AGROFORESTRY SYSTEM AND THEIR CARBON STOCK IN TERAI AND MID-HILL REGIONS OF CENTRAL NEPAL.

A Dissertation

Submitted for the partial fulfillment of Master's Degree in Botany

Institute of Science and Technology,

Tribhuvan University

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LETTER OF RECOMMENDATION

This is to certify that the dissertation entitled "**Agroforestry system and their carbon stock in Terai and mid-hill regions of Central Nepal**" submitted by Mrs. Shashi Kafle for the partial fulfillment of the requirements for Master's Degree in Botany from Tribhuvan University was completed under my supervision and guidance. She has worked sincerely and the entire work is primarily based on the results of her thesis work and has not been submitted for any other degree. Therefore, I recommend this dissertation for the final evaluation and acceptance.

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LETTER OF APPROVAL

This dissertation entitled "**Agroforestry system and their carbon stock in Terai and mid-hill regions of Central Nepa**l" submitted at Central Department of Botany, Tribhuvan University by Mrs. Shashi Kafle has been accepted for the partial fulfillment of requirements for Master of Science in Botany.

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Shashi Kafle

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ABSTRACT

Trees and forests play a critical role in human livelihood as well as in ecosystem functioning. Agricultural emissions from crop and livestock production grew from 4.7 billion tons of CO_2 eq. per year in 2001 to over 5.3 billion tons in 2011 due to agriculture fermentation. Compensation in loss of biodiversity, concern of food security, improvement in the living standard by generating income and the global issue of climate change related with carbon sequestration can be addressed with the scientific knowledge of agroforestry system. It can directly store carbon in tree components and potentially slows down the deforestation rate by reducing the need to clear forest land for agriculture. In the country like Nepal which is very suitable for agriculture, the agroforestry practice can be highly demanding for the overall growth of the nation. The study was carried out in Terai and mid-hill physiographic region. This study focuses mostly on the species grown in the home garden for the various purposes and to determine the total carbon stock of these two regions. The plot of $20 \times 20 m^2$ was set up and the trees inside the plot were listed, counted and the various parameters like dbh, angle of elevation and distance between the observer and tree were measured for biomass carbon stock. The study was conducted in 30 home-gardens from Terai and 50 from mid-hill. Total 171 species were recorded in the study. Shannon's index was 1.247 in Terai and 1.216 in mid-hill. Simpson's index was 0.0915 in Terai and 0.087 in mid-hill. The total mean tree trunk volume was found to be 17.46 m^3/ha. The average total biomass was significantly greater in Terai (21.314 t/ha) than in mid-hill (11.203 t/ha). The mean of total biomass carbon stock was found to be 10.255 tons C / ha and 5.24 tons C / ha for Terai and mid-hill respectively. The soil was collected from 0-20 cm depth. 80 soil samples were air dried and brought to laboratory for further analysis of soil carbon stock. The study found the soil bulk density to be 1.38 g/cm^3 in Terai and 1.076 g/cm^3 in mid-hill region. The soil carbon stock was found to be 61.17 t C ha^{-1} in Terai and 67.608 t C ha^{-1} in mid-hill. The biomass carbon stock and soil carbon stock were summed up to obtain the total carbon stock. However, the study found no significant difference in the total carbon stock between the two regions i.e. 71.433 t C/ha in Terai and 72.856 t C/ha in mid-hill.

Though agroforestry does not contribute as much as the forest, however, it can store enough significant amount of carbon when designed in a proper way. Thus, agroforestry system can be proved to be one of the best alternatives to cope with the alarming problem of biodiversity loss, food security and climate change. Starting from a small area around the home, it can create its impact to the global scale.

Keywords: *Species diversity, Uses, Biomass carbon stock, Soil carbon stock.*

LIST OF ABBREVIATIONS

BISEP-ST - Biodiversity Sector Programme for Siwaliks and Terai

cbm/ha- cubic meter per hectare

IGAs - Income Generating Activities

IFAD - International fund for Agriculture Development

REDD – Reducing Emission from Deforestation and Forest Degradation

NTFPs – Non-Timber Forest Products

C – Carbon

GHG – Green House Gases

Mg C ha^{-1}- Megagram carbon per hectare

Mg/m^3- Megagram per cubic meter

$MtCO_2eq/yr$ – Metric tons carbon dioxide equivalent per year

MDI- Manahari Development Institute

V.D.C. – Village Development Committee

S.E- Standard Error

sq.m/ha- square meter per hectare

t C ha^{-1} – tons carbon per hectare

t/ha – tons per hectare

SOC – Soil organic carbon

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CHAPTER I

INTRODUCTION

1.1 Background

The population growth has been a serious issue worldwide which has led to global concerns of land degradation, food insecurity, climate change etc. The United Nation report indicates that the world's population reached 7.2 billion in 2014 and is expected to increase by more than 2 billion by 2050 (U.N., 2014). According to the Food Agricultural Organization report, there has been gross reduction in the forest land use of 9.5 million hectares per year between 1990 and 2000 and 13.5 million hectares per year between 2000 and 2005(Lindquist *et al.,* 2012). Recognizing the ability of agroforestry systems to address multiple problems and deliver multiple benefits, the IPCC Third Assessment Report on Climate Change (IPCC, 2001) states that "Agroforestry can both sequester carbon and produce a range of economic, environmental, and socioeconomic benefits." Trees and forests play a critical role in human livelihood as well as in ecosystem functioning. So, it is important to understand the condition and changes through time of the globally valuable forest resources. There is also crucial role that forests, trees on farms and agroforestry systems can play in improving the problem of food insecurity and nutrition of rural people, especially in developing countries. It also affects the regional and global climate. Agricultural emissions from crop and livestock production grew from 4.7 billion tons CO_2 eq. per year in 2001 to over 5.3 billion tons CO_2 eq. per year in 2011 due to agriculture fermentation. While GHG emission due to land change and deforestation account for about 3 billion tons of CO_2 eq. per year over the decade (FAO, 2014). The total amount of CO_2 released from land-use change is estimated to be 1.6 Giga tons Carbon per year over the 1990s (IPCC, 2007). Hence, the land use management such as agroforestry system can play a very important role in climate change mitigation by absorbing excess carbon dioxide. Forest ecosystem can sequester a huge amount of carbon such that they can be considered as a carbon sink. But, due to the increasing rate of deforestation in the Tropical region, the forests actually are carbon source (Labata *et al*., 2012). Forest ecosystems have been converted into plantation or croplands by slash and burn and other agriculture practices for the production of food and living. Due to this rapid conversion, the forest ecosystem has become a source of greenhouse gases (Labata *et al*., 2012). Agricultural lands are believed to be a major potential sink and could absorb large quantities of carbon if trees are reintroduced to these systems and managed together with crops and/or animals. Carbon is stored in tree biomass and in soil that helps to protect natural carbon sinks through the improvement of land productivity and the provision of forest products on agricultural lands (Albrecht and Kandji, 2003).

Agroforestry is an integrated system of rural land resource management based on combining shrubs and trees with crops and/or livestock, whose interactions generate economic, environmental and social benefits. Agroforestry can be considered as a promising land use practice to preserve or improve fertility and increase agricultural productivity. It also increases the species diversity when managed properly. Small area of land can be utilized to contain a variety of plants in agroforestry that have several benefits (USAD, 2012).

- diversified income
- cleaner air and water
- improved soil health
- safe and healthy food
- energy conservation
- bioenergy production &
- Sustainable farms, ranches and woodlands.

Utilization of forest products for the livelihoods has been in practice since the evolution of mankind. In the earlier days, people used to utilize the products from the forest which was sufficient for the communities at that time. But, with the increasing population and increasing rate of deforestation, it has created awareness among the people to utilize their own land (usually near their house) rather than overexploiting the forest. When different species are grown nearby the home, it guarantees the product supply and pass on the knowledge about their use to the next generation. In absence of this, there is a high risk of losing the traditional knowledge about the use of plants with the rapid urbanization and modernization. So, preservation of the traditional knowledge is highly demanded with the ascendant of other disciplines like ethno botany, anthropology etc.

Not only the large and dense forest but also the trees grown in agroforestry practices are contributing a lot in sequestering carbon because of carbon storage potential in its multiple plant species and soil. Proper design and management of agroforestry practices can make them effective carbon sink (Montagnini and Nair, 2004). For smallholder agroforestry systems in the tropics, potential carbon sequestration rate ranges from 1.5 to 3.5 $MgCha^{-1}yr^{-1}$ (Montagnini and Nair, 2004). The carbon sequestration potential of agroforestry systems in humid tropical of Southeast Asia has been estimated between 12 and 228 $Mgha^{-1}$ (Albrecht and Kandji, 2003). In addition, agroforestry can be helpful to make the homestead self reliant.

However there is paucity of quantitative data on the contribution of agroforestry in sectors like carbon sequestration, food security, fodder and fuel. Also there is lack of awareness among the people about the importance of agroforestry in their livelihood. So, the effort here is to compile the traditional knowledge of utility of plants grown in the home-garden, compare the species diversity among the two regions (Terai and mid-hill) and to quantify the data on the carbon stock. Moreover, the result of this study is expected to add to the body of knowledge on the potential of agroforestry system to store carbon and ameliorate living standard of the local people by recognizing the useful species in their home-garden and preserving the traditional knowledge being passed on generation to generation.

1.1.1 Agroforestry system in Nepal

About 80% of the people in Nepal are involved in agriculture, which is also known as the backbone of the country's economy. In general, the majority of the Nepalese farmers are subsistence farmers and do not export surplus. Government of Nepal plans to maintain the forest cover at 37% depends on the success of community forestry program which merges traditional and modern agroforestry and conservation practices. Farmers in Nepal have long been growing trees in their farm lands to maintain land productivity and to provide for subsistence needs, such as timber, fodder for livestock and fuel wood for cooking. But, the modern agroforestry practice, with a scientific knowledge of the integration of the crops, trees and livestock is new. In the past, people used to depend on the forest for the fodder collection, timber, grazing, fuel etc. But due to the rapid deforestation and change in the ownership and management of the forest like community forest, people are seeking new alternatives. One of such alternatives is agroforestry involving both indigenous and exotic fodder tree species in private farm lands (Neupane *et al*., 2002). This system is also referred to as home garden. A home garden is a clearly bounded piece of land cultivated with a diverse mixture of annual and perennial crops and on which a house is built (Karyono, 1990). In general, home gardens are characterized by different vegetation strata composed of trees, shrubs and herbs in association with annual and perennial agriculture crops and small livestock within house compounds (Fernandez and Nair, 1986). In home garden, traditional as well as improved varieties of vegetables, fruits, spices, fish, poultry etc. are cultivated. The home garden provides a bridge between the social and biological, linking cultivated species and natural ecosystems, combining and conserving species diversity and genetic diversity (Eyzaguirre and Linares, 2004). Agroforestry practices in Nepal involve cultivating vegetables and crops integrated with the trees/plants for various purposes and also with the live stocks like poultry, small fish pond and cattle or pigs, goats etc. Plants grown for the various purposes are listed below:

- fodder e.g., *Leucaena leucocephala (*Ipil-ipil), *Artocarpus lakoocha* (badahar), *Ficus clavata* (bedulo), *Melia azedirach(* bakaino), *Brassaiopsis sp.(*chuletro)
- timber e.g., *Michelia champaca (*chap), *Machilus gamblei* (kaulo), *Pinus wallichiana (*salla), *Dalbergia sissoo (*sissoo), *Diospyros melanoxylon* (tiju)
- fruit e.g., *Mangifera indica* (aap), *Litchi chinensis* (litchi), *Castanopsis indica* (katus), *Prunus persica* (aaru), *Carica papaya* (mewa)
- medicinal e.g., *Mallotus philippensis* (rohini), *Asparagus officinalis* (kurilo), *Phyllanthus emblica* (amala), *Potentila fulgens* (bajradanti), *Aloe vera* (gheu kumari)
- cash income e.g. *Stevia*, *Aloe vera*, *Thysanolaena maxima* (amriso), *Gossypium hirsutum* (kapash)

- cultural value e.g., *Ficus religiosa (*peepal), *Ficus benjamina (*sami), *Ocimum sanctum* (tulsi)
- land reclamation e.g., *Thysanolaena maxima* (amriso), *Alnus nepalensis* (utis)
- Ornamental e.g., *Polylthia longifolia* (ashok tree), *Hibiscus* sp. *Bougainvillea* etc.

Government of Nepal also has proposed and implemented various programs to enhance the agroforestry practice mostly in the rural areas. Since 2001, the Ministry of Forest and Soil Conservation has been implementing BISEP-ST (Biodiversity Sector Programme for Siwaliks and Terai) programme in central Terai districts: Dhanusha, Mahottari, Sarlahi, Rautahat, Bara, Parsa, Makwanpur and Chitwan. This program supports to fulfill the forest products needs of distant user groups through different modalities like: Private Forestry, Private Agroforestry, Public land agroforestry, different forest products based Income Generating Activities (IGAs) (Yadav, 2008). Private Agroforestry program focuses on promotion of forest on their farm lands as agroforestry such that productivity of agricultural farms can be maximized. The public land agroforestry program focuses involvement of those people who are landless or having land less than 10 Katthas (0.338 hectare) i.e. this program focuses involvement of pro-poor, Dalit, janjati, and involvement of women members. The public land agroforestry program has been very effective in fulfilling the basic needs of pro poor involved (Yadav, 2008).

1.2 Statement of problem

World is facing the rising problem of deforestation, land degradation, food insecurity and climate change. Nepal is also not untouched with these global problems. According to the report of Forest Resource Assessment during 1990's, Nepal's deforestation rate was reported to be about 1.7% per year (Dhital, 2009). Likewise, 28.24% of the total land of the country falls under degraded land (Acharya and Kafle, 2009). Subsistence farming in Nepal is still a dominant mode of production. Improvement in subsistence farm itself has a large potential to improve food security in the country. Farmers in Nepal should be made aware of the importance of modern farming practices and clear their misconception about this modern farming practices. According to report of International fund for Agriculture Development in 2013, almost 70 percent of households have holdings of less than 1 hectare, and many depend on plots that are too small to meet their subsistence requirements (Khan, 2013). Productivity levels remain low as a result of limited access to new farming technologies, inputs and extension services. Apart from these, the impact of climate change due to the global deforestation has been apparent in Nepal mostly in the mountain region. The rapidly retreating glaciers (average retreat of more than 30 m/year), rapid rise in temperature (>0.06°C), erratic rainfalls and increase in frequency of extreme events such as floods and drought like situation are some of the effects Nepal is facing during the last few years (Karki *et al.,* 2009). Government has enacted several acts to address these problems. Community forest approach has been proven effective vision for the conservation and utilization of forest product by the user groups, thereby supporting livelihood of the rural people. REDD+ program has also been conducted in Nepal which provides monetary value to the community forest for its contribution to carbon conservation by reduction in deforestation and degradation.

In present situation, one of the best alternatives can be agroforestry approach through home-garden which can be helpful for solving the problem of deforestation, land degradation, food insecurity and climate change by integrating various trees along with the crop plants. People will utilize the forest products such as fodder, fuel, timber from their own farm which will reduce the forest deforestation rate. Plants grown in home garden can reclaim the land by reducing soil erosion and increasing fertility. Likewise, it can provide enough food for the family. Further, carbon is stored in the biomass grown in the home-garden and in the soil which can definitely contribute to carbon sequestration. So, this study intends to explain agroforestry practice in terms of carbon stock, assessment of trees/plants grown in home garden and its contribution to the conservation of biodiversity.

1.3 Objectives

The main goal of the study is to explore the agroforestry practices in Terai and mid-hill region of Nepal and to compare its status in these regions. The specific objectives are as follows:

- To assess abundance of the plant species in the home garden and document their uses,

- To calculate the species diversity in home gardens of two regions,
- To quantify the biomass carbon stock of the tree species grown in home garden,
- To quantify the soil carbon stock in home garden of two regions,
- To compare the carbon stock and species diversity of the two regions.

1.4 Significance of the study

Nepal's economy is highly dependent on agriculture which is considered as the backbone of the country's economy. Although 80% of the population is involved in agriculture, no enough food can be produced for the nation instead we need to import food to meet the demand of the population. Agroforestry practice of growing trees integrated with live stocks can be very helpful in ensuring the food security. While proper management of this practice can contribute a lot for the food production of not only the family but also the nation as a whole. It also increases the species diversity which ensures the availability of variety of products ensuring the conservation of precious genetic resources and contributes to soil integrity. It can also play a significant role in the reduction of deforestation rate by utilizing the products grown nearby their home-garden which ultimately reduces the carbon emission. Further, the trees grown in the farm can also store the carbon in appreciable amount which can address the issue of global climate change. Thus the compilation of the plants grown in the home garden in two different regions can be useful for the knowledge which can be passed on to the generation by generation. Also, this study can be useful to add to the knowledge about the carbon stock due to the trees in the home garden and people can be made aware of this fact.

1.5 Limitation of the study

- Due to time constraint, only 2 wards of the V.D.C could be sampled.
- Due to the large area of home garden in Terai region, only 30 samples could be studied as compared to the mid hill.
- Since the work was conducted during June, which is time of sowing paddy in their field, elder people of the house were not found in some households.

CHAPTER II

LITERATURE REVIEW

The decline of forest cover has been associated with increased soil erosion, lowered soil fertility, and reduced agricultural productivity. There is a growing evidence that agroforestry can be a promising solution to these problems (Carter and Gilmour, 1989) and hence a key to the sustainability of the hill farming system. Role of agroforestry systems in biodiversity conservation and rural household consumption in a private land of hill area is biologically and socially more complex than other systems for using degraded lands either through fodder trees, fruit trees cultivation or forest farming (Khanal, 2011). Several studies from Nepalese hills indicate a continuous decline in soil fertility due to soil erosion and the depletion of organic matter. Studies indicate improvements in tree growing on the private farm lands to compensate the loss of trees in the forest (Thapa *et al.,* 1994; FSD/FRISP, 1999).

An estimated 65 % of the land in the tropical world, which is home to over 630 million people, is susceptible to degradation (King, 1979, as cited by Schroeder, 1993). In the temperate zone, several studies have shown that growing trees in conjunction with livestock grazing is more profitable than grazing alone (Arthur-Worsop, 1984, Doyle *et al.,* 1986, Anderson *et al.,* 1988 as cited by Schroeder, 1993). The contribution of Non-timber Forest Products (NTFPs) to poverty alleviation has been documented by Garity (2004) and Russell and Franzel (2004). Also, Arnold and Perez (2001) reported that, the importance of NTFPs to rural development and conservation of natural resources has been on the rise during the last 10-20 years. Agroforestry offers many entry points to improve the status, income and health of women and children (Garity, 2004). Land use management such as agroforestry systems or the combination of production of trees with agricultural crops plays a very important role in climate change mitigation by absorbing excess carbon dioxide which is used in the process of photosynthesis by the trees. Old stands will have high carbon stocks, but low carbon accumulation rates since they have reached maturity while young plantations will have low carbon stocks, but higher accumulation rates since the plantation will be in an active growth phase (Labata *et al.,* 2012). According to recent projections, the area of the world under agroforestry will increase substantially in the near future. Undoubtedly, this will have a great impact on the flux and long-term storage of C in the terrestrial biosphere (Dixon, 1995). Agro ecosystem plays a central role in the global Carbon cycle and contain approximately 12% of the world terrestrial C (Smith *et al.,* 1993; Dixon *et al.,* 1994; Dixon, 1995). Nepal's share in the global emission of greenhouse gases (GHGs) is negligible, but the consequences of global warming in the nation are very sensitive and high. The country has always been vulnerable to several types of natural disasters. With limited irrigation sources, rainfall is critical to agriculture in Nepal, so any change in climatic variables is likely to have serious consequences for agriculture (NARC, 2010). Agroforestry has a high carbon sequestration potential on the long term (e.g. by the year 2040) not because it has a high carbon density (compared to forests) but because a lot of lands can potentially be turned into agroforestry (Torquebiau, 2013). Agricultural greenhouse gas (GHG) fluxes are complex and heterogeneous, but the active management of agricultural systems offers possibilities for mitigation. Many of these mitigation opportunities use current technologies and can be implemented immediately. Globally, agricultural CH_4 and N_2O emissions have increased by nearly 17% from 1990 to 2005, an average annual emission increase of about 60 $MtCO_2eq/yr$ (Smith *et al.,* 2007).

Species providing fruit were selected as priority species for domestication in Cameroon and Nigeria, whereas special attention is also given to these species in eastern Africa since they provide cash income to farmers ("high-value trees"). Parallel investigations therefore focused on the exclusive diversity of fruit trees (Kindt *et al.,* 2001). Ethnobotanical knowledge is at the very heart of agroforestry, something we have only realized recently in the developing agroforestry as a modern science. It was recognized that there were numerous niches within the farm where trees could be planted both to provide products like fuel wood and fodder, which were becoming scarce and to return organic matter and nutrients to the soil (Leakey, 1999). Poplars are amongst the fastest growing tree species under appropriate agro climatic conditions. Poplars can be harvested at short rotations of 8 to 10 years (Chaudhary and Chaudhary, 2012). Woods obtained from Poplars are eminently suitable for manufacture of match splints, veneering products, artificial limbs, interior paneling, cheap furniture and packing cases etc. These features combined with good economic returns and availability of long-term bank loans have made versatile. Serving both as an adaptation and mitigation measure, these systems offer countless benefits to the environment and food and nutrition security.

According to Plant Science Research program (undated), the agroforestry research began in Chitwan and Nawalparasi districts of Nepal in 1997 with the introduction of *Ficus, Melia, Artocarpus* and *Bauhinia* sp. According to SNV (Stichting Nederlandse Vrijwilligers), the Netherlands Development Organization, report in 2012, there has been a gradual shift in women's social status, with men taking on a greater share of family responsibilities. Evidence of the growing empowerment of women can be seen in their active participation in public land agroforestry activities, which was almost non-existent in the past in Terai region (Shrestha, 2012). In Nepal, there are some location specific agroforestry practices such as home garden, silvo-pasture and forest based agroforestry practice such as cardamom planting with alder *Alnus nepalensis.* There are some other farm characteristics which were found to be associated with highly integrated agroforestry. Farm households who have adopted highly integrated system have got bigger landholdings and therefore have allocated comparatively larger area for tree crop plantation. Tree planting in farm land is not risk-free because there are some legal formalities that farmers have to meet before harvesting the tree crop which stops smallholder farmers from raising trees extensively. Another reason, why the smallholder farmers who have adopted less and medium integrated agroforestry tends to have a small area of plantation, is that increased tree planting will decrease the land available for agricultural production and hence put them at risk of food insecurity (Dhakal *et al.,* 2012). Many government and non-government organizations are trying to promote suitable agricultural technology that can promote sustainability of farming in middle hills of Nepal. Manahari Development Institute (MDI) Nepal, a non-government organization, started an agroforestry project in the Khoriya farming areas of Makwanpur district. Reduced fallow period in khoriya farming is considered as the major economic downturn of the cultivators and environmental hazards in the area. Despite of these negative consequences, farmers are practicing same because of lack of alternative, poverty and government's negligence over the issue. The project initiated plantation of commercial agroforestry species to enhance the farm income of the Khoriya farmers. The major agroforestry species were banana (*Musa acuminata*), pineapple (*Ananas comosus*), ipilipil (*Leucaena leucocephala*.), Bakaino (*Melia azederach*) and brome grass (*Bromus inermis*). Results of the farm income analysis showed that agroforestry system was financially profitable than the traditional Khoriya farming in the area (Khadka, 2010). Nepal Agroforestry Foundation has been particularly involved in farmer centered fodder/grass research, training and extension since its establishment in 1991 which launches agroforestry programmes in areas where there is scarcity of fodder and grasses for the farmers (Regmi and Vickers, 2000). Agroforestry has considerable significance for the farming system of Nepal where population densities are high and land holding are small and fragmented. As agriculture productivity is declining, traditional agriculture system and forest resources is no longer meeting the growing demand for forest products and other basic needs. Agroforestry is only one best alternative to cope these situations and the indigenous and traditional knowledge of agroforestry practices is very essential to explore and document for its betterment (Khanal, 2011).

It is recommended that agroforestry can be seen as a tool in conjunction with appropriate conservation areas to buffer biodiversity loss, because agroforestry in some sites has 50 to 80% of the diversity of comparable natural forests and can help restrict the conversion of forests to grassland or other monospecific crops (Nobel and Dirzo, 1997, as cited by Khanal, 2011). Agroforestry increases farm profitability by increasing the total output per unit area, by protecting crops and livestock from wind, and by producing new products that add to the financial diversity and flexibility of the farming enterprise. It can also help conserve and protect natural resources by, for example, mitigating non-point source pollution, controlling soil erosion, and creating wildlife habitat (Streed, 1999).

CHAPTER III

MATERIALS AND METHODS

3.1. Study Area

The study was conducted in Terai region and mid-hill region. Ward number 6(Kunjalapur) and ward number 2(Baarah number) of Anandaban V.D.C., Rupandehi district and ward number 8(Kunwarthar) and ward number 9(Poudelthar) of Hemja V.D.C., Kaski district.

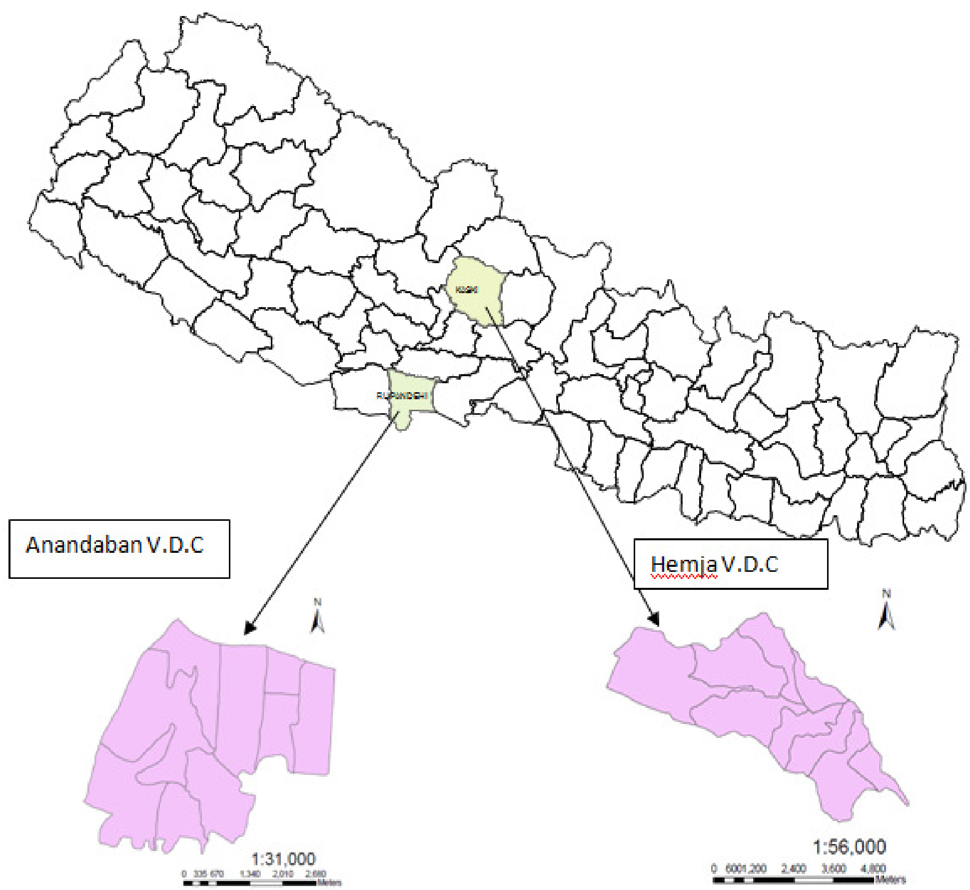


Figure- 1: Map of the study site.

Anandaban V.D.C lies on the opposing sides of the Siddhartha Highway in the western Terai and covers an area of 14.7 km^2. It is situated at an altitude of 134 m.a.s.l. with the longitude 83^{0}27'35.83"E and latitude 27^{0}37'48.19"N. Major ethnic groups include

Brahmin, Chettri, Gurung, Magar and Tharu. The vegetation of the area is dominated by *Dalbergia sissoo, Shorea robusta, Leucaena leucocephala, Pinus wallichiana etc.*

The area experiences the hot and humid climate during the summer and cold during the winter. For the period of 1981-2010, the highest average maximum temperature was 36.4^{0}C and the lowest average minimum temperature was 8.8^{0}C. While, the highest average rainfall was 545.6 mm in the month of July.

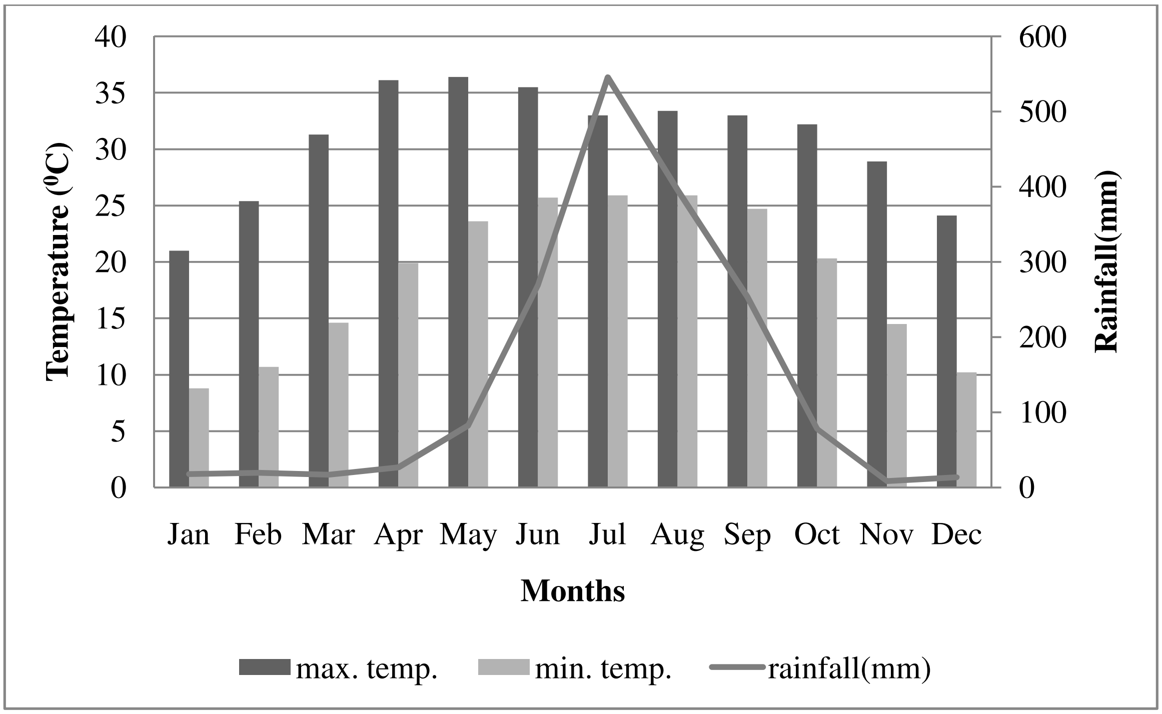


Figure-2: Average minimum-maximum temperature and rainfall (1981-2010) of Bhairahawa airport (Source: Department of Hydrology and Meteorology)

Hemja V.D.C lies on western mid-hill scattered on opposing sides of Baglung highway and covers an area of 19.71 km^2. It is situated at an altitude of 840-1471 m.a.s.l with the longitude 83^{0}52'46"E-83^{0}58'18"E and latitude 28^{0}14'48"N-28^{0}18'05"N. Major ethnic groups inhabiting the area are Brahmin, Cheetri, Magar, Gurung, Newar, Gharti, Kaami, Damai and Sarki. Major vegetations include *Schima wallichi, Castanopsis indica, Myrica esculenta, Alnus nepalensis, Madhuca longifolia* etc.

It experiences the temperate type of climate. For the period of 1981-2010, the highest average maximum temperature was 30.6^0C and the lowest average minimum temperature was 7.1^0C. While, the highest average rainfall was 940.3 mm in the month of July.

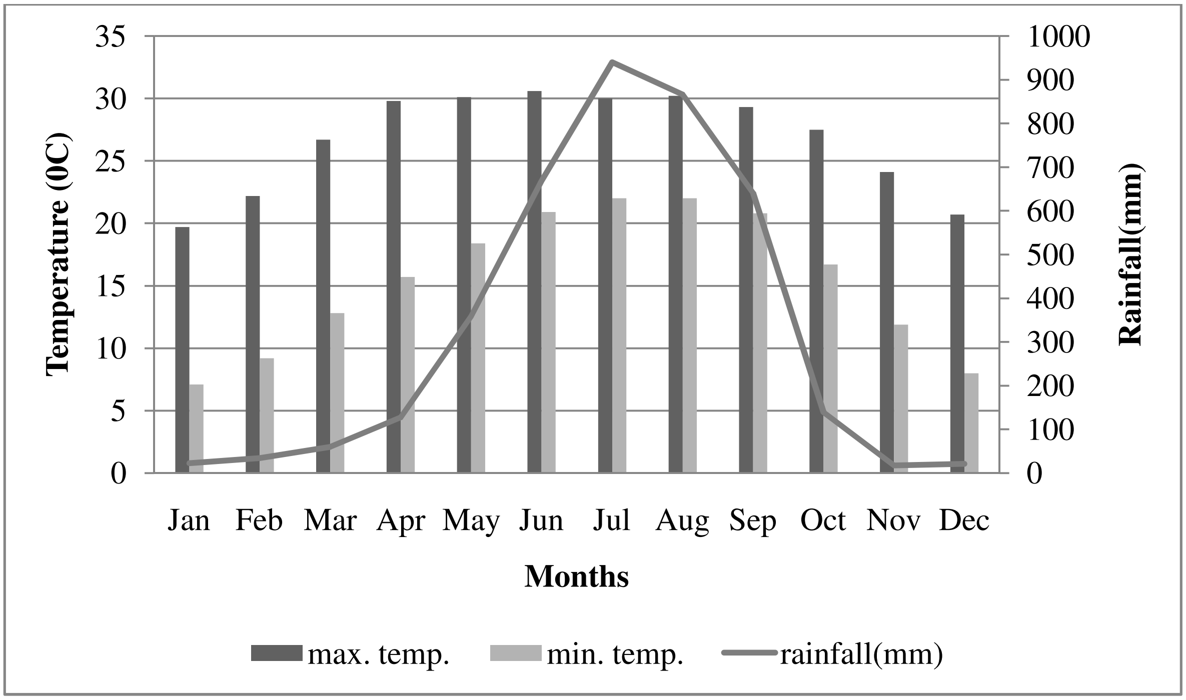


Figure-3: Average minimum-maximum temperature and rainfall (1981-2010) of Pokhara airport (Source: Department of Hydrology and Meteorology).

3.2. Sampling and data collection

Individual households represented the sampling units. 30 samples were studied from Terai region and 50 samples from mid-hill region. The households were chosen randomly for the study. Direct observation of the home garden was carried out with the permission of the house owner or respondent. Likewise, other works were carried out to meet our objectives which are described below:

3.2.1. Floristic Composition and Determination of Species Diversity

A. Floristic composition

The plant species grown in the home garden, irrigated land and non irrigated lands owned by them for different purposes were listed out with the help of the respondents.

B. Species diversity

The species diversity was estimated by using two widely used indices – Simpson's index and Shannon- Wiener index.

$$\text{Simpson's index} = \sum_{i=1}^{s} (Pi)^2$$

$$\text{Shannon} - \text{Weiner} = -\sum_{i=1}^{s} (Pi)(\ln Pi)$$

Where, Pi = proportion of all individuals in the sample that belongs to species

S= total number of species

3.2.2. Determination of Biomass Carbon Stock

Plots were set with the quadrat size of 20m×20m around the home garden of each household. The number of trees occurring inside the plots was counted and named with the help of the respondent. The size of the tree is described by the size of its trunk and by its total height. Trunk size was measured at a height of 1.3m above the average level at the base of the tree called breast height. Trunk size was expressed as its diameter at breast height (dbh).

A. Diameter at breast height (dbh)

Circumference of the individual trees inside the plot was measured with the help of measuring tape and later converted to its diameter equivalent using the equation:

Diameter (cm) = circumference (cm)/π. where π = 3.1416 (Labata *et al*., 2012)

B. Tree height

It was calculated as mentioned by Zobel *et al.,* 1987

By trigonometry,

$$\tan\alpha = \frac{\text{ht. of the tree above the eye ht. of the observer}}{\text{distance between the observer and tree}}$$

The eye-height of the observer was measured with the measuring tape and also the distance between the observer and tree. The angle of observation was recorded with the help of clinometers. For the tree height (H), the height of the observer up to the eye ((h_1) and the height of the tree above the eye height of the observer (h_2) was added up.

$$H = h_1 + h_2 \text{ (m)}$$

C. Basal area (BA)

Often, tree trunk size is also expressed as the area of its cross section at breast height, called basal area (BA) which was calculated as:-

$$BA = \pi r^2 = \pi\,(dbh)^2/4 = (cbh)^2/4\,\pi$$

Basal area per hectare was calculated as: -

$$BA = \frac{\text{sum of basal area of the plot x 100 x 100}}{\text{20 x20}} \ \frac{m^2}{ha}$$

D. Tree trunk volume (TTV)

It was calculated as given by Zobel *et al.,* 1987

$$TTV = \frac{\text{basal area x Height}}{2}$$

$$= \frac{\pi\,(dbh)^2 \times H}{8} \ m^3$$

Tree trunk volume per hectare was calculated as:-

$$\text{TTV per hectare} = \frac{\text{sum of TTV of the plot x 100 x 100}}{\text{20 x20}} \ \frac{m^3}{ha}$$

E. Above ground biomass (AGB)

Above ground biomass of trees was estimated by using different relation and allometric models. AGB of plants with dbh $\geq$ 10cm was estimated by using allometric models developed by Chave *et al.,* (2005).The allometric equation for the above ground tree biomass is given as:-

$$AGB = 0.0509 \times \rho\,(dbh)^2 H \qquad \text{(Chave } et\ al.,\text{ 2005).}$$

where,ρ = wood specific gravity (g/cm^3)

dbh is expressed in cm

The value of ρ was obtained from the secondary data, Zanne et al., 2009. But, the above ground biomass of plants with dbh< 10 cm, were estimated using global equation (Zianis, 2008). The equation is as follows: -

$$AGB = a(dbh)^b \qquad \text{(Zianis, 2008)}$$

Where, a=0.1424 and b=2.3679

Above ground biomass was calculated as:

$$AGB = \frac{\text{sum of AGB of the plot x 100 x 100}}{\text{20 x20}} \times \frac{1}{1000}\ \frac{t}{ha}$$

F. Below ground biomass (BGB)

It was calculated by multiplying the above ground biomass with 0.15. The root: shoot ratio was used to estimate below ground biomass (Mac Dicken, 1997).

$$BGB = AGB \times 0.15$$

Below ground biomass was calculated as:-

$$BGB = \frac{\text{sum of BGB of the plot x 100 x 100}}{\text{20 x20}}\ X\ \frac{1}{1000}\ \frac{t}{ha}$$

G. Total biomass (TB)

Total biomass (tons per hectare) was obtained by adding up above ground biomass per hectare and below ground biomass.

$$\text{TB} = (\text{AGB} + \text{BGB})\ \text{t/ha}$$

H. Total Biomass carbon stock (B.C.S)

To estimate the carbon stock in living biomass, the sum of dry biomass was multiplied by 0.47 which is the default carbon fraction in dry biomass (IPCC, 2006, as cited by Shirish, 2012).

$$\text{B.C.S} = \text{TB} \times 0.47\ \text{kg}$$

The carbon stock in 'kg' unit was converted to 'tons' by dividing the value with 1000. Finally, the carbon stock in the biomass was converted to tons per hectare as following: -

$$\text{B.C.S} = \frac{\text{sum of biomass carbon stock of the plot x 100 x 100}}{\text{20 x20}}\ \text{X}\ \frac{1}{1000}\ \frac{\text{t}}{\text{ha}}$$

3.2.3. Determination of Soil Carbon Stock

Soil samples were collected from 20cm depth from the center of the quadrate with the help of soil sampler. Samples were collected from 30 household of Terai region and 50 households of mid-hill. Samples from both regions were mixed in a single bulk separately. The soil samples were air dried separately for one week in shade and stored in air tight zipper plastic bags. The samples from the two regions were tagged as 'T' for Terai and 'M' for mid-hill and stored zipper plastic bags. Samples were brought to Ecology Laboratory in the Central Department of Botany, Tribhuvan University for further soil analysis of the samples.

A. Soil bulk density

It was calculated as given by Gupta, 2000

$$\text{Bulk density} = \frac{\text{Mass of the soil(g)}}{\text{Volume of soil}(\text{cm}^3)}$$

B. Soil organic carbon

Soil organic carbon of the soil samples was estimated by Walkey and Black's rapid titration method given by Gupta, 2000.

$$\text{Amount of carbon present in soil(g)} = \frac{0.003 \times 10(\text{B} - \text{C})}{\text{B}}$$

$$\%\text{ of organic carbon in soil sample} = \frac{0.003 \times 10(\text{B} - \text{C})}{\text{B} \times \text{S}} \times \frac{100}{1}$$

$$\text{Organic carbon} = \text{Organic carbon estimated} \times 1.3$$

Where, B= blank reading

C= titration reading

S= Weight of soil

C. **Soil carbon stock**

The soil carbon stock was estimated by applying the relation given by Winrock International as REED Methodological Module 2009. The relation is given as: -

$$\text{Csoc}_{\text{sp,i,t=0}} = \text{Csoc}_{\text{sample,sp,i,t=o}} \times \text{BD}_{\text{sample,sp,i=0}} \times \text{Dep}_{\text{sample,sp,i,t=0}} \times 100$$

Where,

$C_{SOCsp,i,t=0}$ = Carbon stock in soil organic carbon for sample plot sp, stratum i, at time t=0; t C ha-1

$C_{SOC\ sample,sp,i,t=0}$ = Soil organic carbon of the sample in sample plot sp, stratum i, at time t=0; determined in the laboratory in g C/100 g soil (fine fraction <2 mm)

$BD_{sample,sp,i,t=0}$ = Bulk density of fine (<2 mm) fraction of mineral soil in sample plot sp, stratum i, at time t =0; determined in the laboratory in g fine fraction cm-^{3} total sample volume

$Dep_{sample,sp,i,t=0}$ = Depth to which soil sample is collected in sample plot species in stratum i at time t=0;

sp = 1, 2, 3 … Pi sample plots in stratum i

i = 1, 2, 3 … M strata

t= 0, 0 years elapsed since the start of the project activity

3.2.4. Determination of Total Carbon Stock

The total carbon stock of the sampled plots was calculated by summing up the carbon stock in biomass and carbon stock in the soil.

Total carbon stock (t C ha^{-1}) = Carbon stock in biomass + Carbon stock in soil

3.3. Statistical analysis

All data were subjected to the test of normality. Mann-Whitney U-test was used for the comparison of mean and Pearson correlation was performed to correlate the variables. Linear regression was carried out to observe the pattern between the variables. Statistical package SPSS 16.0 (SPSS Inc.2007) was used for the statistical analysis. The data were presented using MS-Excel 2007 and SPSS 16.0.

CHAPTER IV

RESULTS

4.1. Floristic Composition and Species Diversity

4.1.1. Floristic composition

A total of 171 plant species belonging to 62 families were recorded from the study area of Terai and mid-hill regions which includes herbs, shrubs and trees. 58 species which belonged to 31 families were found to occur in both the regions. 130 were found in the Terai and 99 were found in mid-hill. 72 species belonging to 21 families were found in Terai only and 41 species belonging to 9 families were found in mid-hill only (Figure 4).

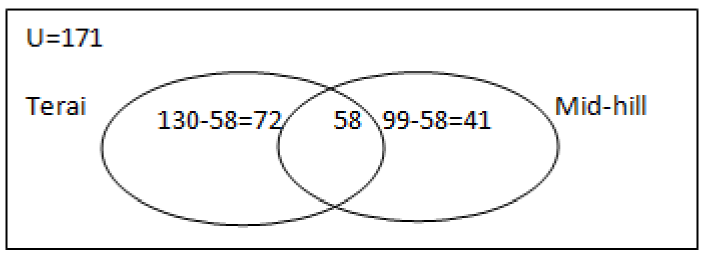


Figure- 4: Number of plant species in Terai and mid-hill regions.

Out of 130 plant species recorded in Terai region, only 35 species were tree. Similarly, in mid-hill region, only 30 species were tree out of 99 plant species recorded. The list of plant species with their uses is tabulated in Annex I.

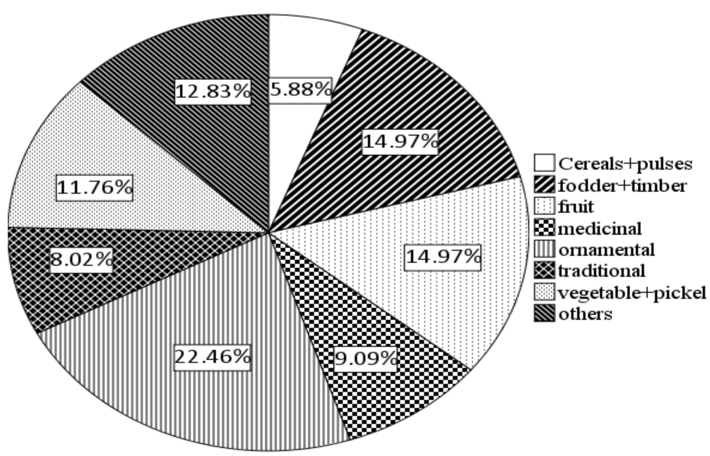
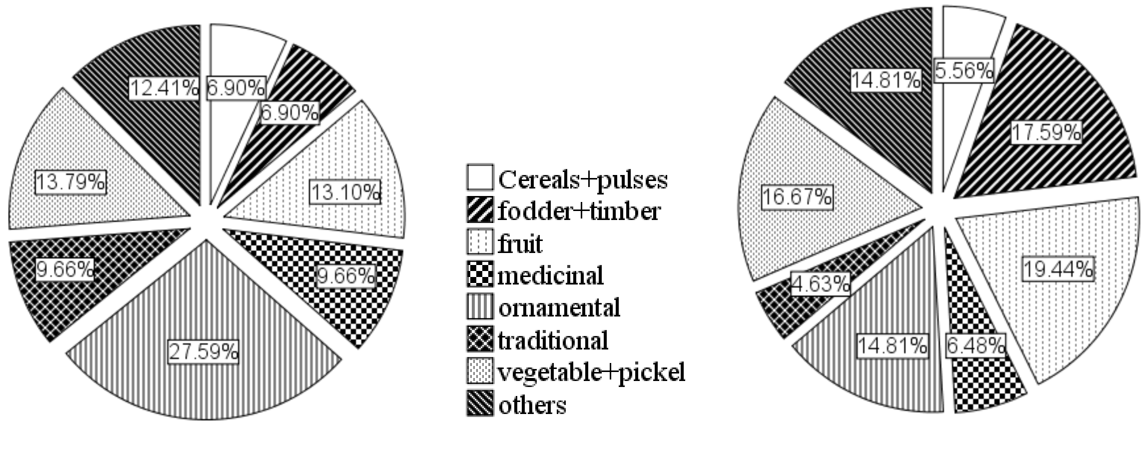


Figure- 5: Proportion of plant species used for various purposes in both regions.



(A) (B)

Figure- 6: Proportion of plant species used for various purposes in (A) Terai (B) mid-hill.

In Terai region, the most plants were grown as ornamental while least as cereals & pulses as well as fodder and timbers. Likewise, in mid-hill region, most of the plants were grown as fruits and least was occupied by other purposes which included plant oil, speciments etc. The result also showed that ornamental plants have gained much preference in both regions. Similarly, the trees providing fruit were also well maintained in both regions though the higher value was in mid-hill. Medicinal and traditional plants with the religious values were more occupied in Terai region as compared to mid-hill. But, fruits, fodder and timber plants were found to be grown in more number in mid-hill. The frequently grown tree species in Terai were *Leucaena leucocephala, Mangifera indica, Psidium guajava, Litchi chinensis, Phyllanthus emblica, Polylthia longifolia var.pendula, Azadirachta indica*. While in mid-hill, frequently grown tree species were *Artocarpus lakoocha, Brassaiopsis spp. Citrus reticulate, Ficus clavata, Ficus lacor, Prunus persica*.

4.1.2. Species diversity

The Shannon's index was obtained to be 1.24 for Terai and 1.21 for mid-hill. The Shannon index was found to be higher in Terai. Similarly, Simpson's index was found as 0.0915 and 0.087 for Terai and mid-hill respectively (Figure 7).

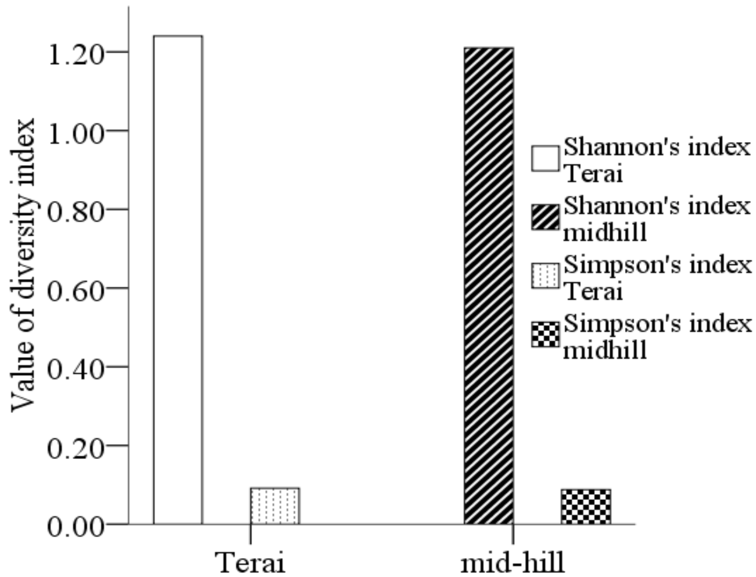


Figure- 7: Diversity indices of plant species in Terai and mid-hill regions.

4.2. Biomass Carbon Stock

4.2.1. Diameter at breast height (dbh)

Mean dbh was found to be 14.8629 cm in Terai which ranged from 3.18- 54.112 and 17.1853 cm in mid-hill which ranged from 2.0371-47.74 cm (Figure 8).

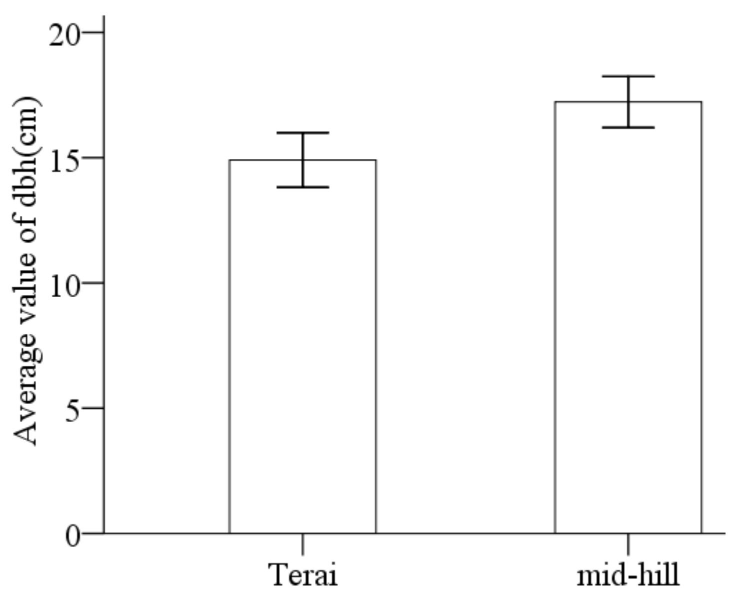


Figure- 8: Diameter at breast height (dbh) of sampled trees in Terai and mid-hill regions. Columns represent average values with vertical bars as SE of the means.

The average dbh of trees in mid-hill was significantly higher than that of Terai (Mann-Whitney U-test, $p<0.05$). The result also showed that the plants with smaller dbh size class were in greater number in Terai than mid-hill (Figure 9) which indicates the fair regeneration of plants in Terai than in mid-hill region.

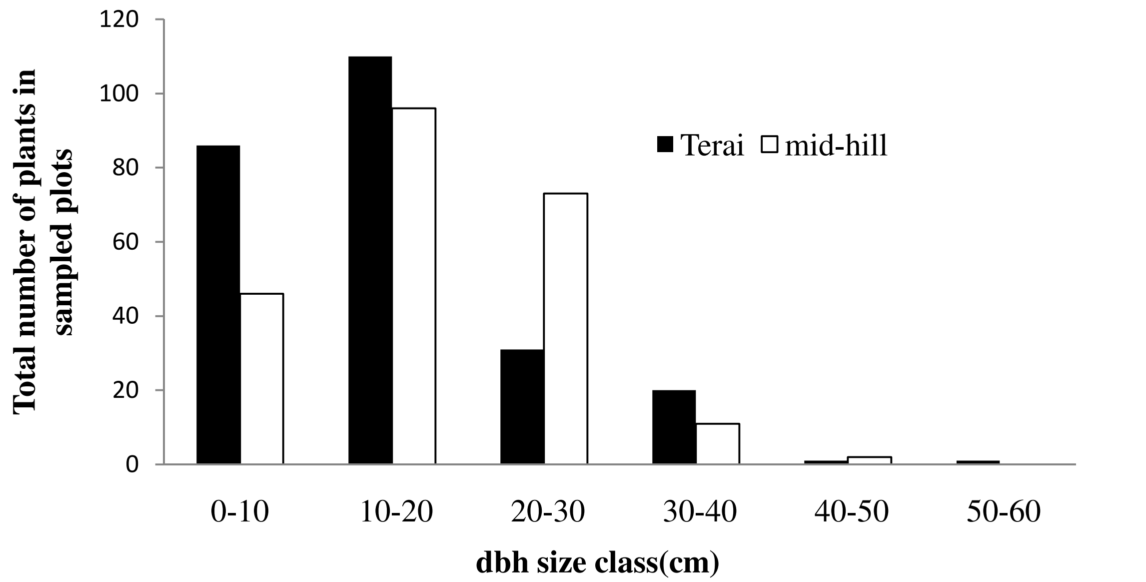


Figure- 9: DBH-class distribution of plants in Terai and mid-hill regions.

4.2.2. Tree height (m)

The mean height of trees in Terai and mid-hill region was found to be 7.13 m and 6.54 m respectively (Figure 10). The average height of trees in Terai was significantly higher than those in mid-hill region (Mann-Whitney U-test, $p=0.005$).

The study showed that the numbers of trees with height ranging 6-12m were higher in Terai region but much taller trees reaching the height up-to 28m were found in mid-hill only but were very few in number (Figure 11).

Pearson correlation showed the significant positive correlation between the diameter at breast height (dbh) and height of the tree in both regions ($r= 0.717$ in Terai and $r= 0.611$ in mid-hill at $p=0.01$).

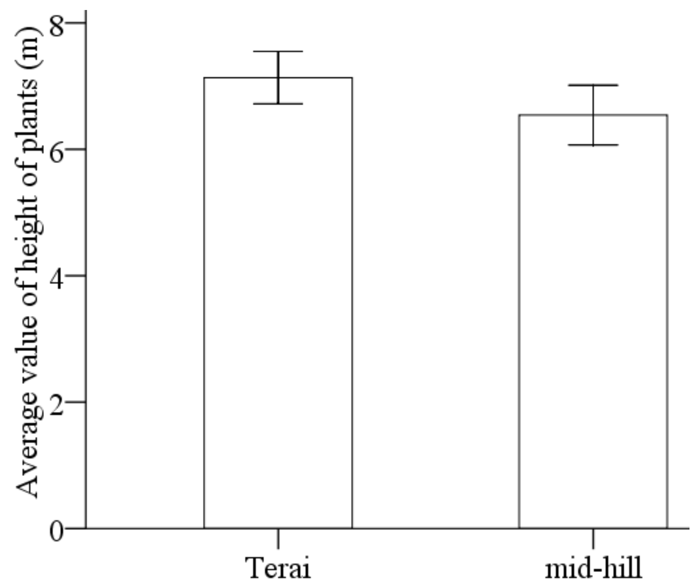


Figure- 10: Height of sampled trees in Terai and mid-hill regions.

Columns represent average values with vertical bars as SE of the means.

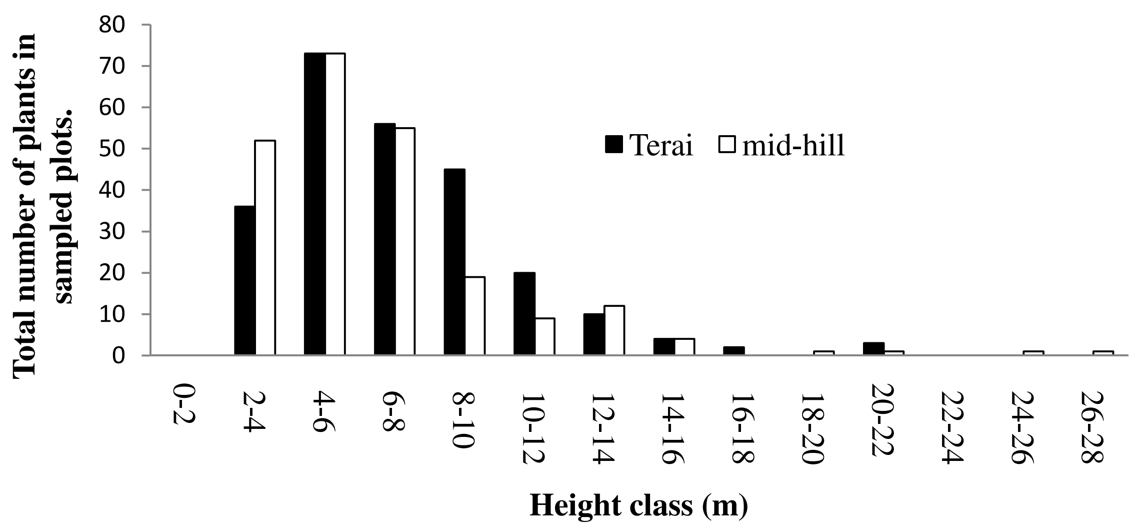
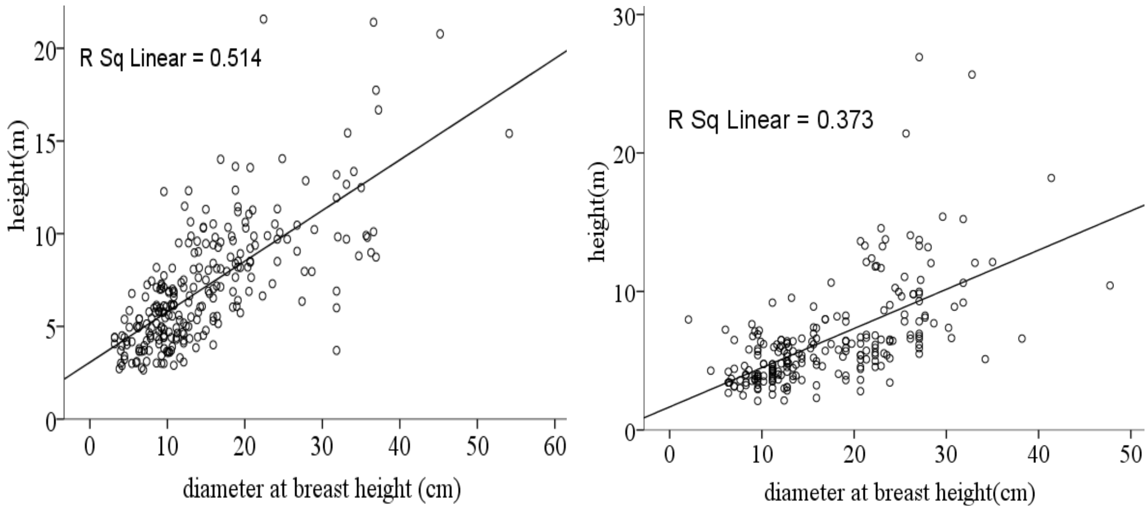


Figure- 11: Number of plants with corresponding tree height in Terai and mid-hill. regions.

The diameter at breast height and the height of the plants in both Terai and mid-hill regions showed statistically significant positive linear relationship (Figure 12A and B).



(A) (B)

Figure- 12: Fitted linear regression line between height and diameter at breast height of plants in (A) Terai and (B) mid-hill region.

4.2.3. Basal area (m^2/ha)

Mean basal area was obtained as 4.788 m^2/ha and 3.1725 m^2/ha in Terai and mid-hill respectively (Figure 13). The average basal area of trees in Terai was significantly higher than those in mid-hill (Mann-Whitney U-test, $p = 0.023$).

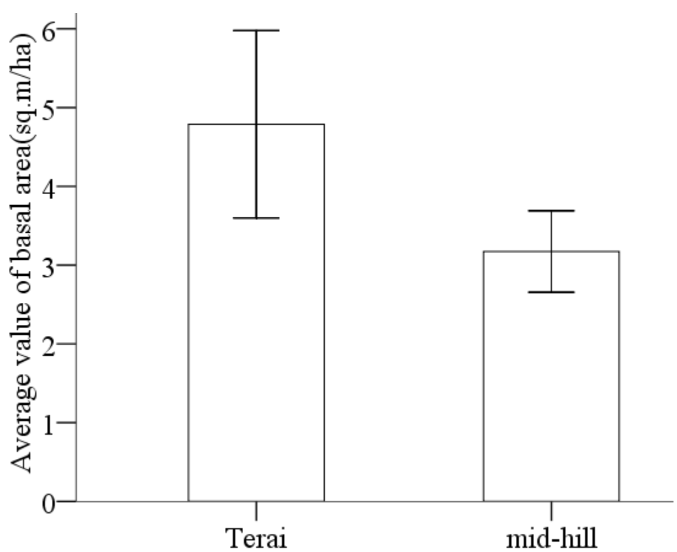


Figure- 13: Basal area per hectare of sampled plots in Terai and mid-hill regions. Columns represent average values with vertical bars as SE of the means.

4.2.4. Tree trunk volume (TTV)

Mean TTV was obtained as 23.95 m^3/ha for Terai and 13.574 m^3/ha for mid-hill (Figure 14). The average Tree trunk volume was significantly higher in Terai than in mid-hill (Mann-Whitney U-test, p = 0.01).

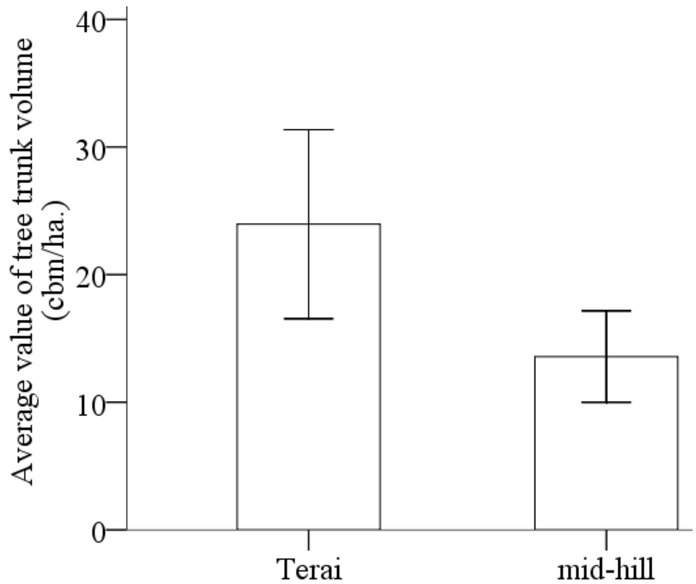
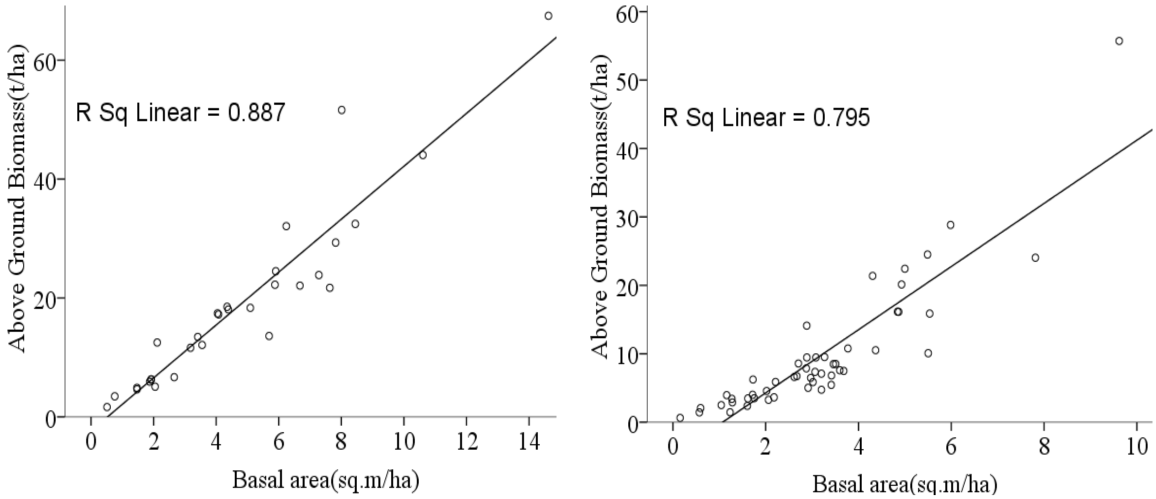


Figure- 14: Tree trunk volume per hectare of sampled plots in Terai and mid-hill regions. Columns represent average values with vertical bars as SE of the means.

4.2.5. Above ground biomass (AGB)

The mean above ground biomass was obtained as 19.22 t/ha and 9.741 t/ha for Terai and mid-hill respectively (Figure 16). The average above ground biomass of trees in Terai was significantly greater than those in mid-hill (Mann-Whitney U-test, p = 0.001).

Pearson correlation showed the significant positive correlation between the above ground biomass and basal area of the plants in both regions (r=0.942 in Terai and r=0.891 in mid-hill at p=0.01). Linear regression showed statistically significant linear positive pattern between the above ground biomass and basal area of the plants in both regions (Figure 15 A and B).



(A) (B)

Figure- 15: Fitted linear regression line between aboveground biomass and basal area of sampled plots in (A) Terai and (B) mid-hill regions.

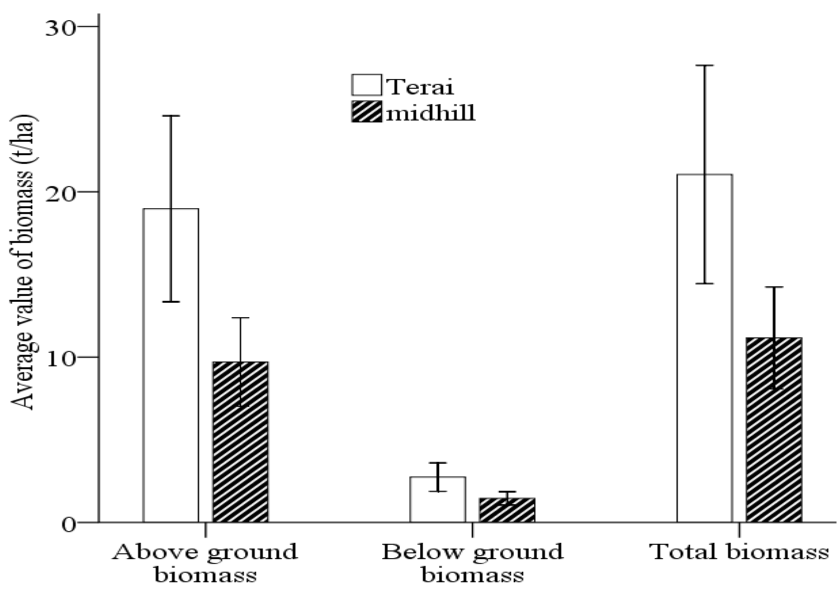


Figure- 16: Biomass of sampled plots in Terai and mid-hill regions. Columns represent average values with vertical bars as SE of the means.

4.2.6. Below ground biomass

The mean below ground biomass was found to be 2.780 t/ha for Terai 1.462 t/ha for mid-hill (Figure 16). The average below ground biomass of trees in Terai was significantly greater than those in mid-hill region (Mann-Whitney U-test, p=0.005).

4.2.7. Total biomass

The mean total biomass was obtained as 21.314 t/ha and 11.203 t/ha for Terai and mid-hill respectively (Figure 16). The average total biomass was significantly greater in Terai than in mid-hill (Mann-Whitney U-test, p = 0.004).

Pearson correlation showed the significant linear correlation between total biomass and the basal area in both regions (r=0.883 in Terai and r=0.892 in mid-hill at p =0.01). Basal area and total biomass in both regions showed statistically significantly positive linear relationship (Figure 17 A and B).

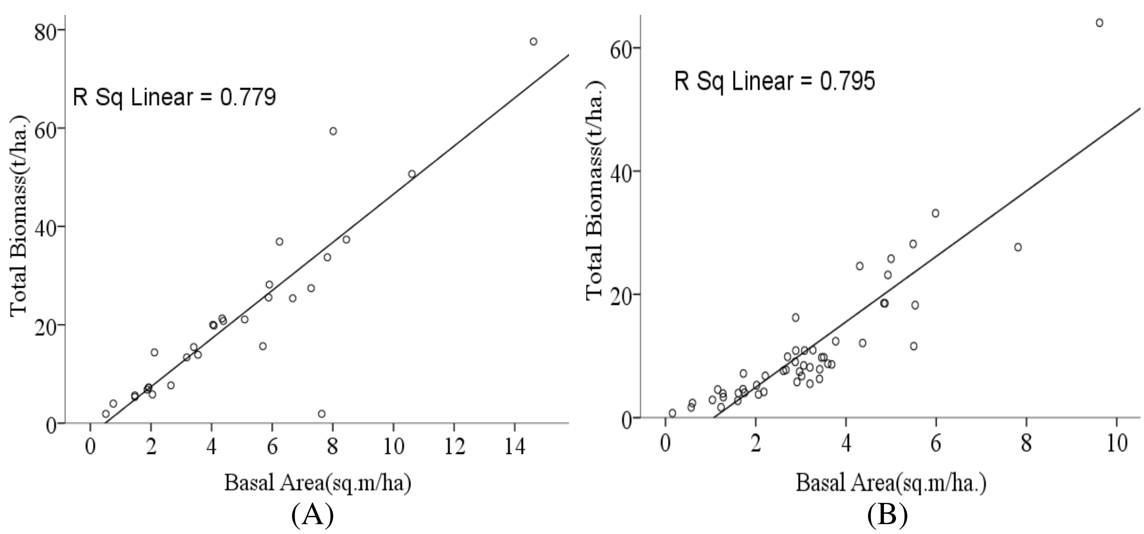


Figure- 17: Fitted linear regression line between total biomass and basal area of sampled plots in (A) Terai and (B) mid-hill regions.

4.2.8. Total biomass carbon stock

The mean of total biomass carbon stock was found to be 10.255 tons C per hectare and 5.24 tons C per hectare for Terai and mid-hill respectively (Figure 18). The average total biomass carbon stock was significantly higher in Terai than in mid-hill (Mann-Whitney U-test, p=0.001).

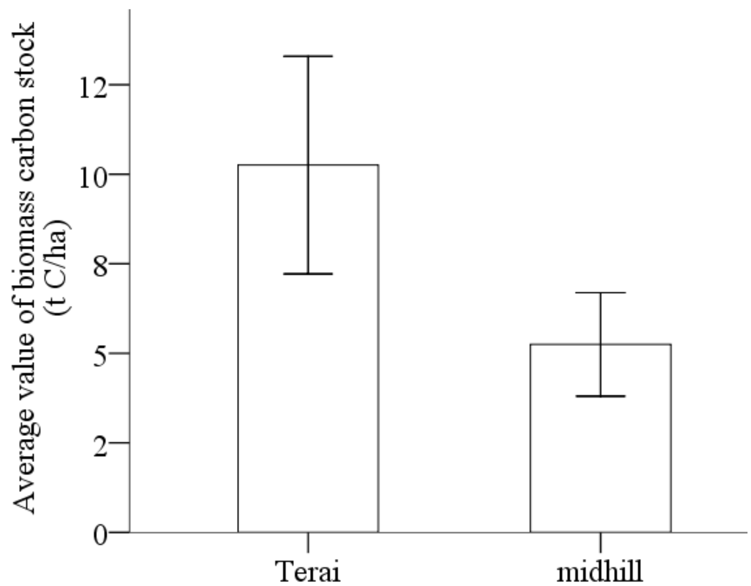


Figure- 18: Biomass carbon stock of sampled plots in Terai and mid-hill regions. Columns represent average values with vertical bars as SE of the means.

4.3. Determination of Soil Carbon Stock

4.3.1. Soil Bulk Density

The mean bulk density was found to be 1.38 g/cm^3 in Terai and 1.076 g/cm^3 in mid-hill region (Figure 19). The average soil bulk density was significantly higher in Terai than that in mid-hill (Mann-Whitney U-test, $p<0.05$).

4.3.2. Soil carbon stock

The mean soil carbon stocks were found to be 61.17 t Cha^{-1} for Terai and 67.608 t Cha^{-1} for mid-hill (Figure 20). The average soil carbon stock was significantly greater in mid-hill than that in Terai (Mann-Whitney U-test, p=0.025).

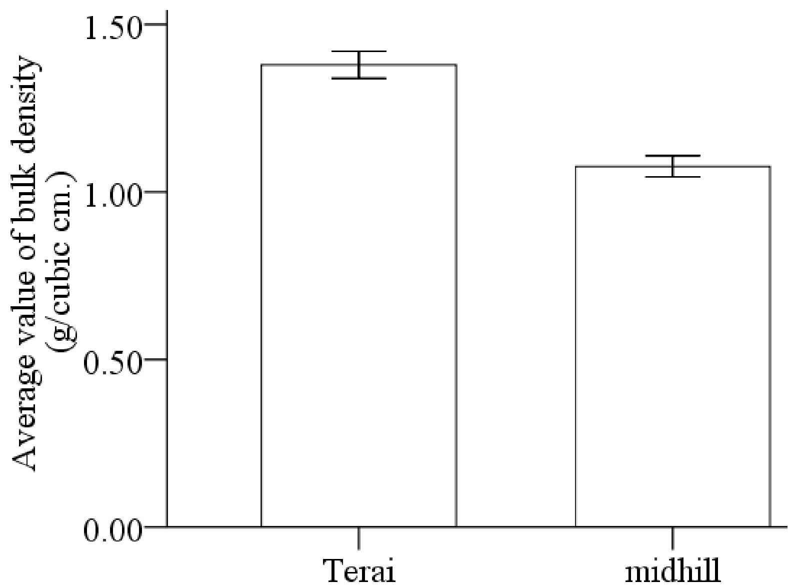


Figure- 19: Soil bulk density of sampled plots in Terai and mid-hill regions. Columns represent average values with vertical bars as SE of the means.

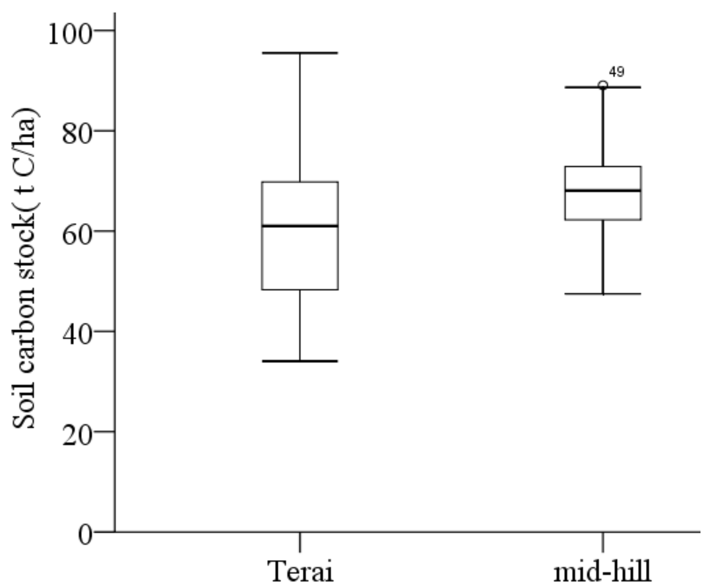
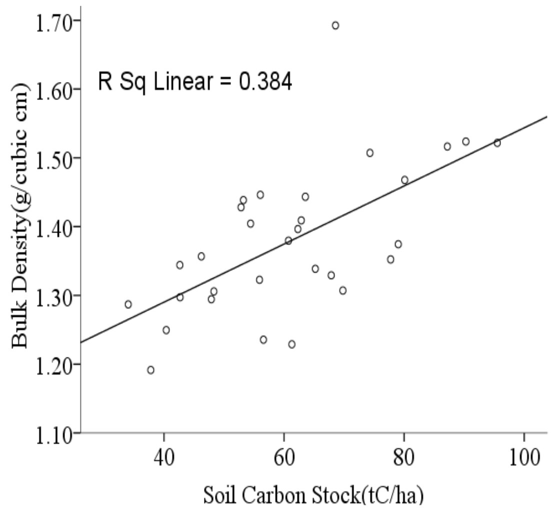
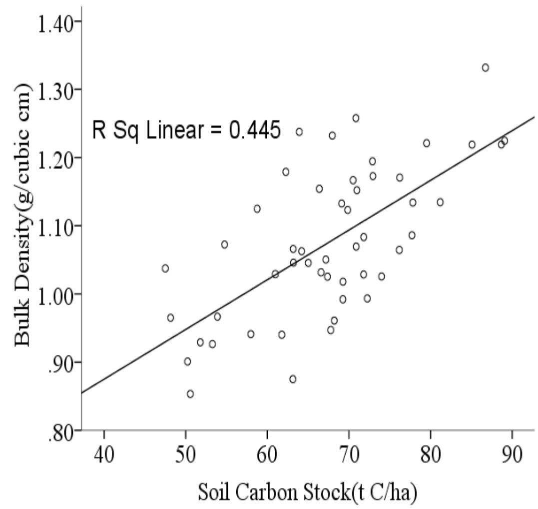


Figure- 20: The soil carbon stock of Terai and mid-hill region. Upper and lower vertical bar represents the highest and the lowest value, horizontal bar represents the mean value.

Pearson correlation showed significant positive correlation between the soil bulk density and soil carbon stock (r=0.620 in Terai and r=0.667 in mid-hill at p=0.01). Linear regression also showed statistically significant linear positive pattern between bulk density and soil carbon stock in both regions (Figure 21 A and B).





(A) (B)

Figure- 21: Fitted linear regression line between soil carbon stock and soil bulk density of sampled soil of (A) Terai and (B) mid-hill regions.

Pearson correlation showed that the biomass carbon stock and the soil carbon stock were not significantly correlated in both regions (r= 0.085, p= 0.655 in Terai and r= -0.05, p=0.730 in mid-hill).

Linear regression showed statistically not significant positive pattern between the biomass carbon stock and the soil carbon stock in Terai region (Figure 22A) and statistically not significant negative pattern between the biomass carbon stock and the soil carbon stock in mid-hill region (Figure 22B).

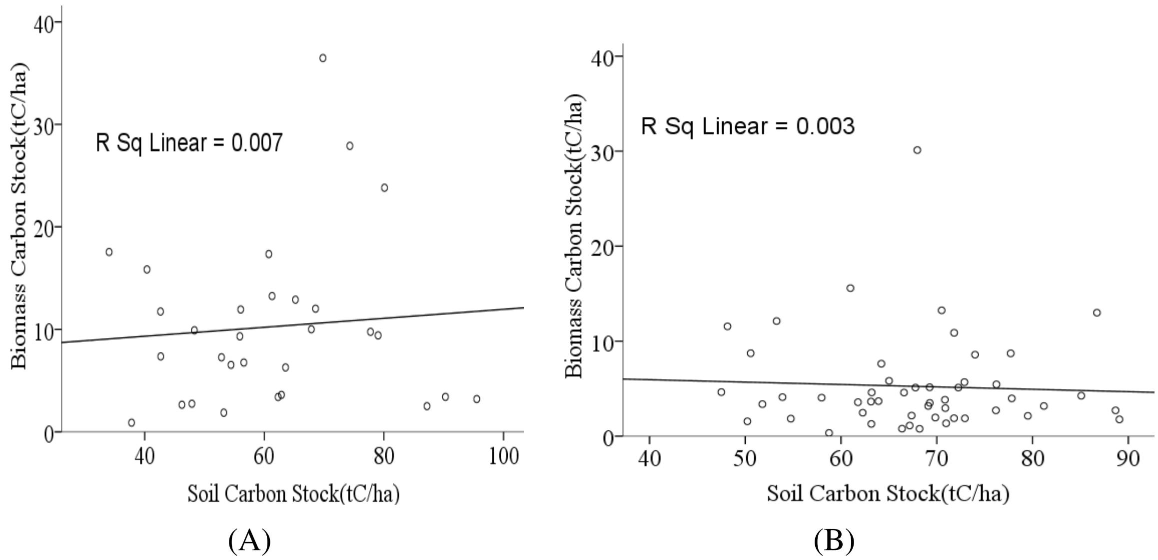


Figure- 22: Fitted linear regression line between biomass carbon stock and soil carbon stock in the sampled plots of (A) Terai and (B) mid-hill regions.

4.4. Total carbon stock

The mean total carbon stock for Terai and mid-hill was found to be 71.433 t C/ha and 72.856 t C/ha respectively (Figure 23). There was no significant difference in the total carbon stock between the two regions (Mann-Whitney U-test, p=0.409).

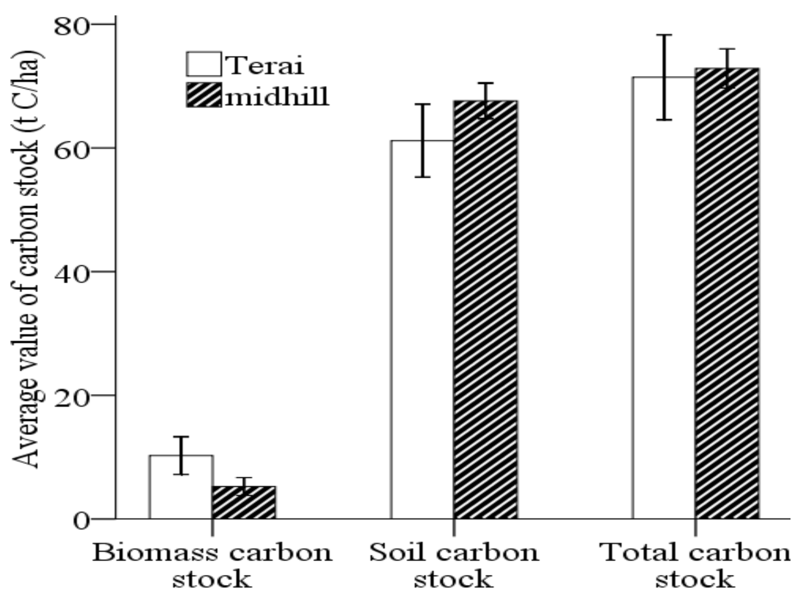


Figure- 23: Carbon stock in biomass and soil in the sampled plots of Terai and mid-hill regions. Columns represent average values with vertical bars as SE of the means.

CHAPTER V

DISCUSSION

5.1. Floristic composition and species diversity

In this study, we found a total of 171 plant species which includes 58 tree species. Another study has reported 165 different crop species in Terai and midhill (Sunwar, 2003), also 71 tree species have been reported from home-garden of India (Devi and Das, 2012) and 45 tree species in home-garden of Indonesia (Roshetko *et al.,* 2002).

The study revealed that there was higher number of species in Terai than in mid-hill region. The result disagreed with the finding of Sunwar (2003) but agreed with those of Hodel and Gesslar 1999, (as cited by Sunwar, 2003). The reason behind the higher number of species in Terai would be that the study was conducted in home garden which is a human practice and not the natural one. It was found that the size of home garden or the land owned was larger in Terai due to which various types of species were integrated in the agroforestry practice. The warm and humid climate of Terai region might have favored the growth of plants like *Polylthia longifolia* var.*pendula*, *Murraya paniculata*, *Amomum subulatum*, *Punica granatum*, *Melia azedirach*, *Cicer arietinum*, *Garuga pinnata* due to which in the study those plants were extensively found in Terai but not in the mid-hill. The result showed that there were almost similar proportions of species used as cereals and pulses, medicinal, traditional etc., but the major difference occurred in the ornamental plants which caused the number of species to be higher in Terai. Due to larger size of home garden, people were found to be interested in growing more ornamental plants in Terai but in mid-hill, people focused on other purposes. It was found that the ornamental plants were more in number in both the regions. This is because they occupy less space and can be grown easily anywhere around the house. Ornamental plants especially small flowers were found to be grown in even those households which did not grow other plants. The plants for fodder and timber were higher in mid-hill which might have been because the people in mid-hill were involved in livestock farming more than those in Terai due to which they grow more fodder plants and the wood of the same can also be used as timber.

The Shannon index was higher in Terai than in mid-hill region which does not agree with the result by Sunwar (2003). It indicates the higher species richness which was due to the high number of species in Terai. Moreover, it was found from the interview and observation that most of the people in mid-hill were attracted towards animal husbandry and leave their live stocks for grazing. Studies have shown that there was a significant increase in richness or abundance of native plants with grazing protection. Regeneration and subsequent self-thinning of mulga (*Acacia aneura)* was promoted with grazing protection (Fensham, 2011). Thus, this grazing phenomenon might have resulted to the degradation in the species richness in mid-hill than in Terai. However, Simpson's index was higher though little in Terai which however agrees with findings of Sunwar (2003). Since, it reflects the dominance and because the frequently grown or the dominant trees were almost equal in both the regions, the index was similar for both regions.

5.2. Biomass carbon stock

5.2.1. Diameter at breast height (dbh)

The mean dbh of the tree was higher in mid-hill region than in the Terai. The number of plants with dbh 20-30 cm was more than double in the mid-hill region. Also the plants with higher dbh were almost similar in both regions which resulted to the higher mean dbh in the mid-hill region. Further, in the mid-hill, most of the plants were used for the fodder and timber purpose which are naturally thicker than the other trees contributing to larger average dbh in mid-hill region.

The study conducted in western hill region reported the dbh of trees with the mean 10.86 cm (Poudel *et al.,* 2011) which is 1.5 times less than the finding from mid-hill of our study. Also, another study from Dhading reported the mean dbh range from 7-10cm (Thapa Magar, 2012).

5.2.2. Tree height

The average height of trees was found to be higher in Terai than in mid-hill region. The study conducted in Dhading reported the height of the tree to be 6.0-9.1m (Thapa Magar, 2012). Also, another study conducted in western hill region reported the mean height of the tree to be 9.74m (Poudel *et al.,* 2011).

Study in plants has shown the property of taperness- the decrease in diameter with an increase in height in order to allocate the resources (Gartner, 1995). Another factor that influences the height of the plant is the amount of the tree covered with the foliage that is capable of photosynthesizing. Photosynthesis is the means of producing food for itself, so more the live crown length and the more food capable of being manufactured and therefore more taper (Anonymus). Since, more fodder plants were found in mid-hill which contained more foliage therefore the dbh was higher but the height was lesser as compared to those in Terai.

5.2.3. Basal Area

Mean basal area in Terai region was higher as compared to mid-hill. The larger number of plants with lower dbh i.e. up-to 20 cm was higher in Terai so mathematically, the square of those lower dbh values has contributed to higher mean basal area in Terai. The study conducted in Far-Western Terai reported the basal area of the dominating species *Shorea robusta* to be 7.6 m^2/ha and that of other miscellaneous species to be 4.1 m^2/ha (Gautam *et al.,* 2010) which is comparable to the finding of Terai region. The study conducted in Chitrepani in Siwalik region reported the tree basal area as: 59.6 m^2/ha in natural forest and 11.4 m^2/ha in degraded forest (Shrestha *et al.,* 2000). Another study in the community forest of Rupandehi district estimated the mean basal area to be 41.22 m^2/ha (Shirish, 2012). The estimated total tree basal area of the study was also comparable to the finding of Western Tabora, Tanzania (Luhende *et al.,* 2006). However, the present finding was 2.5 times lesser than the finding of home garden of Barak valley, Assam, India (Das and Devi, 2013).

5.2.4. Tree trunk volume

The higher basal area and larger height of trees in Terai region than in mid-hill has resulted to higher tree trunk volume of trees in Terai region as compared to that in mid-hill region. The study conducted in Far-Western Terai reported the mean tree trunk volume to be 172 m^3/ha, in which 26.8 m^3/ha was contributed by miscellaneous species in Terai which is comparable with the finding in Terai region while 13.8 m^3/ha was contributed by *Pinus roxburghii* which is comparable with the finding in mid-hill(Gautam *et al.,* 2010). Another study in Chitrepani reported the tree trunk volume to be 132 m^3/ha in the degraded forest (Shrestha *et al.,* 2000). The mean tree trunk volume in community forest of Rupandehi district was reported to be 330.83 m^3/ha (Shirish, 2012) which is almost 19 times more than the finding of our study. This huge difference might have occurred due to the fact that the study conducted by Shirish (2012) was in community forest which is well managed and the trees are grown in large number. Community forest approach is one of the successful approaches for the conservation of forest. The achievements of the community forest can be seen in terms of better forest condition, better social mobilization and income generation for rural development and institutional building at grass root level (Kanel, 2006). The mean tree trunk volume of the present study was 1.16 times greater than that of *Lithocarpus glaber*, 6.9 times less than that of *Pinus massoniana* in Eastern China (Ali *et al.,* 2014).

5.2.5. Above ground biomass

The above ground biomass substantially determines an ecosystem's potential for carbon storage, which plays an important role in the regulation of atmospheric CO_2 and global climate change (Bunker *et al.,* 2005). The dbh distribution of trees significantly contributes to the above ground biomass (Chave *et al.,* 2005). Also, the larger mean height of Terai region has resulted into the greater above ground biomass of trees in Terai than those in mid-hill.

The estimated average above ground biomass of trees in home garden of the two regions viz., Terai and mid-hill was almost similar to the finding in the 15 years old home garden of Lampung, Indonesia (Roshetko *et al.,* 2002). But, it was almost 6 times less than that estimated in *Alnus nepalensis* forest of Hill (Baral *et al.,* 2009), 2.5 times less than that estimated in home garden of central Kerela, India (Kumar, 2011). Another study in community forest of Gorkha district estimated the above ground biomass to be 117.21 t/ha in Laxmi Mahila community forest and 299.62 t/ha in Jalbire community forest (Neupane and Sharma, 2014).

5.2.6. Below ground biomass

The knowledge of relationships between belowground biomass and dynamics and nutrient availability and absorption is very important for understanding forest functioning and terrestrial ecology (West *et al.,* 2004, as cited by Hristovski, 2012). It is considered that the carbon content of the fine roots is more than 5% of the total carbon in the atmosphere (Jackson *et al.,* 1997, as cited by Hristovski, 2012).

The higher value of above ground biomass in Terai region contributed to greater below ground biomass (Mc Dicken, 1997) in same than in mid-hill. The mean below ground biomass of the present study is 11.5 times less than that from the rangeland of Milke, Taplejung (Limbu and Koirala, 2011). The study conducted in community forest of Rupandehi district estimated the mean below ground biomass to be 72.64 Mg/ha (Shirish, 2012). Likewise, it was almost 9 times less than that in the poor site quality mature forest of South- East Norway (Naesset, 2004). Another study in Panchayat forest of India estimated the total below ground biomass to be 0.72 t $ha^{-1}yr^{-1}$ in Anriyakot Van Panchayat forest and 0.79 t $ha^{-1}yr^{-1}$ in Bhatkholi Van Panchayat forest (Rawat, 2013).

5.2.7. Total biomass

Carbon management is a serious concern confronting the world today. The significance of role of biomass of tree species in carbon sequestration has long been recognized but very little attempts have been made to estimate the biomass accumulation and their contribution for sequestration of carbon, especially in mined out areas (Bohre *et al.,* 2012). Higher value of total biomass in Terai than in mid-hill region is attributed to the greater above and below ground biomass in Terai region. Since biomass increases with stand age, postponing harvesting to the age of biological maturity may result in the formation of a large carbon sink (as cited by Alexandrov, 2007).

The mean total biomass was reported to be 186.6t/ha from the study in Far-Western Terai (Gautam *et al.,* 2010). The average value of biomass in the community forest of Dolakha district was estimated to be 70.8 t/ha (Shrestha *et al.,* 2012). The total mean of total biomass estimated in the present study was almost similar to the mean biomass of Falcata-coffee multistorey system of Agroforestry in Bukidnon, Philippines (Labata *et al,* 2012*).* Also, the finding of Kempanaickenapalayam village in Tamil Nadu, India shows the comparable result for the total biomass (Murthy *et al.,* 2013). However, the present finding was 1.6 times greater than the finding of homegarden biomass of Kanchanpur district, Nepal (Baral *et al.,* 2013*).*

5.2.8. Total Biomass carbon stock

The amount of carbon stored in a forest stand depends on its age and productivity (Alexandrov, 2007). The average total biomass carbon stock was almost double in Terai as compared to the mid-hill region. The tall trees having huge aerial parts and also the dense root system and favorable climatic condition for growth and decomposition of Terai region contributed for more biomass carbon stock. Studies of nutrient cycling in moist tropical forests described productive forests rich in nutrient in which rates of primary production and the amounts of nutrients cycled clearly exceeded those in temperate zone forest (Vitousek and Sanford, 1986). Hence, the higher productivity in Terai region has significant role in its higher biomass carbon stock.

The study conducted in Prok village of Manaslu Conservation Area reported the carbon in tree biomass as 74.6 t C/ha in northern aspect and 15.02 t C/ha in southern aspect (Sigdel, 2013). The value in the southern aspect is comparable to the mean biomass carbon stock of our study. The mean biomass carbon stock was estimated to be 205.12 Mg/ha in community forest of Rupandehi district (Shirish, 2012). The mean carbon stock in living biomass of community managed hill *Shorea robusta* forest was 128 Mg/ha (Thapa Magar, 2012). The present result was comparable to the finding in Kempanaickenapalayam village, Tamil Nadu, India (Murthy *et al.,* 2013). However, the finding was 8.9 times less than the finding in the Coniferous forest of Vietnam (Sharma *et al.,* 2013).

5.3. Soil carbon stock

5.3.1. Soil bulk density

The bulk density of a soil is always smaller than its particle density. Generally, in normal soil, bulk density ranges from 1-1.65 Mega-gram per cubic meter ($Mg/m^{3)}$. In very compact soil, sometimes, it goes up-to 2.0 Mg/m^3 (Gupta, 2000). The study showed that both the soil samples were normal in terms of its bulk density.

The mean soil bulk density of mid-hill in the present finding was comparable to the bulk density of soil (0-20 cm depth) in Jarneldhara community forest of Palpa district, Nepal which ranged from 0.88-1.07 g/cm^{-3} (Khanal *et al.,* 2010*).* Another study in Dailekh district reported the soil bulk density to be 1.36 g/cm^{-3} in irrigated lowland (khet) and 1.28 g/cm^{-3} in upland (bari) (Regmi and Zoebisch, 2004).

Soil bulk density greatly depends on the mineral make up of soil and the degree of compactness. Generally, loose, porous soils and those rich in organic matter have lower bulk density. Sandy soils have relatively high bulk density. Soil of Terai region contains less organic matter due to higher decomposition rate and faster mineral cycling than that of the mid-hill. Study shows faster mineral cycling in tropical region than in the temperate region (Vitousek and Sanford, 1986). Lesser organic matter in the soil contributed to higher soil bulk density in Terai than in mid-hill.

5.3.2. Soil carbon stock

More than half of the assimilated carbon is eventually transported below ground via root growth and turnover, root exudates and litter decomposition therefore soil contain the major stock of C in the ecosystem (Montagnini and Nair, 2004). Soil stores approximately 2344 Pg (1 Pg = 1015 g = 1Mt) of organic carbon worldwide - over three times the atmospheric carbon content (Jobbagy and Jackson 2000, as cited by Hobley and Willgoose, 2010). Soil can be source as well as sink of carbon depending upon its management. If minimizing soil disturbance decreases SOC decomposition rate, then this change in management practice would cause decreased transfer of C from soil to the atmosphere and so be genuine climate change mitigation (Powlson *et al.,* 2011*).*

In the present study, the soil carbon stock was higher in mid-hill than in the Terai because in Terai there is higher temperature and humid condition which is considered a favorable situation for the metabolism of micro-organisms. There was higher litter fall and also the rate of decomposition was higher in Terai due to which large number of carbon released is stored in biomass not in soil. While, in mid-hill, the temperature and soil conditions were less favorable for the micro-organisms as compared to Terai. Due to this, the dead matters take much time to be decomposed and ultimately much of the carbon remains in the soil. Early studies of nutrient cycling in moist tropical forests described productive forests rich in nutrients in which rates of primary production and the amounts of nutrients cycled clearly exceeded those in temperate zone (Vitousek and Sanford, 1986).

The result of the present study was comparable to the mean of soil carbon stock in Karahiya community forest of Rupandehi district, Nepal (Shrish, 2012). Likewise, the finding was 1.3 times greater than the soil organic carbon stock in the farm with trees in Kanchanpur district, Nepal (Baral *et al.,* 2013*)*. Also, the mean soil carbon stock of this work was 1.24 times greater than that in Jarneldhara community forest and 2.06 times more than that in Lipindevi Thulopakho community forest in Palpa district, Nepal (Khanal *et al.,* 2010). The negative correlation between biomass carbon stock and soil carbon was also supported by the finding in Kenya (Omoro *et al.,* 2013).

5.4. Total carbon stock

In temperate regions, agroforestry practices have been estimated to have the potential to store C in the range of 15–198 Mg C ha^{-1}. In the tropics, agroforestry systems are estimated to have helped to regain 35% of the original C stock of the cleared forest, compared to only 12% by croplands and pastures (Pokhrel *et al.*, 2013). C is accumulating in the atmosphere at a rate of 3.5 Pg (Pg = 1015 g or billion tons) per annum, the largest proportion of which resulting from the burning of fossil fuels and the conversion of tropical forests to agricultural production (Paustian et al., 2000, as cited by Albrecht and Kandji, 2003).

The average of total carbon stock in the present study was comparable to the finding in the tropical agroforestry system which ranged from 12- 228 Mg C ha^{-1} (Albrecht and

Kandji, 2003). The finding was however 1.2 times less than the Falcata- coffee multistory system in Bukidnon, Philippines (Labata *et al.,* 2012) and 3.75 times less than the Karahiya community forest of Rupendehi district, Nepal (Shrish, 2012). Also, the mean carbon stock was 1.48 times less than the mean carbon stock of home-garden in Indonesia (Roshetko *et al,* 2002).

The total carbon stock was slightly higher in mid-hill than in Terai but the difference was statistically not significant. Due to higher soil carbon stock, though the biomass carbon stock was less in the mid-hill region, the net total carbon stock was higher in mid-hill region.

CHAPTER VI

CONCLUSION

Agroforestry system can be proved to be one of the best alternatives to cope with the alarming problem of biodiversity loss, food security and climate change. Starting from a small area around the home, it can create its impact to the global scale. The increase in species richness due to agroforestry system is obvious and can contribute to the biodiversity enrichment. Likewise, the food security is also addressed by this practice. Growing vegetables, fruits and fodder plants around the home garden or in any abandoned land can meet the food requirements for large number of people especially the rural people. This can enhance the living standard of the people. In case of Nepal which is agro-based country can be well benefitted from such practice in agriculture. It helps in enrichment of soil fertility, provides the better way to grow various types of plants in a small area. Though, this study does not focus on the livestock approach in agroforestry, many studies have proved it to be much beneficial rather than growing plant alone. In this study, we found the agroforestry practice was being upgraded slowly. People were utilizing the land for the various purposes. Trees can be a source as well as a sink of carbon. Agroforestry can store the large amount of carbon from the atmosphere. The biomass carbon stock in the present study was 10.255 t C/ha in Terai and 5.24 t C/ha in mid-hill region .Likewise, soil carbon stock was 61.17 t C/ha in Terai and 67.60 t C/ha in mid-hill. The soil stores large amount of carbon as compared to that of the biomass because soil is a product of various mechanisms occurring since millions of years. In the present study, we found that there was no significant difference between the total carbon stock of the two regions which was 71.43 t C/ha in Terai and 72.85 t C/ha in mid-hill region.

Recommendations

Based on this study, the following recommendations have been made:

- Most of the people do not have the scientific knowledge about the way and importance of agroforestry practice. So, it is now high time to aware the people about the importance of the agroforestry practice so that large area of land can be utilized properly to cope with the global concern of biodiversity loss, food insecurity, climate change etc.
- Increasing rate of degradation of soil and deforestation in the forest should be addressed by implementation of strict laws and action. And simultaneously, the government should create new programs and ideas to make people aware and encourage them towards the agroforestry practice.
- The people should be provided with various types of hybrid species of food value, fodder value etc so that they get attracted towards this practice.
- The queries and concerns of the people regarding this practice should be well noted and the local bodies of government should be responsible to solve it.
- There should be the provision of reward and punishment so that the local people get motivated towards the agroforestry practices.
- Nutritional analysis of fruits, fodder and their consumable products will help to attract people for the use of local products.

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ANNEX

ANNEX I

LIST OF SPECIES FOUND IN TERAI AND MID-HILL REGION

Local name	Scientific name	Family	Uses
aadahar dal	*Cajanus cajan* L.	Fabaceae	cereals
aalaichi	*Amomum subulatum* Roxb.	Zingiberaceae	spicement
aalas	*Linum usitatissimum* L.	Linaceae	oil
aalu	*Solanum tuberosum* L.	Solanaceae	vegetable
aap	*Mangifera indica* L.	Anacardiaceae	fruit
aaru	*Prunus persica* L.	Rosaceae	fruit
aasare ful	*Lagerstroemia indica* (L). Pers.	Lythraceae	ornamental
adhuwa	*Amomum zingiber* Roxb.	Zingiberaceae	spicement
aloe vera	*Aloe vera* (L).Burm.	Xanthorrhoeaceae	ornamental/medicinal
amala	*Phyllanthus emblica* L.	Phyllanthaceae	fruit/medicinal
amba	*Psidium guajava* L.	Myrtaceae	fruit
amilo bel	*Feronia limonia* (L.) Swingle	Rutaceae	spicement
amriso	*Thysanolaena maxima* Kuntze	Poaceae	making broom
anar	*Punica granatum* L.	Lythraceae	fruit
ashok	*Polylthia longifolia* var.*pendula* (Soon.)Thwaites	Annonaceae	ornamental
badahar	*Artocarpus lakoocha* Wall. ex Roxb.	Moraceae	fodder
bajradanti	*Murraya paniculata* (L.)Jack	Rosaceae	medicinal
bakaino	*Melia azedirach* L.	Meliaceae	fodder
bamari	*Ocimum basilicum* L.	Lamiaceae	ornamental

banda	*Brassica oleracea* L.var *capitata* L.	Brassicaceae	vegetable
baramase ful(pink)	*Hibiscus* L.	Malvaceae	ornamental
baramase ful(white)	*Hibiscus* L.	Malvaceae	ornamental
baramase ful(yellow)	*Hibiscus* L.	Malvaceae	ornamental
bass	*Arundinaria* Michx.	Poaceae	timber
bedulo	*Ficus clavata* Wall. ex Miq.	Moraceae	fodder
bel	*Aegle marmelos* L.	Rutaceae	traditional
beli ful	*Jasminum multiflorum* (Burm.f.)Andrews	Oleaceae	ornamental
besaar	*Curcuma longa* L.	Zingiberaceae	spicement
bhatmas	*Glycine max* (L.) Merr.	Fabaceae	cereals/oil
bhogate	*Citrus maxima* Merr.	Rutaceae	fruit/spicement
bhuikatahar	*Ananas comosus* (L) Merr.	Bromeliaceae	fruit
bimiro	*Citrus medica* L.	Rutaceae	fruit
bodi	*Vigna unguiculata*(L) Walp.	Fabaceae	vegetable
bougainvellia	*Bougainvillea spectabilis* Willd.	Nyctaginaceae	ornamental
brocoli	*Brassica oleracea L. var. italica*	Brassicaceae	vegetable
cauli	*Brassica oleracea* L. var.*botrytis*	Brassicaceae	vegetable
chameli ful	*Jasminum officinale L.*	Oleaceae	ornamental
chana	*Cicer arietinum L.*	Fabaceae	pulses
chap	*Michelia champaca (L.)Baill. Ex Pierre.*	Magnoliaceae	timber
chicinda	*Trichosanthes cucumerina L.*	Cucurbitaceae	vegetable

chilaune	*Schima wallichi (DC.)Korth*	Theaceae	timber
chiuri	*Diploknema butyracea (Roxb.) H.J.Lam.*	Sapotaceae	medicinal
christmas tree	*Araucaria* Juss.	Araucariaceae	ornamental
chuletro	*Brassaiopsis* Decne. & Planch.	Araliaceae	fodder
dabdabbe	*Garuga pinnata* Roxb.	Burseraceae	fodder
dahlia	*Dahlia* Cav.	Asteraceae	ornamental
dalchini	*Cinnamomum zeylnicum* Blume.	Lauraceae	spicement
damai ful	*Ardisia solanaceae* Roxb.	Myrsinaceae	ornamental
dhan	*Oryza sativa* L.	Poaceae	cereals
dhaniya	*Coriandrum sativum* L.	Apiaceae	spicement
dhaturo	*Datura stramonium L.*	Solanaceae	traditional
dhupi	*Juniperus L.*	Cupressaceae	ornamental
dumri	*Ficus racemosa* L.	Moraceae	fodder
farsi	*Cucurbita pepo* Mill.	Cucurbitaceae	vegetable
gahun	*Triticum aestivum L.*	Poaceae	cereals
gajar	*Daucus carota* L.	Apiaceae	vegetable
galaichi ful	*Verbena hybrida*	Verbenaceae	ornamental
ganja	*Cannabis sativa* L.	Cannabaceae	medicinal
gante ful	*Leucas indica* (L.) R.Br. Ex. Vatke	Lamiaceae	ornamental
ghadi ful	*Passiflora caerulea* L.	Passifloraceae	ornamental
ghiraula	*Luffa cylindrica* (L.) M. Roem.	Cucurbitaceae	vegetable
godawari	*Chrysanthemum* L.	Asteraceae	ornamental
golachi ful	*Clerodendrum serratum* (L.)Moon	Verbenaceae	ornamental
golveda	*Lycopersicon esculentum*	Solanaceae	spicement/pickel

	Mill.		
gulaf(pink)	*Rosa L.*	Rosaceae	ornamental
gulaf(red)	*Rosa* L.	Rosaceae	ornamental
gulaf(white)	*Rosa L.*	Rosaceae	ornamental
haluwabed	*Diospyros kaki* Thunb.	Ebenaceae	fruit
imli	*Tamarindus indica* L.	Fabaceae	spicement
indrakamal	*Gardenia* J.Ellis	Rubiaceae	ornamental
ipilipil	*Leucaena leucocephala* Lam.	Fabaceae	fodder
iskuss	*Sechium edule* (Jacq.) Swartz	Cucurbitaceae	vegetable
jagar	*Caryota urens* L.	Arecaceae	earthing
jamun	*Syzygium cumuni* (L.) Skeels	Myrtaceae	fruit
jau	*Avena sativa*L.	Poaceae	traditional
jimbu	*Allium hypsistum* Stearn.	Amaryllidaceae	spicement
kadam	*Anthocephalus chinensis* A. Rosh. & Walp.	Rubiaceae	traditional
kafal	*Myrica esculenta* Buch.-Ham	Myricaceae	fruit
kagati	*Citrus aurantifolia* Christn	Rutaceae	fruit/spicement
kakro	*Cucumis sativus* L.	Cucurbitaceae	fruit
kamana ful	*Murraya paniculat*a (L.) Jack	Rutaceae	ornamental
kaner	*Nerium oleander* L.	Apocynaceae	ornamental
kapash	*Gossypium hirsutum L.*	Malvaceae	traditional/making clothes
kapur	*Cinnamomum camphora* (L.)J.Presl.	Lauraceae	traditional
karela	*Momordica charantia* L.	Cucurbitaceae	pickel/vegetable
katahar	*Artocarpus heterophyllus* Lam	Moraceae	fruit
katus	*Castanopsis indica* (Roxb.) Miq.	Fagaceae	fruit/timber

kaulo	*Machilus gamblei* King.ex.Hook.f.	Lauraceae	pickel/timber
kauro	*Ficus lacor* Buch.-Ham.	Moraceae	fodder
kera	*Musa paradisiaca* L.	Musaceae	fruit
kera ful	*Hedychium spicatum* Smith	Zingiberaceae	ornamental
kerau	*Pisum sativum* L.	Fabaceae	pulses
kerkala	*Colocasia esculenta* (L.) Schott	Araceae	vegetable/pickel
khurpani	*Prunus domestica* L.	Rosaceae	fruit
khursani	*Capsicum annum* L.	Solanaceae	spicement
khursani ful	Pyrostegia vanusta (Ker-Gawl) Miers	Bignoniaceae	ornamental
kimbu	*Morus alba* L.	Moraceae	fruit
kodo	*Eleusine coracana* Gaertn.	Poaceae	cereals
koirala	*Bauhinia variegata* L.	Fabaceae	fodder/pickel
kurilo	*Asparagus officinalis* L.	Liliaceae	medicinal/vegetable
kusum	*Schleichera oleosa (Lour.) Merr.*	Sapindaceae	fruit
kutmero	*Litsea monopelata* (Roxb.) Korth	Lauraceae	fodder
laari ful	*Barleria cristata* L.	Acanthaceae	ornamental
lakuri	*Fraxinus floribunda Wall.*	Oleaceae	timber
lalupate	*Euphorbia pulcherrima* Wild. Ex Kletzch	Euphorbiaceae	ornamental
lapsi	*Choerospondias axillaris* (Roxb.) B.L.Brutt. & A.W.Hill.	Anacardiaceae	fruit
lasoon	*Allium sativum* L.	Amaryllidaceae	spicement
latte sag	*Amaranthus viridis* L.	Amaranthaceae	vegetable
lauka	*Lageenaria siceraria* (Mol.)	Cucurbitaceae	vegetable

litchii	*Litchi chinensis* Sonner	Sapindaceae	fruit
lywang	*Caryophyllus aromaticus* L.	Myrtaceae	spicement
machha ful	*Asclepias curassavica* L.	Apocynaceae	ornamental
makkai	*Zea mays* L.	Poaceae	fruit
malati ful	*Mirabilis jalapa* L.	Nyctaginaceae	ornamental
marahati	*Spilanthes clava* D.C.	Asteraceae	medicinal/spicement
mass ko dal	*Vigna mungo* (L.) Hepper	Fabaceae	pulses
mauwa	*Madhuca longifolia* (J.Konig) J.F.Macbr.	Sapotaceae	fodder
mehendi	*Lawsonia inermis* L.	Lythraceae	ornamental/traditional
mewa	*Carica papaya* L.	Caricaceae	fruit
mula	*Raphanus sativa L.*	Brassicaceae	vegetable
musuro	*Lens culinaris* Medic	Fabaceae	pulses
nariwal	*Cocos nucifera* L	Arecaceae	fruit
naspati	*Pyrus communis* L.	Rosaceae	fruit
neem	*Azadirachta indica* A.Juss.	Meliaceae	medicinal
nimaro	*Ficus auriculata* Lour.	Moraceae	fodder
paiyun	*Prunus cerasoides* D. Don.	Rosaceae	fodder/timber
pakhuri	*Ficus glaberrima* Blume.	Moraceae	fodder
parijat	*Nyctanthes arbor-tristis* L.	Oleaceae	ornamental/traditional
parvar	*Trichosanthes dioica* Roxb.	Cucurbitaceae	vegetable
pati	*Artemisia vulgaris* L.	Asteraceae	medicinal
pipal	*Ficus religiosa* L.	Moraceae	traditional
pudina	*Mentha spicata* L.	Lamiaceae	ornamental
pyaj	*Allium cepa* L.	Amaryllidaceae	spicement
rahar daal	*Cajanus cajan* (L.) Huth	Fabaceae	pulses
rajma	*Phaseolus vulgaris* L.	Fabaceae	pulses
raktachandan	*Pterocarpus santalinus L.*	Fabaceae	medicinal/timber
rayo saag	*Brassica juncea* Czern. & Coss.	Brassicaceae	vegetable

ritha	*Sapindus mukorossi* Gaertn.	Sapindaceae	timber
rohini	*Mallotus philippensis*(Lam.)Muller	Euphorbiaceae	medicinal
rudrakshya	*Elaeocarpus sphaericus* (Gaertn.) K. Schum.	Eleocarpaceae	traditional
sal	*Shorea robusta* Gaertn.	Dipterocarpaceae	traditional/timber
salifa	*Annona squamosa* L.	Annonaceae	fruit
salla	*Pinus wallichiana* Sargent	Pinaceae	timber
sami	*Ficus benjamina* L.	Moraceae	traditional
sarpaganda	*Rauvolfia serpentina* (L.) Benth.	Apocynaceae	ornamental/medicinal
sayapatri	*Tagetes erecta* L.	Asteraceae	ornamental
silam	*Perilla frutescens* (L.) Britton	Lamiaceae	spicement
simi	*Dolichos lablab* L.	Fabaceae	vegetable
sincauli	*Cinnamomum zeylanicum Breyn.*	Lauraceae	spicement
sindoor	*Bixa Orellana* L.	Bixaceae	traditional
sirkhanda	*Santalum album* L.	Santalaceae	medicinal/traditional
sissoo	*Dalbergia sissoo* Roxb.	Fabaceae	timber
siudi ful	*Euphorbia royleana* Boiss	Euphorbiaceae	ornamental
stevia	*Stevia* Cav.	Asteraceae	medicinal
suntala	*Citrus reticulata* Blanco.	Rutaceae	fruit
supari	*Areca catechu* L.	Arecaceae	nuts/medicinal
supari ful(makmali ful)	*Gomphrena globosa* L.	Amaranthaceae	ornamental
tiju	*Diospyros melanoxylon* Roxb.	Ebenaceae	timber
til	*Sesamum orientale* L.	Pedalliaceae	spicement
tiuri ful	*Impatiens scabrida* DC.	Balsaminaceae	ornamental
tooni	*Toona ciliata* M.Roem	Meliaceae	fodder
tori	*Brassica campestri*s L. var.	Brassicaceae	oil

	toria		
tuke ful	*Myriactis nepalensis* Less.	Asteraceae	ornamental
tulsi	*Ocimum sanctum* L.	Lamiaceae	traditional/medicinal
tulsi ful	*Salvia splendens* Sellow ex J.A. Schultes	Lamiaceae	ornamental
ukhu	*Saccharum officinarum* L.	Poaceae	fruit/traditional
utis	*Alnus nepalensis* D.Don	Betulaceae	timber
vaja ful	*Quisqualis indica* L.	Combretaceae	ornamental
vanta	*Solanum melongena* L.	Solanaceae	vegetable
vicks	*Plectranthus purpuratus* Harv.	Lamiaceae	medicinal
vindi	*Abelmoschus esculentus* (L.) Moench.	Malvaceae	vegetable

ANNEX II

VARIOUS PARAMETERS MEASURED FOR TOTAL CARBON STOCK

FOR TERAI

Household no.	B.A (m^2/ha)	TTV (m^3/ha)	AGB (t/ha)	BGB (t/ha)	Total biomass (t/ha)	Carbon stock in Biomass(t C/ha)	soil bulk density (g/cm^3)	soil carbon stock (t C/ha)	total carbon stock (t C/ha)
1	5.091258	21.64244	18.33243	2.749865	21.0823	9.908681	1.305759	48.31117	58.21985
2	5.690958	18.66338	13.60989	2.041483	15.65137	7.356145	1.297273	42.67819	50.03434
3	8.445525	35.98083	32.46316	4.869474	37.33264	17.54634	1.286931	34.04616	51.5925
4	2.656753	7.272003	6.679457	1.001918	7.681375	3.610246	1.409103	62.86447	66.47472
5	6.240767	44.84777	32.09197	4.813795	36.90577	17.34571	1.3796	60.74015	78.08586
6	1.919402	7.065578	6.282151	0.942323	7.224474	3.395503	1.396444	62.29971	65.69522
7	10.6069	58.76433	44.05472	6.608208	50.66293	23.81158	1.467769	80.09704	103.9086
8	5.90463	26.2024	24.50022	3.675033	28.17525	13.24237	1.228828	61.29971	74.54208
9	7.281697	32.51826	23.85995	3.578993	27.43895	12.8963	1.338629	65.20894	78.10525
10	6.675895	31.66486	22.08381	3.312572	25.39639	11.9363	1.446207	56.04883	67.98513
11	5.879289	30.35754	22.22876	3.334314	25.56307	12.01464	1.6925	68.56817	80.58282
12	7.818932	38.35423	29.3176	4.39764	33.71524	15.84616	1.249552	40.37634	56.22251
13	2.048867	5.388414	5.080212	0.762032	5.842244	2.745855	1.294379	47.89015	50.636
14	4.347791	23.84602	18.50801	2.776202	21.28421	10.00358	1.329167	67.86218	77.86576
15	14.61858	82.3892	67.47009	10.12051	77.5906	36.46758	1.307074	69.79661	106.2642
16	1.47151	4.125956	4.642128	0.696319	5.338447	2.50907	1.516462	87.19543	89.7045
17	4.041629	20.33285	17.4091	2.611365	20.02046	9.409618	1.37438	79.02581	88.43543
18	1.925206	6.992828	6.319351	0.947903	7.267254	3.415609	1.523686	90.28825	93.70386
19	7.632451	31.03217	21.7111	0.24784	1.900108	11.73486	1.344111	42.64452	54.37938
20	0.51124	1.561131	1.652268	0.24784	1.900108	0.893051	1.191472	37.80175	38.6948
21	1.469041	3.85403	4.895824	0.734374	5.630198	2.646193	1.35669	46.22224	48.86843
22	1.876799	6.442929	5.929149	0.889372	6.818522	3.204705	1.521692	95.51798	98.72268
23	4.387382	23.72555	18.06101	2.709152	20.77017	9.761978	1.352276	77.75488	87.51686
24	8.011636	70.4012	51.62411	7.743616	59.36773	27.90283	1.507171	74.30201	102.2048
25	0.75653	3.586291	3.458411	0.518762	3.977172	1.869271	1.438552	53.22432	55.09359
26	3.411015	17.14762	13.45383	2.018074	15.4719	7.271795	1.428136	52.83896	60.11076
27	3.551672	13.47398	12.09212	1.813818	13.90594	6.535792	1.404379	54.42777	60.96356
28	4.077028	21.73354	17.24085	2.586128	19.82698	9.318681	1.322655	55.90884	65.22753
29	2.114931	13.52966	12.51385	1.877078	14.39093	6.763737	1.235567	56.56989	63.33362
30	3.179743	15.77113	11.62995	1.744493	13.37444	6.285989	1.44337	63.54779	69.83378

FOR MID-HILL

Household no.	B.A (m^2/ha)	TTV (m^3/ha)	AGB (t/ha)	BGB (t/ha)	Total biomass (t/ha)	Carbon stock in Biomass(t C/ha)	soil bulk density (g/cm^3)	soil carbon stock (t C/ha)	total carbon stock (t C/ha)
1	3.266513	13.44035	9.526576	1.428986	10.95556	5.149115	0.992123	69.24992	74.39903
2	2.884409	16.481	14.11134	2.116701	16.22804	7.627179	1.062591	64.21019	71.83737
3	4.865061	21.18395	16.12667	2.419	18.54567	8.716463	1.086082	77.71671	86.43317
4	4.928167	31.08878	20.12943	3.019415	23.14885	10.87996	1.083345	71.80983	82.68979
5	5.533192	23.28449	15.87473	2.381209	18.25594	8.580291	1.025644	73.99264	82.57293
6	1.753157	5.232086	3.504819	0.525723	4.030542	1.894355	1.028561	71.79325	73.6876
7	5.502183	15.50626	10.08075	1.512112	11.59286	5.448644	1.170611	76.22294	81.67159
8	1.040843	3.056107	2.50204	0.375306	2.877346	1.352353	1.152111	70.96935	72.3217
9	1.157646	6.378965	3.954942	0.593241	4.548183	2.137646	1.221086	79.50956	81.64721
10	0.154609	0.595685	0.632371	0.094856	0.727227	0.341796	1.12489	58.75035	59.09215
11	4.3048	25.4061	21.38337	3.207506	24.59088	11.55771	0.965069	48.1422	59.69992
12	3.596832	10.21192	7.597369	1.139605	8.736974	4.106378	0.966655	53.88336	57.98973
13	2.913712	8.009774	5.030281	0.754542	5.784824	2.718867	1.219154	88.66713	91.386
14	2.613171	9.570605	6.614656	0.992198	7.606855	3.575222	0.940166	61.76851	65.34373
15	3.081337	11.21774	9.465405	1.419811	10.88522	5.116051	0.993345	72.24436	77.36042
16	4.999161	29.79544	22.42021	3.363032	25.78324	12.11812	0.92645	53.27022	65.38835
17	3.682814	10.81565	7.499598	1.12494	8.624537	4.053533	0.94111	57.97166	62.02519
18	2.704477	10.35062	8.583236	1.287485	9.870721	4.639239	1.037429	47.49822	52.13746
19	2.060798	5.089288	3.268248	0.490237	3.758485	1.766488	1.224686	89.06946	90.83595
20	3.01902	8.113556	5.868152	0.880223	6.748375	3.171736	1.134521	81.18285	84.35459
21	3.200646	7.828637	4.741865	0.754041	5.495906	2.71706	1.064483	76.1711	78.88816
22	5.487704	28.83014	24.50471	3.675706	28.18042	13.2448	1.166804	70.50758	83.75237
23	9.619293	74.50005	55.71217	8.356826	64.069	30.11243	1.232227	67.96514	98.07756
24	2.179516	7.171696	3.63114	0.544671	4.175811	1.962631	1.123162	69.84397	71.8066
25	4.369139	15.9888	10.52192	1.578288	12.10021	5.687097	1.194519	72.88197	78.56907
26	5.985189	37.4912	28.8268	4.324019	33.15082	15.58088	1.029114	60.98164	76.56253
27	7.812545	40.1942	24.0405	3.606076	27.64658	12.99389	1.331897	86.72488	99.71878
28	3.416784	11.63407	6.822544	1.023382	7.845926	3.687585	1.23763	63.91357	67.60116
29	1.270793	3.337385	3.412321	0.511848	3.924169	1.844359	1.072521	54.75882	56.60318
30	2.018991	6.070024	4.57249	0.685873	5.258363	2.471431	1.179	62.26699	64.73842

MID-HILL CONTD….

Household no.	B.A (m^2/ha)	TTV (m^3/ha)	AGB (t/ha)	BGB (t/ha)	Total biomass (t/ha)	Carbon stock in Biomass(t C/ha)	soil bulk density (g/cm^3)	soil carbon stock (t C/ha)	total carbon stock (t C/ha)
31	1.28101	3.674128	2.891081	0.433662	3.324743	1.562629	0.900905	50.2183	51.78093
32	1.231154	4.466291	1.455869	0.21838	1.674249	0.786897	1.154187	66.3649	67.1518
33	3.19966	9.521253	7.093467	1.06402	8.157487	3.834019	1.2578	70.84911	74.68313
34	1.716674	5.673528	4.006923	0.601038	4.607961	2.165742	1.025342	67.36455	69.53029
35	1.602295	3.9693	2.388354	0.358253	2.746608	1.290906	1.065979	63.16618	64.45709
36	0.596547	1.866493	2.066051	0.309908	2.375959	1.116701	1.050406	67.16543	68.28213
37	3.458986	13.54774	8.488533	1.27328	9.761813	4.588052	1.031724	66.57519	71.16324
38	2.211266	12.46962	5.889026	0.883354	6.77238	3.183019	1.132612	69.10481	72.28783
39	2.671347	12.6916	6.734648	1.010197	7.744845	3.640077	0.875069	63.12979	66.76987
40	0.569924	1.628592	1.44151	0.216226	1.657736	0.779136	0.960942	68.19917	68.97831
41	2.886892	10.91239	9.460446	1.419067	10.87951	5.113371	0.947059	67.76861	72.88198
42	3.063391	11.5305	7.355419	1.103313	8.458732	3.975604	1.134048	77.82775	81.80335
43	2.87506	9.865072	7.87256	1.180884	9.053444	4.255119	1.218971	85.08385	89.33897
44	3.771754	13.42249	10.78174	1.617261	12.399	5.827529	1.045548	65.01756	70.84509
45	3.412642	11.35284	5.45783	0.818675	6.276505	2.949957	1.069416	70.88655	73.8365
46	2.969719	8.773352	6.478293	0.971744	7.450037	3.501517	1.017934	69.26275	72.76427
47	3.508287	11.0264	8.518056	1.277708	9.795765	4.604009	1.045862	63.1993	67.80331
48	1.614916	5.428013	3.471426	0.520714	3.99214	1.876306	1.172818	72.93186	74.80816
49	4.840016	21.50898	16.14709	2.422063	18.56915	8.727502	0.853345	50.56621	59.29371
50	1.725154	7.51	6.235285	0.935293	7.170577	3.370171	0.929086	51.78917	55.15934

ANNEX III

Mean ± S.E values of B.A, TTV, AGB, BGB, Total biomass, Carbon stock in biomass, Soil carbon stock and Total carbon stock of total households and two regions

	Terai	Mid-hill	All households
B.A (m^2/ha)	4.7882 ± 0.58217	3.172 ± 0.257	3.7784 ± 0.28294
TTV (m^3/ha)	23.955 ± 3.61994	13.5743 ± 1.7829	17.4673 ± 1.8319
AGB (t/ha)	18.9732 ± 2.7499	9.7039 ± 1.33155	13.1799 ± 1.4082
BGB (t/ha)	2.7457 ± 0.42116	1.4564 ± 0.19967	1.9399 ± 0.21167
Total biomass (t/ha)	21.0502 ± 3.2288	11.1603 ±1.5312	14.869 ± 1.62304
Carbon stock in Biomass(t C/ha)	10.255 ± 1.48637	5.248 ± 0.71948	7.1256 ± 0.76103
Soil carbon stock (t C/ha)	61.1786 ± 2.8862	67.6082 ± 1.4314	65.1971± 1.4365
Total carbon stock (t C/ha)	71.4336 ± 3.3568	72.8562 ± 1.5695	72.3227 ± 1.5849