boundary and composite cropland agroforestry. The amount of carbon in any cropland agroforestry systems depends on the structure and function of different components within the systems put into practice (Murthy *et al.*, 2013).

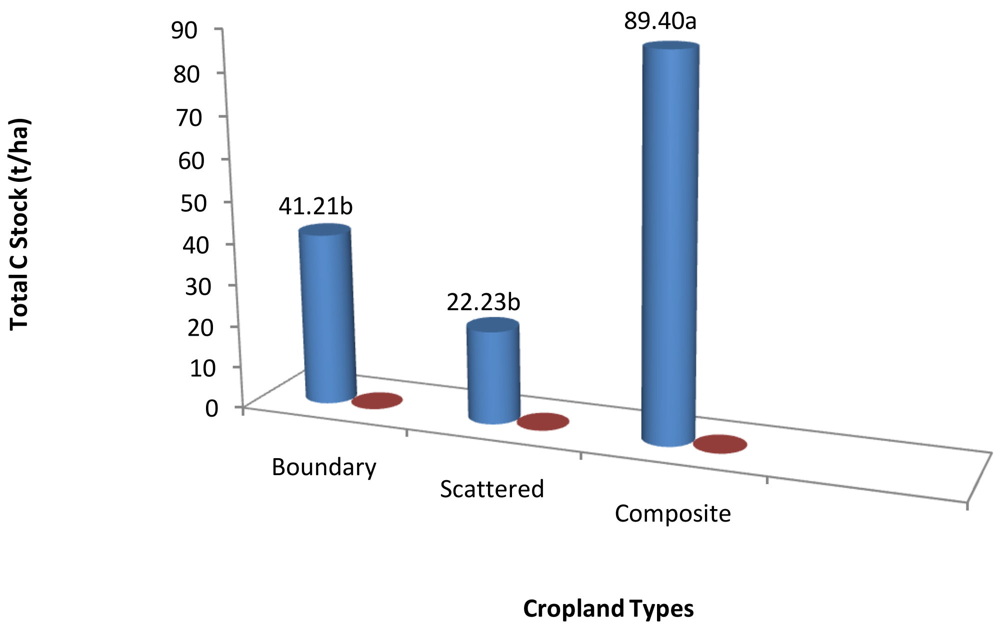


Fig. 4.14: Effect of different cropland system on the total carbon stock estimation (t/ha) [In a figure, different letter(s) are significantly different at P≤ 0.05 level of significant by Tukey HSD test]

4.3.8 Total carbon sequestration per hectare (t/ha)

Total carbon sequestration (TCS) was significantly influenced by different cropland systems (Fig. 4.15). The highest total carbon sequestration (TCS) (328.11 t/ha) was recorded from the composite cropland agroforestry which was followed by boundary and scattered cropland agroforestry. On the other hand the lowest total carbon sequestration (TCS) (81.611 t/ha) was recorded from scattered cropland agroforestry which was followed by boundary and composite cropland agroforestry. Tree crop sequestered Carbon at a higher rate than those containing only annual crops or grass lands. It can be showed that variability in the carbon sequestration potential under variation agro-ecological zones depends primarily on climatic factors as rainfall, temperature and soil, which influenced the stand density and finally carbon sequestration ability (Kibret and Ayanssa, 2014).

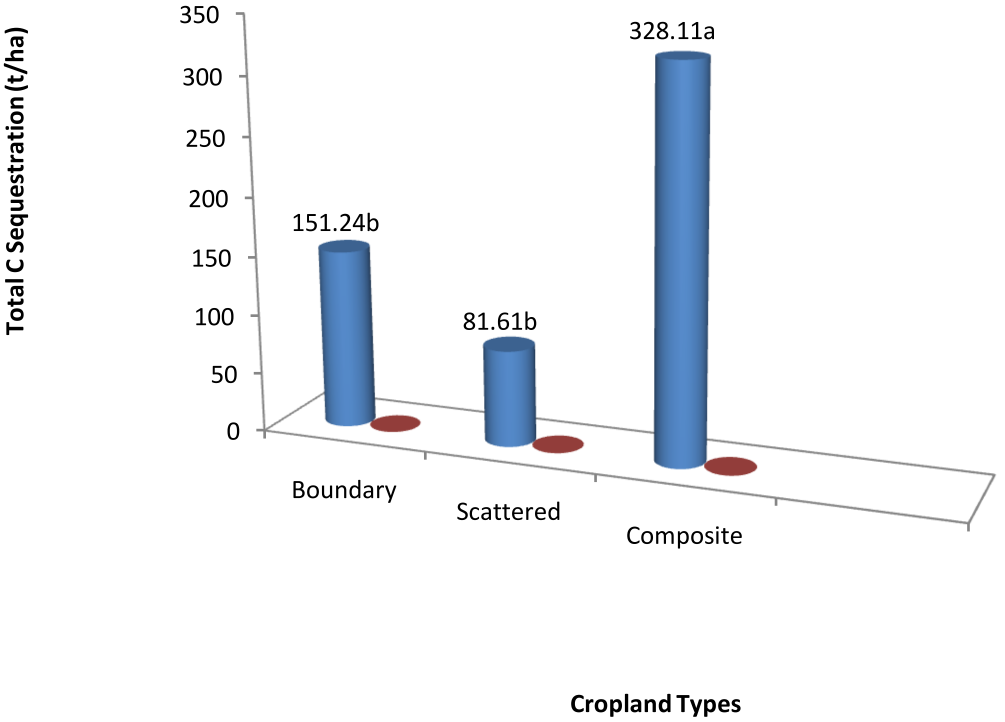


Fig. 4.15: Effect of different cropland system on the total carbon sequestration estimation (t/ha) [In a figure, different letter(s) are significantly different at P≤ 0.05 level of significant by Tukey HSD test]

4.4 Economic value of carbon sequestration (US$ /ha)

The economic value of carbon sequestration provides market for greenhouse Gases (GHG) reduction in monetary value (Fig. 4.16 & 4.17). According to Vivian (2010) 1 ton of carbon was sold at US$ 15. So, the highest carbon price (39713.95 $/ha) was recorded from the composite cropland agroforestry which was followed by boundary and scattered cropland agroforestry. On the other hand, the lowest carbon price (8060.73 $/ha) was obtain from the scattered cropland agroforestry which was followed by boundary and composite cropland agroforestry.

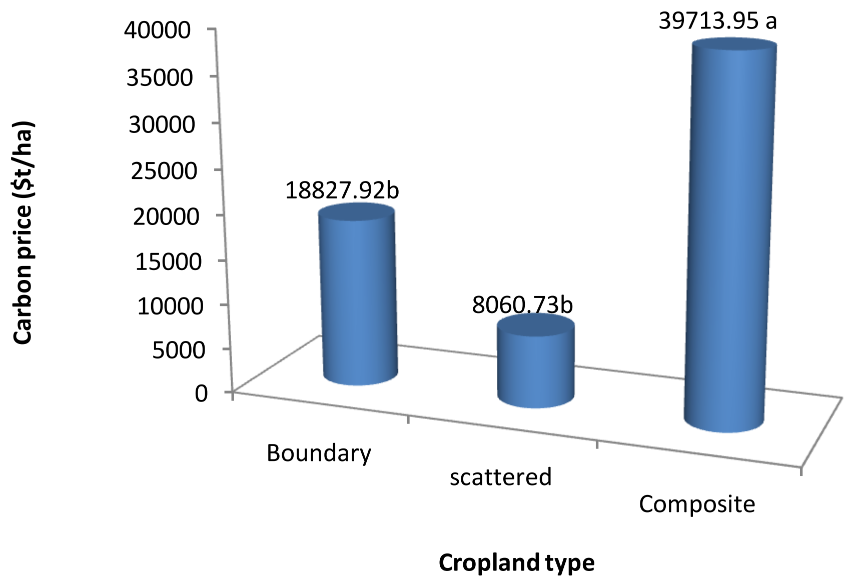


Fig. 4.16: Economic value of carbon sequestration on the different cropland ($/ha) [In a figure, different letter(s) are significantly different at P≤ 0.05 level of significant by Tukey HSD test]

In agroforestry practices the highest carbon price (13987.38 $/ha) was recorded from Eucalyptus-Mahagoni-Maize and the lowest carbon price (334.1 $/ha) was recorded from Mango-Rice Agroforestry practices. Vivian (2010) estimated the economic value of carbon trading for Kakamega forest and its environs and reported that the carbon sequestration potential for Kakamega forest was 334Mg C/ha, then the economic value of carbon trading was US$ 5010 per hectare. On comparison to that of the farms which was US$ 3045 per hectare, it implies that the forest has a higher capacity to generate revenue to the country if it is participated in carbon trading.

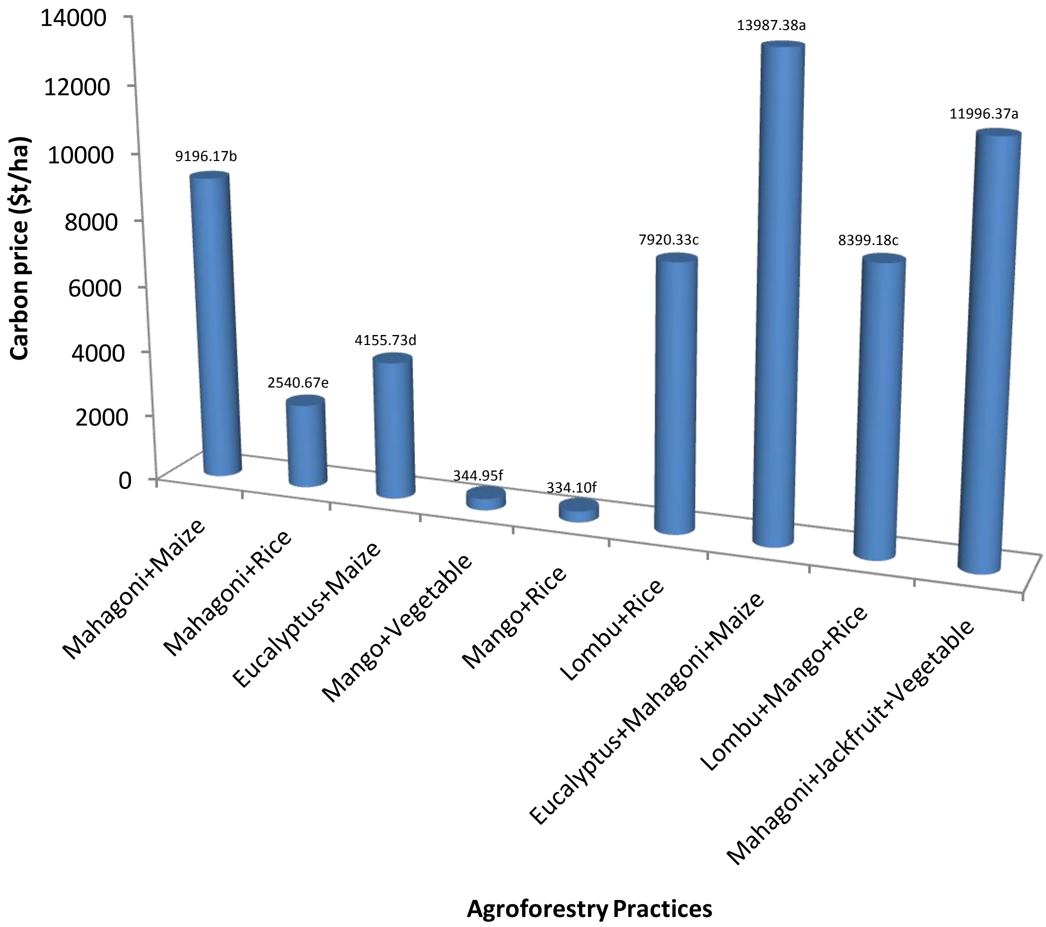


Fig. 4.17: Economic value of carbon sequestration on the different agroforestry Practices ($/ha) [In a figure, different letter(s) are significantly different at P≤ 0.05 level of significant by Tukey HSD test]

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The study was carried out on the Carbon Sequestration Potentiality of Cropland Agroforestry System, Dinajpur districts from October, 2018 to September, 2019. The experiment comprised of three cropland agroforestry system viz., T_1= Boundary cropland agroforestry, T_2= Composite (mixture of species) cropland agroforestry, T_3= Scattered cropland agroforestry. In case of T_1 and T_3 seven years eucalyptus, mahagoni, lombu, jackfruit etc. was selected as the main component. Similarly, in T_2 five years mango and lombu were also selected. In T_1, T_2, T_3, only mature trees were considered. The experiment was laid out in nine Agroforestry practices viz., P_1= mahagoni-maize, P_2= mahagoni-rice, P_3= eucalyptus-maize, P_4= mango-vegetable, P_5= mango-rice, P_6= lombu-rice, P_7= eucalyptus-mahagoni-maize, P_8= lombu-mango-Rice, P_9= mahagoni-jackfruit-vegetable. Experimental plots were selected randomly in different location from each experimental unit (agroforestry practices and different cropland agroforestry), in a randomized complete block design (RCBD) with nine treatment and three replications. The parameters like tree height (TH) and diameter at breast height (DBH) of tree which was used to calculate above ground, below ground and total biomass of all the cropland agroforestry systems were recorded. Leaf litter, herb and grass or under stories biomass was estimated using quadrant of 1m×1m as a sample plots. The data was analyzed statistically and means were adjusted by Tukey HSD.

In case of the main effect of different agroforestry practices on biomass production and estimation for carbon sequestration, the result was found in respect of TH (m), DBH (cm), total tree biomass (t/ha) and leaf litter, herb and grass or under stories biomass (t/ha) was significantly different. The highest leaf litter, herb and grass biomass (107.7 t/ha) was obtain from under stories biomass of eucalyptus-mahagoni-maize (P_7) and the smallest (2.0 t/ha) was obtain from under stories biomass of mango-rice (P_5).

Again, the result of this study showed that the main effect of different agroforestry practices on biomass allocation and accumulation was found significantly different according to total tree carbon stock (t/ha) and total leaf litter, herb and grass carbon stock (t/ha) due to different in agroforestry practices. The highest total tree carbon stock (58.957 t/ha) was recorded from eucalyptus-mahagoni-maize (P_7) and the lowest CT (1.5867t/ha) was observed from mango-vegetable (P_4). The highest leaf litter, herb and grass carbon stock (50.6 t/ha) was obtain from eucalyptus-mahagoni-maize (P_7) and the smallest (1.0 t/ha) was obtain mango+ rice (P_5).

Again, the result of this study showed that the main effect of different agroforestry practices on carbon sequestrations was also significantly different according to total tree carbon sequestration (t/ha) and total leaf litter, herb and grass carbon sequestration (t/ha) due to different in agroforestry practices. The highest total tree carbon sequestrations (t/ha) was recorded from eucalyptus-mahagoni-maize (P_7) and the lowest CST (5.82 t/ha) was observed from mango-vegetable (P_4). The highest leaf litter, herb and grass carbon sequestrations (185.7 t/ha) was obtain from eucalyptus-mahagoni-maize (P_7) and the smallest CSLHG (3.5 t/ha) was obtain mango-rice (P_5). The highest total carbon sequestration of agroforestry practices (402.09 t/ha) was recorded from eucalyptus-mahagoni-maize (P_7) whereas the lowest (9.7533 t/ha) was recorded from mango-vegetable (P_4).

On the other hand, the main effect of different cropland agroforestry system on biomass production and estimation for carbon sequestration, the result were found that, the diameter at breath height DBH (cm), aboveground biomass (kg/ha), belowground biomass (kg/ha), total tree biomass (t/ha) and leaf litter, herb and grass biomass (t/ha) were differed significantly except the tree height. The highest total biomass of LHG (78.22 t/ha) was obtained from the composite cropland agroforestry (T_2) whereas the lowest total biomass of LHG (9.50 t/ha) was recorded the scattered cropland agroforestry (T_3). The highest carbon stock of LHG (36.76 t/ha) was recorded from the composite cropland agroforestry (T_2) and the lowest carbon stock of LHG (9.50 t/ha) was recorded from the scattered cropland agroforestry (T_3). Again the highest carbon sequestration of LHG (134.92 t/ha) was obtained from the composite cropland agroforestry (T_2) and the lowest carbon sequestration of LHG (34.87 t/ha) was recorded from the scattered cropland agroforestry (T_3).

Again the result also showed that the highest total biomass of tree (105.28 t/ha) was recorded from the composite cropland agroforestry (T_2) and the lowest total biomass of tree (25.46 t/ha) was recorded from the scattered cropland agroforestry (T_3). The highest carbon stock of tree (52.63 t/ha) was recorded from the composite cropland agroforestry (T_2) and the lowest carbon stock of tree (12.73 t/ha) was recorded from the scattered cropland agroforestry (T_3). Again the highest carbon sequestration of tree (193.18 t/ha) was recorded from the composite cropland agroforestry (T_2) and the lowest carbon sequestration of tree (46.73 t/ha) was recorded from the scattered cropland agroforestry (T_3).

Again the result also showed that the interaction effect of the highest total carbon sequestration of tree and LHG (328.11 t/ha) was recorded from the composite cropland agroforestry (T_2) and the lowest total carbon sequestration of tree and LHG (81.61 t/ha) was recorded from the scattered cropland agroforestry (T_3).

Finally, the result also showed that the highest carbon sequestration of agroforestry species (402.09 t/ha) was obtained from eucalyptus-mahagoni-maize species and the lowest carbon sequestration of agroforestry species (9.75 t/ha) was recorded from mango-vegetable species. Again, the highest carbon sequestration of cropland agroforestry system (328.11 t/ha) was recorded from the composite cropland agroforestry and the lowest carbon sequestration of cropland (81.61 t/ha) was recorded from the scattered cropland agroforestry system.

The finding of this study showed that the different cropland and agroforestry practices had significant effects on the biomass and carbon accumulation. Planting of multipurpose tree species in non-forest land like cropland can serve a dual purpose by promoting carbon sequestration and production timber forest product for local people. The present investigation find out that seven years eucalyptus and mahagoni plantation in composite cropland gave highest sequestration ability of CO_2 due to high biomass stand density, which followed by mango in scattered cropland plantation on the same age. However, lombu, jackfruit tree species with composite and boundary cropland gave the medium sequestration ability of CO_2. The study also found that, among the three cropland system and nine agroforestry practices have 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 market for GHG reduction in monetary value. So, the highest carbon price (13987.38 $ t/ha) was recorded from eucalyptus-mahagoni-maize agroforestry practices and lowest carbon price (334.1 $ t/ha) was recorded from mango-rice agroforestry practices. Again, the highest carbon price (39713.95 $ t/ha) was recorded from the composite cropland agroforestry and the lowest carbon price (8060.73 $ t/ha) was recorded from the scattered cropland agroforestry system.

Finally, it may be concluded that composite cropland agroforestry plantation sequestrated more carbon and a better option for reducing atmospheric carbon, but they cannot be extended too many large areas of Bangladesh due to high population pressure and demand of agricultural land. Therefore, the composite cropland agroforestry system and eucalyptus-mahagoni -maize agroforestry practices seems to be a better option for large tree plantation coverage and reduction of GHGs effects.

Based on the result of the study carried out, the following recommendations were made.

1. Composite cropland plantation contained more carbon than scattered and boundary cropland system, so farmers should consider composite cropland than scattered or boundary plantations.

2. Research should be undertaken to collect data on above ground biomass by converted into below ground biomass, it should be done to collect data soil carbon and below ground biomass in order to know the actual carbon sequestration of cropland system.

3. Carbon content varies with species, so species wise carbon sequestration should be carried out.

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APPENDICES

Appendix I: CV% of all the considered parameters (agroforestry practices and crop land agroforestry systems)

Agroforestry practices (t/ha)

Total biomass of leaf litter (t/ha)

Alpha	0.05	Standard Error for Comparison	1.2133
Critical Q Value	4.955	Critical Value for Comparison	4.2509

Carbon stock of LHG (t/ha)

Alpha	0.05	Standard Error for Comparison	0.5703
Critical Q Value	4.955	Critical Value for Comparison	1.9981

LHG carbon sequestration (t/ha)

Alpha	0.05	Standard Error for Comparison	2.0928
Critical Q Value	4.955	Critical Value for Comparison	7.3323

Tree carbon stock (t/ha)

Alpha	0.05	Standard Error for Comparison	0.9224
Critical Q Value	4.955	Critical Value for Comparison	3.2318

Tree carbon sequestration (t/ha)

Alpha	0.05	Standard Error for Comparison	3.3843
Critical Q Value	4.955	Critical Value for Comparison	11.857

Total carbon stock (t/ha)

Alpha	0.05	Standard Error for Comparison	1.3031
Critical Q Value	4.955	Critical Value for Comparison	4.5655

Total carbon sequestration (t/ha)

Alpha	0.05	Standard Error for Comparison	4.7827
Critical Q Value	4.955	Critical Value for Comparison	16.756

Different cropland agroforestry systems

Total biomass of leaf litter (t/ha)

Alpha	0.05	Standard Error for Comparison	10.85
Critical Q Value	3.533	Critical Value for Comparison	27.101

Carbon stock of LHG (t/ha)

Alpha	0.05	Standard Error for Comparison	5.0993
Critical Q Value	3.533	Critical Value for Comparison	12.737

LHG carbon sequestration (t/ha)

Alpha	0.05	Standard Error for Comparison	18.714
Critical Q Value	3.533	Critical Value for Comparison	46.746

Total biomass of tree (t/ha)

Alpha	0.05	Standard Error for Comparison	13.675
Critical Q Value	3.533	Critical Value for Comparison	34.157

Tree carbon stock (t/ha)

Alpha	0.05	Standard Error for Comparison	6.8373
Critical Q Value	3.533	Critical Value for Comparison	17.079

Tree carbon sequestration (t/ha)

Alpha	0.05	Standard Error for Comparison	25.092
Critical Q Value	3.533	Critical Value for Comparison	62.677

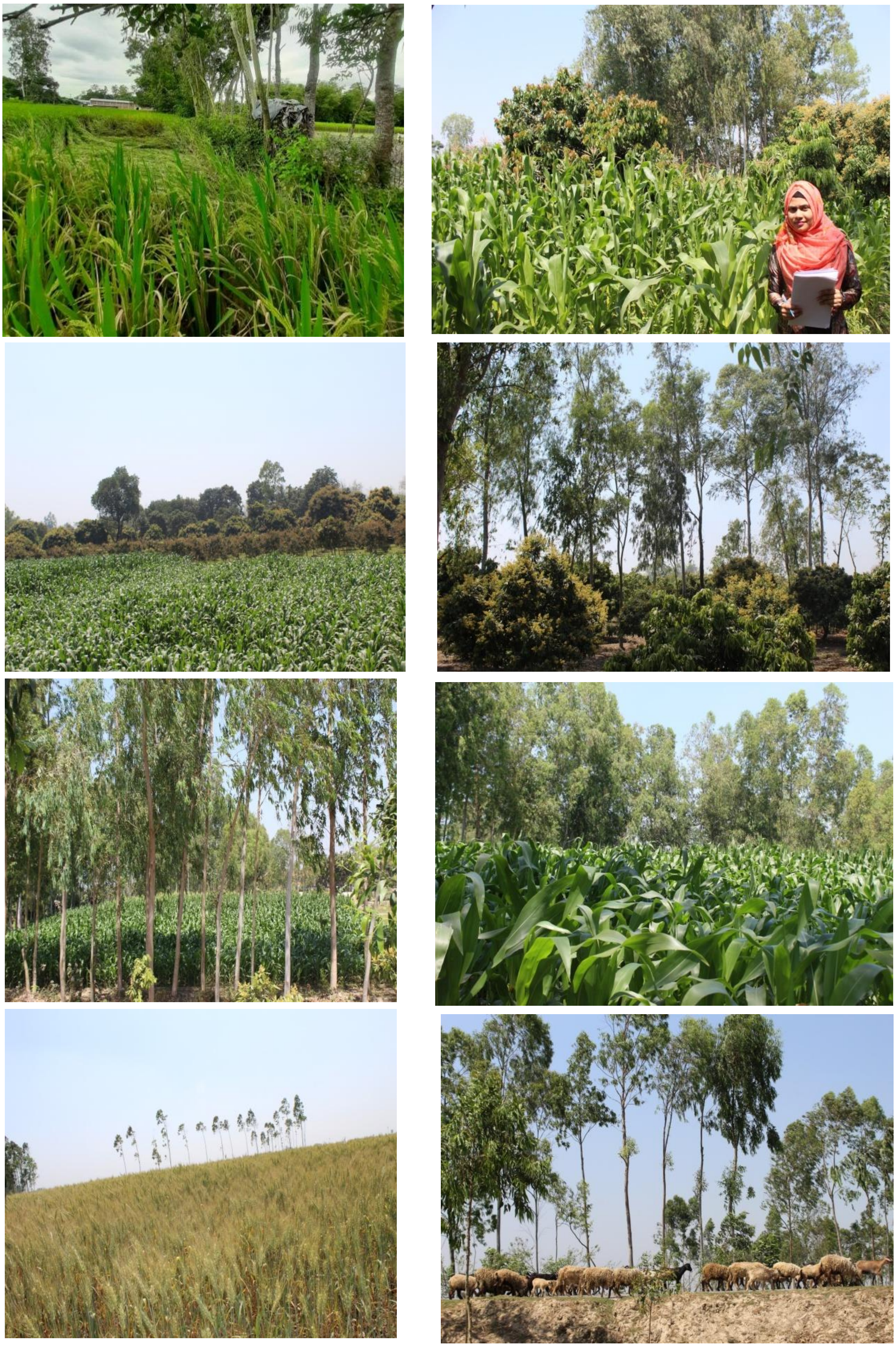
Total carbon stock (t/ha)

Alpha	0.05	Standard Error for Comparison	11.57
Critical Q Value	3.533	Critical Value for Comparison	28.9

Total carbon sequestration (t/ha)

Alpha	0.05	Standard Error for Comparison	42.461
Critical Q Value	3.533	Critical Value for Comparison	106.06

Appendix II: Some Plates of the Research



(Source: Filed Survey, 2019)
Plate 1: Selecting different cropland and Agroforestry Practices




(Source: Filed Survey, 2019)

Plate 2: Height and diameter measurement in cropland


(Source: Filed Survey, 2019)

Plate 3: Collection of understory biomass

(Source: Filed Survey, 2019)

Plate 4: My respective supervisor, fallow friends and field worker were helping me for collecting data