CARBON SEQUESTRATION ESTIMATES OF VARIOUS LAND USES IN TERAI ZONE OF WEST BENGAL

A Thesis submitted
in partial fulfillment of the requirements
for the Degree of

MASTER OF SCIENCE
IN
FORESTRY

By

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CERTIFICATE- I

This is to certify that the work recorded in the thesis entitled **"Carbon sequestration estimates of various land uses in Terai Zone of West Bengal"** submitted by **MR.DIVY NINAD KOUL** (H-2004-24-M) in partial fulfillment of the requirements for the degree of Master of Science in Forestry of the Uttar Banga Krishi Viswavidyalaya, is the faithful and bonafide research work carried out under my personal supervision and guidance. The results of the investigation reported in the thesis have not so far been submitted for any other degree or diploma. The assistance and help received from various sources during the course of investigation have been duly acknowledged.

Place : Cooch Behar
Date : 14.6.06

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CERTIFICATE –II

APPROVAL OF EXAMINERS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN FORESTRY

We, the under signed, having been satisfied with the performance of MR.DIVY NINAD KOUL (H-2004-24-M) in the post- submission seminar on final Evaluation of thesis entitled **"Carbon sequestration estimates of various land uses in Terai Zone of West Bengal"** conducted today, the 14.8........ 2006, recommended that the thesis be accepted for the award of the degree of Master of Science in Forestry.

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(DIVY NINAD KOUL)

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ACRONYMS, SYMBOLS, AND ABBREVIATIONS USED

C – Carbon

GHG – Green House Gas

GIS – Geographic Information System

GNP – Gross Net Product

Gt –Gigatonnes or10^9 tonnes

ha – Hectare

IPCC – Intergovernmental Panel on Climate Change

IUCN – International Union for the Conservation of Nature

Kg/ha – Kilograms/hactare

MCS – Mean Carbon Storage

m ha – Million Hectares

Mg – Megagram=10^6 g=1 ton

Pg – Pentagram (10^{12} grams) 1Pg = 1Gt

SOC – Soil Organic Carbon

t ha^{-1} – tons per hectare

UNFCCC – United Nations Framework Convention on Climate Change

WRI – World Resources Institute

Yr – Year

$ tC^{-1} – U.S. Dollars per ton of Carbon

°C – Degrees Celsius

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CHAPTER- 1

INTRODUCTION

INTRODUCTION

United Nations Framework Convention on Climate Change defines climate change as "A change in climate which is attributed directly or indirectly to human activity that alter the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods."

Over the past 1,000 years, the global mean surface temperature has remained relatively stable. During this time, changes in climate have been less than 1°C (IPCC, 1996). Because of the climate's predictability, societies have developed a fairly rigid reliance upon climatic conditions for everything from food to inhabitable lands. It can therefore, be assumed that changes in climatic conditions associated with increased atmospheric Carbon (C) will be very costly, both socially and economically. There is considerable debate regarding the magnitude of change associated with elevated C levels in the atmosphere. The relationship between CO_2 in the atmosphere and increased temperature is fairly well understood. CO_2 absorbs infrared radiation emitted from the earth's surface, trapping heat that would otherwise have escaped out of the atmosphere. The more CO_2 present in the atmosphere, the more infrared radiation will be trapped. CO_2 and other gases that absorb infrared radiation are referred to as greenhouse gases (GHGs) because they act in a manner similar to the glass of a greenhouse. CO_2, Water Vapours, CO, O_3, Chlorofluorocarbons, N_2O, and CH_4 are GHGs and atmospheric concentrations of these compounds are increasing as a function of human development. There is no doubt that the cumulative effect of increasing GHGs causes increase in temperature. However, human development has also dramatically increased the amount of tropospheric aerosols, particularly sulfate aerosols, which function as reflectors of incoming solar radiation (Jager and Barry, 1990). In addition to their reflective characteristics, aerosols contribute to cloud formation. Increasing the potential for cloud formation will not only increase the albedo of the planet, but will also modify precipitation patterns and the atmospheric water vapour content (Charlson *et al.* 1992; Jager and Barry, 1990). Soil disturbance associated with agricultural practices has also increased the amount of particulate matter in the atmosphere which has a similar effect as that of aerosols.

Most climate models that account for both greenhouse gases and aerosols suggest substantial warming of the atmosphere ($1^{0}C$ to $5.5^{0}C$) through the next century (Houghton *et al.*, 1990; IPCC, 1996). These projected global temperature changes exceed recent natural fluctuations derived from geological evidence, and occur at the highest rate recorded since the end of the last ice age over 10,000 years ago (IPCC, 1996). As a result of these rapid change in climate, reduction in agriculture production, variation in rainfall, collapse of civilization, rise in sea level, receding of glaciers, shrinkage of forest cover, increase in diseases and insect pests, shift of species towards pole etc. had been reported (Bhardwaj and Panwar, 2003). Different ways of mitigating and/or reducing negative effect of climate change has been suggested by various agencies, of which sequestering carbon through vegetation have been recommended as a suitable and efficient way to reduce carbon in the atmosphere. As per the Kyoto protocol of 1997, the industrialized countries are expected to reduce the GHG emissions by 5.5 per cent by 2008-2012 over 1990 levels. Such countries are expected to buy carbon credits from developing countries under the Clean Development Mechanism (CDM) (Gera *et al.*, 2003).

Carbon sequestration refers to the removal of carbon, as CO_2, from the atmosphere through photosynthesis and dissolution, and the storage of C in soil as organic matter or secondary carbonates (Lal, 2001). Terrestrially, carbon is stored in vegetation and in the soil. Plants store carbon for as long as they live, in terms of live biomass. Once they die, the biomass becomes a part of the food chain and eventually enters the soil as soil carbon. If the biomass is incinerated, the carbon is re-emitted into the atmosphere and is free to move in the carbon cycle. 99.9% of the C present in the world's biota is represented by vegetation; animals are a negligible C reservoir. Fossil fuel reserves such as coal, oil and gas are estimated to contain about 5,000 Gt of C, representing the second largest reservoir on earth (Houghton and Skole, 1990). Dissolved inorganic C in the ocean is the largest near-surface pool

(38,000 Gt), and is more than 50 times greater than the atmospheric C pool (Keller, 1996; Schlesinger, 1997).

The role of forests in carbon sequestration is probably best understood and appears to offer the greatest near-term potential for human management as a sink in terrestrial ecosystem. Unlike many plants and most crops, which have short lives or release much of their carbon at the end of each season, forest biomass accumulates carbon over decades and centuries. Furthermore, carbon accumulation potential in forests is large enough that forests offer the possibility of sequestering significant amounts of additional carbon in relatively short periods. Simultaneously, forests managed for timber, wildlife or recreation sequesters carbon as a byproduct. Forests may also be managed strictly to sequester carbon. If forests managed for carbon sequestration are allowed to mature and remain unharvested, one of the long-term effects may be enhanced biodiversity. There are four components of carbon storage in a forest ecosystem. These are trees, plants growing on the forest floor (under-storey material), detritus such as leaf litter and other decaying matter on the forest floor, and forest soils.

Current terrestrial (plant and soil) carbon is estimated at 2000 ± 500 Pg, which represents 25 per cent of global carbon stock. The sink option for CO_2 mitigation is based on the assumption that this figure can be significantly increased if various biomes are judiciously managed and / or manipulated. Among these the carbon sequestration potential of three biomes viz. agricultural lands, biomass croplands and deserts and degraded lands has been estimated as 0.85-0.90,0.50-0.80 and 0.80-1.30 Pg/year respectively (that might be sustained for a period of 25-50 years) (DOE, 1999). The carbon sequestration potential of tropical Agroforestry systems is estimated between 12 and 228 Mg/ha with a median value of 95 Mg/ha. Therefore, based on earth's area that is suitable for practice (585-1215 X 10^6 ha), 1.1-2.2 Pg C could be stored in the terrestrial ecosystems over the next 50 years (Alberecht and Kandji, 2003). It is estimated that as much as 90% of the world's terrestrial C is stored in forests (Houghton, 1996b). These forests account for 3.6 billion hectares, or

28% or the land area. If the definition of forests incorporates lands such as forest fallows, and shrubland, then this number climbs to 5.3 billion hectares, or 40% of the world's land area (Sharma *et al.*, 1992). Trees are important sinks for atmospheric carbon i.e. carbon dioxide, since 50% of their standing biomass is carbon itself (Ravindranath *et al.* 1997). IPCC (1996) estimated that forestry practices could sequester between 12-15% of all fossil fuel C emissions in the period of time between 1995 and 2050. This estimate was based on the preservation of 138 Mha of land slated for deforestation, regeneration of natural forests on 217 Mha in the tropics, and the implementation of a global forestation program consisting of agroforestry and plantation practices on 345 Mha of suitable lands. The result of these aggressive forestry efforts would yield storage of between 60 and 87 Gt of C over a 55- year period. This equates to storage of between 1 and 1.6 Gt of C per year over the 55- years, although this storage would not occur proportionately each year. According to Ravindranath *et al.* (1997) the standing biomass (as above and below ground biomass) in India is estimated to be 8,375 million tons for the year 1986, of which the carbon storage would be 4,178 million tones. The total carbon stored in forests, including soil is estimated to be 9578 m t.

Furthermore, in many instances forestry practices have a beneficial impact on local economies. This is especially true in developing regions where forested areas continue to decline rapidly (Houghton, 1996b; Trexler and Haugen, 1994). Finally, many studies have indicated that the costs associated with sequestration of C are quite modest (Sedjo, 1996; Dixon *et al.*, 1993; Houghton *et al.*, 1991).

Worldwide, Soil Organic Carbon (SOC) in the top 1 meter of soil comprises about 3/4 of the earth's terrestrial carbon; nevertheless, there is tremendous potential to sequester additional carbon in soil. The soils of the earth are estimated to contain between 1,400 and 1,700 Gt of C (Houghten and Skole, 1990). Soil accumulated greater amount of carbon as compared to forest litter as the target quantities of C is stored for longer period of time in the soil then in live component of terrestrial ecosystem (Schlesirger, 1997).

Carbon sequestration potential varies with the species under consideration, the kind of land use, climate of the region, soil conditions, biotic pressure and degree of land use management. Extrapolating the carbon sequestered at one study site with a particular set of above mentioned parameters to another region may lead to erroneous results. Hence, there is a need to study site specific land use potentials with regards to sequestering carbon. This will allow us to generate authentic data and accordingly projects related to carbon credits can be framed for upliftment of rural economy. It is in this context that the present study entitled "Carbon sequestration estimates of various land uses in Terai Zone of West Bengal" was planned with the **following objectives**:

- To study the amount of carbon stored in above ground biomass in different land uses.
- To evaluate carbon sequestered in soil under different land uses.

CHAPTER- 2

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Carbon sequestration through forestry has the potential to play a significant role in ameliorating global environmental problems such as atmospheric accumulation of GHGs and climate change. Unlike other alternatives, forestry has social and economic benefits, ranging from maintenance of biodiversity and endangered habitats, to providing sources of sustainably harvested forest products or employment for forest communities. The present study entitled "Carbon sequestration estimates of various land uses in Terai Zone of West Bengal" was carried out to judge the capacity of different land uses with regards to capturing the carbon from the atmosphere. In the present chapter attempt has been made to collect the results of similar studies carried out elsewhere in order to provide sound explanation for the results obtained under the present study under following heads:

2.1 Carbon sequestration in above ground biomass
2.2 Soil Physico-chemical properties
2.3 Carbon sequestration in soil
2.4 Land use and carbon sequestration
2.5 Carbon sequestration economics

2.1 Carbon sequestration in above ground biomass

Carbon storage in two thicket restoration sites was investigated to determine potential rates of carbon sequestration. At the farm Krompoort, near Kirkwood, 11 kg C/m^2 was sequestered over 27 years (average rate of 0.42 ± 0.08 kg C m^{-2} yr^{-1}). In the Andries Vosloo Kudu Nature Reserve, near Grahamstown, approximately 2.5 kg C/m^2 was sequestered over 20 years (0.12 ± 0.03 kg C m^{-2} yr^{-1}). Slower sequestration in the Kudu Reserve was ascribed to browsing by black rhinoceros and other herbivores, a shallower soil and greater stone volumes. Planting density and *P.*

afra genotype appeared to affect sequestration at Krompoort (Mills and Cowling, 2006).

The changes in under storey biomass, forest floor carbon (C) stock and vegetation composition were studied in six age-classes of Siberian larch (*Larix sibirica*) and two age-classes of native birch (*Betula pubescens*) in Iceland. The ground vegetation was less in the larch during the thicket stage and in the old-growth birch compared to a treeless pasture. Under storey biomass was strongly related to canopy gap fraction across forest stands ($P<0.001$), but not to soil pH or soil C: N ratio. Increased mass of dead wood and alterations in vegetation composition increased the forest floor C-stock of older forests (Sigurdsson *et al.*, 2005)

Density, storage and spatial distribution of carbon in *Phyllostachys pubescens* forest were studied by means of sample plot. Carbon density of different bamboo organ ranged from 0.4683 to 0.5210 g g-1, which was in the order: root > trunk > underground trunk > branch > underground stem > leaf. The organ distribution of carbon storage was 50.97 per cent for trunk, 19.79 per cent for root and 4.87 per cent for leaf (Zhou and Jiang, 2004).

A study was carried out in the Forest Research Institute Campus in Dehra Dun, Uttar Pradesh, India, to estimate the carbon content of some important tree species. *Pinus roxburghii* stored the highest amount of carbon followed by *Pterospermum acerifolium*, *Syzygium cumini* and *Tectona grandis*. The carbon storing efficiency of some species like *P. roxburghii*, *Shorea robusta* and *Syzygium cumini* decreased with increasing concentration of CO2, indicating that the biota is currently releasing additional carbon to the atmosphere rather than storing carbon (Dhand *et al.*, 2003). Carbon in the form of vegetation biomass ranged from 1.96 to 2.83 t ha^{-1} in Gujarat and 0.24 to 1.73 t ha^{-1} in Rajasthan. (Singh *et al.*, 2003).

The carbon content of 54 plant species was estimated by two methods, first by ash content method and secondly by regression equation derived between carbon and Ca content. On the average, the carbon content in different parts of various species depends on the ash content and the ash content depends on the amount of structural components. The more the structural tissue, the higher the ash content and lower will be the carbon content. Thus, ash and Ca content showed decreasing trend: bark < leaf < wood, whereas the carbon content showed an increasing trend: bark > leaf > wood. These observations revealed that the wood, which constitutes maximum portion of total biomass, stored maximum amount of carbon. While comparing the different life forms, it was observed that the maximum carbon was stored in the order: conifers > deciduous > evergreen > bamboos. Therefore, it can be said that the conifers are more efficient in carbon sequestration (Negi *et al.*, 2003)

A case study in Pilibhit District (Uttar Pradesh, India) was carried out to judge the potential of farm forestry to sequester CO_2. Medium farmers grow more trees on their lands as compared to other categories (small and large landholders). Usually, eucalypts, poplar, teak, kadam (*Eucalyptus spp.*, *Populus spp.*, *Tectona grandis* and *Anthocephalus chinensis*, respectively) are being planted. It was estimated that total biomass production is likely to be 32 800 t/year and the stored carbon 16 400 t/year. Thus, farm forestry holds tremendous potential for sequestering and storing carbon (Singh, 2003)

Stand biomass ranged from 3.94 (1-year old) to 53.67 Mg ha^{-1} (6-year old) and stand carbon in 6-year old plantations ranged from 24.12 to 31.12 Mg ha^{-1} at different sites. Among the tree components, the stem wood accounted for maximum C (56.25 per cent at site 1) followed by branches (19.8 per cent at site 3), roots (18.51 per cent at site 2) and foliage (7.01 per cent at site 3) (Swamy *et al.*, 2003).

Bhadwal and Singh (2002) did a comparative estimate of land-use and carbon sequestration potential of different forestry options in India using Land Use and Carbon Sequestration (LUCS) model. It estimates the amount of carbon sequestered by approximating land-use and relative biomass changes in the landscape over time. They found that the carbon sequestered in above ground vegetation of India will be more than double by the year 2050.

Ability of forest, trees and other vegetation as terrestrial carbon sinks to absorb CO_2 emissions and mitigate the climate change, has attracted wide attention. Currently, total above ground biomass in the world's forests is 421 $X10^6$ tonnes distributed over 3869 M ha. Of this, 3682 X 10^6 ha or 95 per cent is natural forest and 187 X 10^6 or 5 per cent is plantation area. On an average, forests contain 1.00 m^3/ha wood volume and 109 t/ha wood biomass. Forests store 1200 Gt carbon in vegetation and soil globally. Carbon in forests constitutes 54 per cent of the total carbon pool in terrestrial ecosystem (FAO 2001 report).

Haripriya (2001) estimated that if the entire area of feasible land of India is used for forestry, the mean estimate of carbon sequestered by natural forests along with newly afforested plantations is around 153 Tg (teragrams) carbon per year by 2030, equivalent to the 1990 fossil fuel emissions of India.

The carbon pool for the Indian forests is estimated to be 2026.72 Mt for the year 1995. Estimates of annual carbon uptake increment suggest that Indian forests and plantations have been able to remove at least 0.125 Gt of CO_2 from the atmosphere in the year 1995. Assuming that the present forest cover in the country will sustain itself with a marginal annual increase by 0.5 Mha in area of plantations, it is expected that the Indian forests will continue to act as a net carbon sink in the future (Lal and Singh, 2000).

Carbon is accumulating in the atmosphere at a rate of 03.5 Gt ($10^{15)}$ per annum as a result of fossil fuel combustion and tropical deforestation (Rosenberg, 1999). Presently the global biomass carbon pool has been estimated at about 385Gt C (Prentice *et al.*, 2000). According to Singh and Lal (2000), further mitigation of about 3.32 Gt in the next 50 years at an annual reduction of about 0.072 Gt of carbon is possible through plantation.

The estimates of net release of carbon at global level are highly uncertain because of difficulty in obtaining reliable data, ranging from 0.4 – 1.6 G t of C per year (Detwiler and Hall, 1998) to 1.1 – 3.6 G t C per year (Houghton, 1990). The net annual carbon emission estimates for India vary from 0.672 Tg (Pachauri *et al.*, 1992) to 41 Tg (Houghton, 1990) where Tg is equal to 10^{12} g. Drawing CO_2 out of air and sequestering it into biomass is the only known practical way to remove large volume of greenhouse gases from the atmosphere (WRI, 1998).

The concentration of atmospheric CO_2 has increased by 25 per cent since pre industrial era (IPCC, 1992). It was observed that level of atmospheric CO_2 has recorded an increase from ~ 280 ppmv in 1800 to ~ 315 ppmv in 1957 to ~ 356 ppmv in 1993 (Schimel, 1994). Three quarters of this added CO_2 has come from burning fossil fuels and roughly a quarter from destruction of tropical rain forests (Panos media briefing, 1996).Every hectare of actively growing forest sequesters between 2 and 5 tonnes of carbon per year (Brown *et al.*, 1996)

According to Flint and Richards (1994), carbon storage in the vegetation in India from the year 1880 onwards shows a decreasing trend. Carbon storage in vegetation in India was 8.6 bt in year 1880,7 bt in year 1920,6.39 bt in 1950, 5.23 bt in 1970 and 4.39 bt in 1980.

There are approximately 10^{23} grams of carbon (C) on earth. The majority of this C is held within sedimentary rocks. There are about 40×10^{18} grams of C in the active pools near the Earth's surface (Schlesinger, 1977). There are 750 Gt of C in the atmosphere, the majority of which is in the form of carbon dioxide (CO2). A slightly smaller amount (560 Gt) is contained in the living biomass of the terrestrial biosphere. (Houghten and Skole, 1990).

2.2. Soil Physico-chemical properties

Chavan *et al.* (1995) and Contractor and Badnur (1996) have reported low soil pH under forest plantation. In Assam soils, distribution of pH in profiles ranged from the surface downwards from 6.0 to 8.0 in the soils near the Brahmaputra river, 4.4 to

7.5 in old flood plains and 4.8 to 6.4 in upland soils near the hills (Chakravarty and Barthakur, 1997). This shows that though the surface soil of old flood plain and old uplands are very strongly acidic due to heavy leaching, these are near to the neutral range in lower horizon. The higher pH in the lower horizons of these soils may be owing to impeded drainage for low-lying positions and / or incomplete leaching due to impermeable layer.

Gupta *et al.*, (2001) reported that organic carbon, N and C: N ratio values were lowest in barren land and highest in those of forest, cultivated unmanaged and cultivated well managed soil groups had intermediate values. The values were higher in cultivated well-managed land in comparison to cultivated unmanaged land. The values of organic carbon, total N and C: N ratio was higher in the surface soils in comparison to sub-surface soils. The findings are supported by positive and significant relationship of total N and organic matter with organic carbon.

2.3 Carbon sequestration in soil

Afforestation can increase soil organic carbon (SOC) storage, but the selection of tree species may be critical. This study explored soil CO_2 production and effluxes in relation to SOC contents in temperate forests in northern New Zealand. Sites included even-aged (38 years) first generation stands of eight coniferous and two deciduous species planted at three sites along a gradient in soil fertility. SOC stocks (forest floor + mineral soil 0-50 cm) differed significantly between tree species, but soil type influenced SOC stocks the most. SOC stocks were significantly higher for stands on low-fertility sandy soils than stands on fertile loamy soils. Results suggest that selection of soil type and tree species are important for SOC sequestration in future afforestation projects (Ladegaard *et al.*, 2005)

The soil organic carbon (SOC) pool is estimated at 21 Pg to 30 cm depth and 63 Pg to 150 cm depth. The soil inorganic carbon (SIC) pool is estimated at 196 Pg to 1m depth. The SOC concentration in most cultivated soils is less than 5 g/kg compared with 15 to 20 g/kg in uncultivated soils. Low SOC concentration is attributed to plowing, removal of crop residue and other biosolids, and mining of soil fertility. Accelerated soil erosion by water leads to emission of 6 Tg C/y. Potential of soil C sequestration in India is estimated at 7 to 10 Tg C/y for restoration of degraded soils and ecosystems, 5 to 7 Tg C/y for erosion control, 6 to 7 Tg C/y for adoption of RMPs on agricultural soils, and 22 to 26 Tg C/y for secondary carbonates. Thus, total potential of soil C sequestration is 39 to 49 (44±5) Tg C/y (Lal, 2004)

Alternative land management practices, including agroforestry, help to maintain levels of soil organic matter (SOM) and can facilitate soil carbon (C) sequestration for mitigating atmospheric CO_2 emissions. This study quantified C inputs and determined the changes of the soil C pool in a 19-year-old *Gliricidia sepium* alley cropping system, studied at two fertilizer levels The soil organic C (SOC) pool in the alley crop was 16-23 per cent higher than the sole crop (Oelbermann *et al.*, 2004).

The carbon sink capacity of the world's agricultural and degraded soils is 50 to 66 per cent of the historic carbon loss of 42 to 78 gigatonnes of carbon. An increase of 1 tonne of soil carbon pool of degraded cropland soils may increase crop yield by 20 to 40 kg/ha for wheat, 10 to 20 kg/ha for maize, and 0.5 to 1 kg/ha for cowpeas. As well as enhancing food security, carbon sequestration has the potential to offset fossil-fuel emissions by 0.4 to 1.2 gigatonnes of carbon per year, or 5 to 15 percent of the global fossil-fuel emissions (Lal, 2004). Soil carbon was 3.60 to 6.38 t ha^{-1} compared to 1.13 to 5.18 t ha^{-1} in Rajasthan, being lowest in the sandy area of Mokal and Ramgarh (Singh *et al.*, 2003).

A total of 9815.95 million tonnes of Soil Organic Carbon (SOC) store was estimated in total forest soils (as per 1994 forest stands) under 19 species spread over 27 States and Union territories in India. Spruce forest soil has maximum SOC store (386.0 t/ha) while Khair has minimum (51.93 t/ha). In India, miscellaneous forests are spread over an area of 40.7316 million ha, and their soils have maximum

SOC store (6469.80 million tonnes) while in Hollong forest with an area of 0.0068 million ha, soils have the least SOC store (0.82 million tonnes). Among the Indian States, Arunachal Pradesh has maximum SOC store (1702.08 million tonnes) while Dadra & Nagar Haveli has minimum (2.42 million tonnes) SOC store. Arunachal Pradesh ranks first in India having 248.11 t/ha SOC store in the soils of the State. Soil conservation practices should be strengthened to conserve these natural resources so that carbon store may not deplete especially from hilly terrain (Jha *et al.*, 2003). Whereas, Chhabra *et al.*(2002) estimated the total soil organic C pool in Indian forests is 4.13 PgC in the top 50 cm and 6.81 PgC in the top 100 cm soil depth. The historic loss in forest soil organic C pool (1880-1981) in the top 100 cm soil depth has been estimated as 4.13 PgC. According to Gupta and Rao (1994) and more recently Rastogi *et al.* (2002), the amount of carbon stored in Indian soils is 23.4 – 27.1 Gt, which is 1.6-1.8 per cent of the carbon stored in the worlds soils.

Smith and Johnson (2003) evaluated whether changing the type of plant input to soils alter soil organic carbon (SOC) distribution or soil carbon (C) storage? The answer is critical because woody encroachment may alter C cycling over millions of hectares in the Great Plains and Midwest. In spite of fast dynamics of soil C turnover, there was no net change in SOC amounts over 40-60 years (cumulative mineral and organic SOC in forest, 8782 g C/m^2 ± 810; in grassland, 7699 ± 1004). Thus as junipers expand into mesic areas of the Great Plains, juniper forests will provide little additional soil C storage.

Rhoades *et al.* (2000) estimated the loss of forest-derived soil C (light in 13C) and the accumulation of C from replicate sugarcane and pasture vegetation (heavy in 13C) using a stable C isotope technique. They also measured differences in the proportion of soil C derived from C3 and C4 plants across a land-use progression from agricultural fields through successional communities and undisturbed forest. Total soil C was 23 t/ha lower in the upper 30 cm following 50 year of sugarcane production (24 percent decrease) compared to old-growth forest. The net change (-0.4 t ha^{-1} year^{-1}) in soil C consisted of 1.3 t/ha annual losses of original forest C and

0.9 t/ha annual gains of C from sugarcane. After 15 years beneath pasture, soil C was 11 t/ha less in the upper 30 cm than beneath forest (12 percent decrease).

Global warming, atmospheric deposition and increase in atmospheric CO_2 concentration are the primary atmospheric factors which may have impact on forest soils (Josline and Johnson, 1997). The soils of the earth are estimated to contain between 1,400 and 1,700 Gt of C (Houghten and Skole, 1990). Soil accumulated greater amount of carbon as compared to forest litter as the target quantities of C is stored for longer period of time in the soil then in live component of terrestrial ecosystem (Schlesirger, 1977). Das (1975) & Banerjee *et al.*(1986) have reported 40.2 t/ha to 79.2 t/ha soil carbon in the top 30 cm soil of tropical moist deciduous forests of India.

2.4 Land use and carbon sequestration

Intensified agricultural practices lead to reduction in ecosystem carbon stocks, mainly due to removal of aboveground biomass as harvest and loss of carbon as CO_2 through burning and/or decomposition. In the humid tropics, the potential of agroforestry (tree-based) systems to sequester C in vegetation can be over 70 Mg C ha^{-1}, and up to 25 Mg ha^{-1} in the top 20 cm of soil. In degraded soils of the sub-humid tropics, improved fallow agroforestry practices have been found to increase top soil C stocks up to 1.6 Mg C ha^{-1} y^{-1} above continuous maize cropping (Mutuo *et al.*, 2005).

A study was conducted to determine biomass production, C sequestration and nitrogen allocation in *Gmelina arborea* planted as sole and agrisilviculture system on abandoned agricultural land. The comparative study was conducted at the Forestry Research Farm of Indira Gandhi Agricultural University, Raipur, Chhattisgarh, India. Total C storage in abandoned agricultural land before planting was 26.3 Mg ha^{-1}, which increased to 33.7 and 45.8 Mg ha^{-1} after 5 years in plantation and agrisilviculture system, respectively. The studies suggest that competitive interactions played a significant role in agrisilviculture system. Plantations were more efficient in sequestering C than agrisilviculture system on abandoned agricultural land (Swamy and Puri, 2005).

Average carbon storage by agroforestry practices has been estimated as 9, 21, 50, and 63 Mg C ha-1 in semiarid, subhumid, humid, and temperate regions respectively. For smallholder agroforestry systems in the tropics, potential C sequestration rates range from 1.5 to 3.5 Mg C ha^{-1} yr^{-1}. Agroforestry can also have an indirect effect on C sequestration when it helps decrease pressure on natural forests, which are the largest sink of terrestrial C. Agroforestry systems with perennial crops may be important carbon sinks, while intensively managed agroforestry systems with annual crops are more similar to conventional agriculture (Montagnini and Nair, 2004).

The study of communities of pure Pine, Pine – Michelia, mixed Pine and pure *Cinnamomum camphora* community shows that the carbon content and organic carbon percentage was higher in Pine – Michelia and mixed Pine communities than in pure pine and pure *Cinnamomum camphora* communities. Therefore, it may be concluded that pine plantation mixed with broad leaved species is beneficial in carbon stock as well as organic carbon percent (Chauhan *et al.*, 2004).

Total carbon pool (million tonnes) in standing crop was 363.01 for dense (cover >40 percent and above) and 80.30 for open-forests (cover <40 percent). The contribution of litter and soil carbon was 9.425 and 167.83 million tonnes, respectively in natural forests of Madhya Pradesh (Pande, 2003).

Raizada *et al.* (2003) reported that plantations of short rotation tree species with regular leaf shedding patterns have more C sequestering capacity than species with unimodal or bimodal leaf shedding patterns.

Forests act as carbon sinks. Therefore, farm forestry can be immensely useful for CO_2 sequestration. Usually, Eucalyptus, Popular, Teak, Kadamb are being planted. It is estimated that total biomass production is likely to be 32,800 tonnes / year and the stored carbon 16,400 tonnes / year. Thus farm forestry hold tremendous potential for sequestering and storing carbon (Singh, 2003).

A study was conducted in the surroundings of Wondo Genet College of Forestry in Ethiopia during May and June 2002 to examine the effect of land use change on carbon and nitrogen storage in soils. Two different land uses were studied: a Eucalyptus forest plantation and a farmland under maize production. It was shown that Eucalyptus on set-aside farmland had significantly higher soil carbon concentrations at 10 and 60 cm depth. Planting Eucalyptus on set-aside farmland also showed a significant increase in the total organic nitrogen concentration at 50 and 70 cm depth. However, Eucalyptus plantation on set-aside farmland did not significantly increase the C : N ratios in any of the studied soil layers down to 70 cm. Eucalyptus plantation on set-aside farmland seems to only have a short-term effect as a carbon sink (Silfver, 2003)

The C sequestration potential of agroforestry systems is estimated between 12 and 228 Mg ha-1 with a median value of 95 Mg ha-1. Therefore, based on the earth's area that is suitable for the practice (585-1215x10^6 ha), 1.1-2.2 Pg C could be stored in the terrestrial ecosystems over the next 50 years (Albrecht and Kandji, 2003).

In a study in Japan, Fukuda et al (2003) found that sugi (*Cryptomaria japonica*) and hinoki (*Chamaecyparis obtuse*) plantations store 346 X 10^6 and 139.2 X 10^6 Mg of carbon with an area weighted mean of 76.81 and 58.01 Mg C ha^{-1} respectively.

According to Houghton and Tellus (1999), between 1850 and 1990 approximately 100 Gt C was released into the atmosphere as a result of land use changes.

Moura-Costa, (1996) estimated C sequestration over different time periods for various forest management methods in the tropics. Various approaches for such study were selected based upon extensive review of literature. He concluded that Plantation of fast growing species sequestered or conserved 100-200 t ha^{-1} carbon in 10-20 years (Freedman *et al* .,1992), Agroforestry sequestered 90-150 t ha^{-1} in 5-20 years (Faeth *et al* .,1994 ; Schroeder1993) and Silviculture also sequesters same amount of carbon as agroforestry but time frame is 30 years (Hoen and Solberg, 1994) . Maximum amount of carbon (300-400 t ha^{-1}) is sequestered in Rainforest conservation (IPCC, 1992).

Most of the terrestrial ecosystem (forests, grasslands, pasture, agriculture lands) have significant potentials to store carbon. The IPCC's second Assessment report (SAR) estimated the storage capacity until 2050 at 60-87 Gt C for forests (Brown,1996) and at 23-44 GtC for agriculture (Cole *et al* .,1996).This adds up to 90-130 Gt and is 1.8-2.6 Gt per year over 50 years. Agroforestry systems can sequester carbon at the time averaged rates of 0.2 to 3.1 t C /ha/yr though the rates can be as high as 10 t C /ha/yr. Deforestation in the tropics contributes over 1.0 Gt of C to the atmosphere each year (IPCC ,1996b).

The carbon content of plants on agricultural land is less than 5 per cent of a forest, while that of agricultural soil is typically 60 to 80 percent that of forest soil (Freedman and Keith, 1996). Changes in land use have resulted in a net flux of C to the atmosphere over the last 300 years, and it is estimated that in recent years, land conversion contributes about1.6 Gt of C to the atmosphere annually (IPCC 1996b).

Nilsson and Schopfhauser (1995) estimated the potential for C sequestration through a global afforestation program and found that significant C accumulation would take on the order of 40 to 50 years from the initiation of a global afforestation program, and that a maximum C fixation rate of 1.5 Gt of C annually would be reached about 60 years after the initiation of the program. One hundred years after the initiation of the project, 104 Gt of C would be sequestered.

Agroforestry has the potential to mitigate C emissions for two reasons. First, there is a great deal of land in the tropics currently being used for agricultural practices. Provided that region-specific economically viable practices can be discerned, the increasing use of Agroforestry through the next century could yield substantial increases to the biotic pool of C (Unruh *et al.*, 1993). Second, while the amount of C sequestered per unit area is low compared to natural forests, or even plantations, the wood produced is often used as an alternative fuel source to fossil fuels (Unruh *et al.*, 1993; Trexler and Haugen, 1994).

Winjum *et al.* (1992) estimated the amount of C sequestered per unit area for five major forestry practices: reforestation (artificial regeneration), afforestation (similar to reforestation, but done on land that has not supported forests for 50 years), natural regeneration, silviculture, and agroforestry. According to him, median tropical forest carbon ($tCha^{-1}$) was highest for Natural reforestation (119 $tCha^{-1}$) followed by agroforestry (95 $tCha^{-1}$), reforestation (65 $tCha^{-1}$), Silviculture (34 $tCha^{-1}$) and lastly afforestation (29 $tCha^{-1}$).

Forestry can play a major role towards increasing the global sequestration if the worlds forests could be managed properly with due importance to afforestation and reforestation. Winjum *et al.* (1992) were of the view that the most promising management practices for CO_2 mitigation are reforestation in the temperate latitudes, and agroforestry and natural reforestation in the tropics.

Houghton *et al.* (1991) considered three methods of forestry practices for C sequestration: plantations, agroforestry, and protection/regeneration. Potential sequestration of C (GtC) by region and management option based on all available land were estimated .In Latin America, carbon sequestration was maximum in agroforestry (16 GtC) followed by plantation (9 GtC)and protection (7 GtC).In Africa, plantation sequestered maximum amount of carbon(15 GtC) followed by agroforestry(6 GtC) and protection (3 GtC). In case of Asia, protection sequestered maximum C (7 GtC), followed by plantation (3 GtC) and agroforestry (1 GtC).

The study conducted by Brown (1988) shows that in Africa, Asia and Latin America carbon amounts to 187 tc /ha, 160 tc/ha and 155 tc/ha respectively in the Wet tropical forest and 63 tc/ha, 27 tc/ha and 27 tc/ha in Dry tropical forest respectively.

All ecosystems continuously emit and sequester CO_2 with the forests storing 20-100 tonnes more carbon per unit area than agricultural crops (Ehlarihgar & Bjorkman, 1977). Estimates of the potential for tropical plantations to sequester C range from 0.8 to 24 t $ha^{-1}yr^{-1}$ depending on location and the stand age (Vitousek, 1991).

Dixon *et al.* (1991a) conducted a study to develop estimates of the amount of land needed to sequester a given amount of carbon. A total of 570 million ha would be required to store 55 Gt of carbon over a 50 year period, distributed as 190 million ha in the humid tropics, 220 million ha in the dryland ecoregions, and 160 million ha in the humid temperate zones. At this level of sequestration, 24 Gt would be stored in humid tropics, 20 Gt would be stored in dryland ecoregions, and 11 Gt in the humid temperate zones.

2.5 Carbon sequestration economics

The average value of carbon sequestration is $2 per ton. The size of a program that compensates landowners for sequestering carbon in western Washington riparian forests is $230 million over a 50-year period. The projected carbon sequestered over the 50-year period is 110 million tons (Perez *et al.*, 2004)

The costs for moderate increases of carbon sequestration were rather low, with present values of 1-6 Euro/ton CO_2, and they depended on the amount of carbon sequestered, initial stand age, site, and growing stock characteristics. For mature stands, the present value of costs to sequester a given amount of carbon was considerably higher, exceeding 20 Euro/ton CO_2. This was due to the higher annual rate of carbon sequestration and the fact that all the additional sequestration had to be obtained by increasing the rotation length (Pohjola *et al.*, 2004)

Khajuria and Chauhan (2003) reported that a project to restore 10,000 ha of degraded community land in Handia Forest Range of Madhya Pradesh, India has been estimated to earn US$ 300,000.The sequestered carbon under the project can be sold as "Carbon Credits" at the global rate of US$16-20 per tonne. They further reported that in Punjab 15 percent of geographical area should be under forest trees that equals 7.5 lac hectares. If this forest will give $10m^3$ of increment per annum per hectare then 7, 50,000 m^3 wood will be added annually. This will fix approximately 1.5 million tonnes of carbon worth US$ 20-25 million and remove 2.5 million tonnes CO_2 from atmosphere. It has been observed that present rate for these carbon credits is about US$7 per tonne (Annon., 2002).

The value of carbon sequestered in forests is evaluated by cost that would be incurred in offsetting by alternative projects, the CO_2 released if the forest land were converted into alternate land use. Accounting for additional aboveground carbon stock only in the forestry, yields an annual flow of 433.12 US$ /ha. This reflects the immense economic and ecological value that the forests provide by storing carbon despite low productivity of Indian forests (Lal and Singh, 2003). Trees sequester CO_2 from the atmosphere and lock away carbon. This is a comparatively cost effective option for reducing the net emissions that has additional social, economic and ecological benefit (Pandey, 2002).

Sedjo (1989) observed that annual atmospheric increase of carbon is 2.9 Bt and to sequester this amount, 456 million ha new plantations required at a cost of US $ 372 billion.

CHAPTER- 3

MATERIALS AND METHODS

MATERIALS AND METHODS

The present study entitled "Carbon sequestration estimates of various land uses in Terai Zone of West Bengal" was conducted in the year 2004-2006. The details about experimental site, materials used and methodology adopted in conducting the study are given below:

3.1 Site description

3.1.1. Physiographic information of the Terai Zone

West Bengal is divided into six agro-climatic zones and Terai Zone is one of such zone located at northern fringe of this state at the foothills of the Himalayas and sub-Himalayan mountain belts. Districts Cooch Behar, Jalpaiguri, Siliguri Sub-Division of Darjeeling district and Islampur Sub-Division of North Dinajpur district falls under terai zone of West Bengal. A little over one-fifth of the state's geographical area is covered by the four Terai districts.

The terai zone lies between 26° 30' North and 26° 56' North latitude and 88° 7' East and 89° 53' East longitude. It covers an area of 12015 sq. km. and is administratively divided into 32 development blocks.

3.1.2. Land use pattern of the Terai Zone

The land use pattern of this region can be classified into five broad categories. About 50% of the land is net sown and 22% is under non-agricultural uses. Forests occupy a little over 14% mainly confined to the Jalpaiguri district and Siliguri sub-division of Darjeeling district. Orchards and plantation crops occupy about 9% of the land, tea being the most important commercial plantation crop, dominantly grown in the Jalpaiguri district. The area under barren land is about 4 percent and 1 percent falls under fallow and cultivable waste (Paul, 2004).

3.1.3. Location and Locality factors of Experimental site

The experiment site is situated at 26°19′86″ N latitude and 89°23′53″ E longitude and at an elevation of 43 meters above mean sea level. The Maximum temperature reaches upto 33^{0}C in the month of May. The Minimum temperature ranges from 5-7^{0}C in January. Average annual rainfall varies from 2100 to 3300 mm. About 80 per cent of the rainfall is received between June to October months. The terrain of the area is flat. Texture of the soil is sandy to silty loam, average organic matter content is 0.58 %. pH varies from 5.5 – 6.0, Total N content is 0.41 per cent; Available P – 23.58 kg/ha and Available K – 175.30 kg/ha. Bulk density of soil at 0-15 cm is 1.35 g/cc and at 15 – 30 cm is 1.37g/cc.

The climatic condition of terai zone is sub-tropical in nature. Based on the old system of classification the soils of the terai zone can be broadly classified into Teesta alluvium, terai and brown forest soils. However, according to the modern system of classification terai soils are association of Dystrochrepts and Haplaquepts of the order Inceptisols and Udifluvent / Udorthent / Ustorthent of the order Entisol (Paul, 2004).

3.2. EXPERIMENTAL METHODOLOGY

In the present study, a total of seven land uses were selected for estimating carbon sequestration potential. The land use chosen under the study are presented overleaf:

Experiment 1. Carbon sequestration potential of soil under different land uses

A) Land use description

Notation	Land use	Components of land use
L_1	Fallow land	Pure grass
L_2	Agriculture field	*Oryza sativa*
L_3	Tea Garden	*Camellia sinensis* + *Albizzia procera*
L_4	Agri-Horticulture Agroforestry System	*Mangifera indica* + *Amorphophallus campanulatus*
L_5	Pure Plantation of *Dalbergia sissoo*	*Dalbergia sisoo*
L_6	Pure Plantation of *Terminalia arjuna*	*Terminalia arjuna*
L_7	Natural Forest of *Shorea robusta*	*Shorea robusta* + Shrubs + Herbs + Grasses

B) Soil Depths (cm) Four

D_1	0-10
D_2	10-20
D_3	20-30
D_4	30-40

Replications: Three

Design : Split plot

Experiment 2. Carbon sequestration potential of above ground biomass

A) Land use description

Notation	Land use	Components of land use
L_1	Fallow land	Pure grass
L_2	Agriculture field	*Oryza sativa*
L_3	Tea Garden	*Camellia sinensis* + *Albizzia procera*
L_4	Agri-Horticulture Agroforestry System	*Mangifera indica* + *Amorphophallus campanulatus*
L_5	Pure Plantation of *Dalbergia sissoo*	*Dalbergia sisoo*
L_6	Pure Plantation of *Terminalia arjuna*	*Terminalia arjuna*
L_7	Natural Forest of *Shorea robusta*	*Shorea robusta* + Shrubs + Herbs + Grasses

B) Above ground Biomass partitioning

Notation	Component
B_1	Stem
B_2	Branch
B_3	Leaf
B_4	Whole tree
B_5	Crop/associated crop
B_6	Grass/herb/shrubs
B_7	Total

Replications: Three

Statistical Analysis : Two Way ANOVA

3.3. Experiment details

Land Use System	Plot size (m)	No. of trees (ha $^{-1}$)	Initial Tree Spacing (m)	Year of Planting
Fallow land	1 x 1	-	-	The land has not been cultivated from the last 15 years
Agriculture field	1 x 1	-	-	-
Tea Garden	10 x 10	400	6 x 6	1996
Agri-Horticulture Agroforestry System	10 x 10	400	8 x 8	1996
Pure Plantation of *Dalbergia sissoo*	10 x 10	1800	1.5 x 1.5	1997
Pure Plantation of *Terminalia arjuna*	10 x 10	2200	1.5 x 1.5	1997
Natural Forest of *Shorea robusta*	10 x 10	700	-	1976

3.4. Observation recorded and procedure adopted

3.4.1. Above ground biomass

Above ground biomass was estimated by non-destructive method for different plant parts viz., stem, branch and leaf.

3.4.1.1. Stem biomass

Stem biomass of all the trees falling in the sample plot of 10 x 10 m were enumerated. The diameter at breast height was measured with Caliper and height with Ravi's multimeter. Form factor was calculated with Spiegel relaskope to find out the tree volume using formula given by Pressler (1865) and Bitjerlich (1984).

$f = 2h_1/3h$

Where f- form factor

h_1 -height at which diameter is half of dbh.

h- total height

Volume was calculated by Pressler formula (1865)

$V = f \times h \times g$

Where V - volume

f- form factor

h- total height

g- basal area

$g = \pi r^2$ or $(dbh/2)^2$

r- radius ,dbh- diameter at breast height

Specific gravity was found out by taking the stem cores to find out the specific gravity which was further used to determine the biomass of stem using maximum moisture method (Smith, 1954).

$$Gf = \frac{1}{\frac{Mn-Mo}{Mo} + \frac{1}{Gso}}$$

Where,

Gf- Specific gravity based on gross volume

Mn - Weight of saturated volume sample

Mo- Weight of oven dried sample

Gso- Average density of wood substances equal to 1.53

Thus, the weight of wood was estimated using the formula i.e. mass per unit volume.

Biomass = specific gravity x volume

3.4.1.2. Branch Biomass

Total number of branches irrespective of size were counted on each of the sample tree, then these branches were categorized on the basis of basal diameter into three groups viz < 6 cm, 6-10 cm, and > 10 cm. Fresh weight of two sampled branches from each group was recorded separately. The following formula (Chidumaya, 1990) was used to determine the dry weight of branches:

$$B_{dwi} = B_{fwi}/1+M_{cdbi}$$

Where, B_{dwi} - oven dry weight of branch

B_{fwi} - fresh/green weight of branches

M_{cdbi} - Moisture content of branch on dry weight basis

Total branch biomass (fresh/dry) per sample tree was determined as given by :

$$B_{bt}= n_1bw_1 + n_2bw_2 +n_3bw_3 = \sum_{i=1}^{n} nibwi$$

Where,

B_{bt} - branch biomass (fresh/dry) per tree

n_i - number of branches in the i^{th} branch group

b_{wi} – average weight of branch of i^{th} group

i= 1,2,3,.......... Refers to branch group

3.4.1.3. Leaf biomass

Leaves from five branches of individual tree were removed. In similar manner 5 trees per plot were taken for observation. The leaves were weighed and oven dried separately to a constant weight at 80± 5° C (Chidumaya, 1990). The average leaf biomass was then arrived at by multiplying the average biomass of the leaves per branch with number of branches in a single tree and number of trees in a plot.

3.4.1.4. Tree biomass

The total tree biomass was the sum of stem biomass, branch biomass and leaf biomass.

3.4.1.5. Crop biomass

Crop biomass was estimated using 1m x 1m quadrates. All the crop plants occurring within the borders of the quadrate were cut at ground level and collected samples were weighed, sub sampled and oven dried at 65 ± 5° C to a constant weight.

3.4.1.6. Grass/ Herb/ Shrub biomass

It was estimated using 1m x 1m quadrates. The total biomass occurring within the borders of the quadrate were cut at ground level and collected samples were weighed, sub sampled and oven dried at 65 ± 5° C to a constant weight.

3.4.1.7. Estimation of carbon in wood

The biomass was converted into carbon by multiplying with a factor of 0.45 (Woomer, 1999).

3.4.2. Soil analysis

3.4.2. 1. Collection and preparation of samples

Three soil samples per plot were collected at four different soil depths. Composite samples were obtained for each depth for a plot of 10 x 10 m. Samples were air dried in shade, ground with wooden pestle, passed through 2mm sieve and stored in cloth bags for further laboratory analysis. The following physio-chemical attributes of soils were determined.

Sl.No.	Parameters	Method employed
1.	pH	Potentiometric method (Jackson,1967)
2.	Bulk density (g cm^{-3})	Core sample method (Piper, 1950)
2.	Organic carbon (%)	Walkley and Black (1934)
3.	Available Nitrogen	Subbiah and Asija, (1956)
4.	Volumetric Soil Moisture	Piper (1966)

3.4.2.2. Soil Organic Carbon Stock (tonnes ha^{-1})

Soil organic carbon stocks were calculated by multiplying the organic carbon with weight of the soil for a particular depth and expressed as tonnes ha^{-1}.

3.4.2.3. Soil Organic Carbon Pool inventory ($Mgha^{-1}$)

The soil organic carbon pool inventory expressed as mega grams per ha^{-1} ($Mgha^{-1}$) for a specific depth was computed by multiplying the soil organic carbon (g kg^{-1}) with bulk density (g cm^{-3}) and depth (cm) (Joao Carlos *et al.*, 2001).

3.5. Statistical analysis

The data obtained were subjected to statistical analysis following method suggested by Gomez and Gomez (1984) using the package "INDOSTAT".

CHAPTER- 4

EXPERIMENTAL RESULTS

EXPERIMENTAL RESULTS

The results obtained while estimating Carbon sequestration of various land uses in Terai Zone of West Bengal are presented in this chapter under following headings:

4.1 Below ground physical and chemical characteristics

4.2 Above ground biomass and carbon content

4.3 Contribution of different plant component towards biomass and carbon

4.4 Total biomass and carbon under different land uses

4.1 Below ground physical and chemical characteristics

4.1.1 Soil bulk density

Scrutiny of the data in table 4.1 indicates that mean soil bulk density was highest in Fallow land- L_1 (1.55) which was significantly different from all of the remaining land uses. L_1 was followed by Agriculture field - L_2 (1.44), Pure Plantation *of Dalbergia sissoo* - L_5 (1.41), Tea Garden - L_3 (1.40), Agri-Horticulture Agroforestry System - L_4 (1.37) and Pure Plantation *of Terminalia arjuna* -L_6 (1.33).The lowest soil bulk density was recorded in Natural Forest of *Shorea robusta*- L_7 (1.21).

In case of soil depth, mean soil bulk density was highest (1.42) in case of 30-40 cm soil depth (D_4). 20-30 cm soil depth (D_3) recorded the next highest soil bulk density (1.40) followed by 10-20 cm soil depth-D_2 (1.38) and 0-10 cm soil depth-D_1 (1.36). All of them displayed no significant difference.

From the table 4.1, it can be seen that in Fallow land, there was gradual increase in the soil bulk density with increase in soil depth.D_4 (1.59)was statistically at par with D_3 (1.56) and it differed significantly from D_1 (1.51)and D_2 (1.53) .In case of Agriculture field, highest soil bulk density was observed in case of D_4 (1.49) followed by D_1 (1.38) which was not at par with it.D_2 (1.46) and D_3 (1.47) were at par wit D_4.Tea garden had soil bulk density of 1.44 in D_4 followed by D_3 (1.42) , D_1(1.38) and D_2 (1.37). Here, D_4 was at par with D_3 and not at par with D_1 and D_2.In case of Agri-Horticulture Agroforestry System, the soil bulk density increased with soil depth. The highest soil bulk density was recorded in D_4 (1.40) followed by D_3 (1.38), D_2 (1.36) and lastly D_1 (1.35). All the soil depths were at par. Similar trend of data was found in case of Pure Plantation of *Dalbergia sissoo* - L_5 and Pure Plantation of *Terminalia arjuna* - L_6.In Natural Forest of *Shorea robusta* - L_7, it was observed that the soil bulk density was low.D_4 (1.23), D_3 (1.22), D_2 (1.21) and D_1 (1.20) were statistically on par.

Table 4.1. Effect of land use and soil depth on soil bulk density (g/cm^3)

Land use	Soil depth (cm)				Mean
	0-10	10-20	20-30	30-40	
L_1	1.51	1.53	1.56	1.59	1.55
L_2	1.35	1.46	1.47	1.49	1.44
L_3	1.38	1.37	1.42	1.44	1.40
L_4	1.35	1.36	1.38	1.40	1.37
L_5	1.39	1.40	1.42	1.44	1.41
L_6	1.31	1.33	1.34	1.35	1.33
L_7	1.20	1.21	1.22	1.23	1.21
Mean	1.36	1.38	1.40	1.42	

	CD $_{(p= 0.05)}$
Land use	0.091
Soil depth	0.203
Interactions: Land use x soil depth $_{1---n}$	0.054
Soil depth x landuse$_{1---n}$	0.103

Interaction studies by varying the land use and keeping the soil depth constant indicated that in the 0-10 cm depth, soil bulk density was highest in L_1 (1.51) and it differed significantly from L_5 (1.39), L_3 (1.38), L_2 (1.35), L_4 (1.35), L_6 (1.31) and L_7 (1.20).In the 10-20 cm soil depth L1 (1.53) was statistically on par with L2(1.46) and different from rest of the land uses viz. L_3 (1.37), L_4 (1.36), L_5 (1.40), L_6 (1.33) and L_7 (1.21).The changes in D_3 were in the same form as in case of D_2.For the 30-40 cm soil depth, L_1 (1.59) and L_2 (1.49) exhibited no statistical difference but they were not at par with the other land uses. L_6 (1.35) was followed by L_3 (1.44), L_5 (1.44) and L_4 (1.40) and the lowest soil bulk density was observed in case of L_7 (1.23).

4.1.2 Volumetric Soil moisture per cent

Upon analysis of table 4.2, it was found that mean soil moisture per cent was maximum in Agriculture field- L_2 (35.33) and it was not at par with other land uses. Natural Forest of *Shorea robusta* - L_7 (31.87) followed L_2 in terms of moisture content. In all remaining land uses, moisture content was low. The moisture content was 23.91 in L_6, 23.31 in Agri-Horticulture Agroforestry System (L_4), 21.24 in Tea Garden (L_3), 18.25 in Pure Plantation of *Dalbergia sissoo* (L_5) and 15.78 in Fallow land (L_1) respectively.

Table 4.2. Effect of land-use and soil depth on per cent soil moisture.

Land use	Soil depth (cm)				Mean
	0-10	10-20	20-30	30-40	
L_1	12.700	15.10	16.80	18.50	15.78
L_2	32.133	34.27	36.20	38.70	35.33
L_3	23.767	23.43	20.60	17.17	21.24
L_4	21.967	22.33	24.27	24.67	23.31
L_5	14.300	16.53	20.167	22.00	18.25
L_6	21.700	23.60	24.83	25.50	23.91
L_7	30.600	32.20	33.23	31.43	31.87
Mean	22.450	23.92	25.16	25.42	

	CD $_{(p=0.05)}$
Land use	2.12
Soil depth	1.16
Interactions: Land use x soil depth $_{1---n}$	3.08
Soil depth x landuse$_{1---n}$	3.40

Perusal of data in table 4.2 reveals that soil depth 30-40 cm had the maximum (25.42) mean soil moisture per cent and the soil depth 20-30 cm with mean moisture per cent of 25.16 was at par with it whereas other soil depths were not at par. Lowest moisture per cent was in soil depth 0-10 cm (22.45) followed by 20-30 cm soil depth (23.92).

In case of interaction, it was seen that in Fallow land, there was gradual increase in the soil moisture percent with increase in soil depth.D_4 recorded highest soil moisture percent (18.50) which was significantly different from D_1 (12.70) and D2 (15.10) and not significantly different with D_3 (16.80).In case of Agriculture field, it was observed that soil moisture percent was very high. Here also D_4 (38.70) significantly differed from D_1 (32.133) and D_2 (34.27) whereas it was it was at par with D3 (36.20). In case of Tea garden, a completely different trend was observed and the moisture per cent decreased with the soil depth. The maximum soil moisture per cent was observed in D_1 (23.767) which was statistically at par with D_2 (23.43) and D_3 (20.60) and differed significantly from D_4 (17.17). In L_4, L_5 and L_6 the soil moisture per cent increased with increase in soil depth. In case Natural Forest of *Shorea robusta*, all the land uses were at par with each other.D_3 (33.23) recorded the highest soil moisture per cent followed by D_2 (32.20), D_4 (31.43) and D_1 (30.60) respectively.

In case of interaction studies varying the land use and keeping the soil depth constant, it was seen that in the 0-10 cm depth, soil moisture per cent in L2 (32.133) and L_7 (30.60) was significantly higher then the remaining land uses. L_3 (23.767) was followed by L_4 (21.967), L_6 (21.7) and L_8 (14.30) .The least soil moisture percent was found in L_1 (12.70).In D_2 similar trends were observed. In case of 20-30 cm soil depth, the maximum soil moisture per cent was in D_2 (36.20) which was not at par with any of the land uses. L_7 (33.23) was followed by L_6 (24.83), L_4 (24.27), L_3 (20.60), L7 (20.167) and L1 (16.80) respectively. In the 20-30 cm depth, L2 again recorded the highest soil moisture (38.70) and differed from the rest of the land uses. It was followed by L_7 (31.43), L_6 (25.50), L_4 (24.67), L_5 (22.00) and L_1 (18.50).The least soil moisture per cent was observed in L_3 (17.17).

4.1.3 Soil pH

Scrutiny of data in table 4.3 reflects that mean soil pH was highest in Fallow land (6.09). It was significantly different from Tea garden plantation (5.72), Agri-Horticulture Agroforestry System (5.49) and Pure Plantation of *Terminalia arjuna*

(5.98). L_1 was on par with Natural Forest of *Shorea robusta* (5.09), Agriculture field (5.98) and Pure Plantation of *Dalbergia sissoo* (5.86).

Table 4.3. Effect of land-use and soil depth on soil pH

Land use	Soil depth (cm)				Mean
	0-10	10-20	20-30	30-40	
L_1	5.74	5.92	6.23	6.45	6.09
L_2	5.84	5.90	6.04	6.13	5.98
L_3	5.25	5.58	5.98	6.05	5.72
L_4	4.90	5.10	5.73	6.23	5.49
L_5	5.51	5.74	5.96	6.21	5.86
L_6	5.21	5.67	5.78	6.36	5.75
L_7	4.87	5.02	5.14	5.32	5.09
Mean	5.33	5.57	5.84	6.11	

	$CD_{(p=0.05)}$
Land use	0.27
Soil depth	0.12
Interactions: Land use x soil depth $_{1---n}$	0.31
Soil depth x landuse$_{1---n}$	0.38

While comparing the changes in soil pH with soil depth irrespective of land uses, it was seen that mean soil pH was significantly higher in D_4 (6.11) then all other land uses. The next highest level of soil pH was in D_3 (5.84) followed by D_2 (5.57) and D_1 (5.33) respectively.

Analysis of data shows that in Fallow land, there was gradual increase in the soil pH with increase in soil depth.D_4 recorded highest soil pH (6.45) which was at par with D_3 (6.23) and significantly different from D_1 (5.74) and D_2 (5.92) and in case of Agriculture field, it was observed that soil pH was maximum in D_4 (6.13) and it was on par with all other soil depths. D_3 (6.13) was followed by D_1 (5.84) and D_2 (5.90). In L_3 similar results were obtained. In case of Mango based agroforestry system it was observed that highest soil pH was obtained in D_4 (6.23) and there was significant difference with the rest of land uses. D_3 (5.73), D_2 (5.10) and D_1 (4.90) followed D_4 in terms of soil pH. In case of Pure Plantation of *Dalbergia sissoo* and Pure Plantation of *Terminalia arjuna on* similar trends were observed. In Natural Forest of *Shorea* *robusta*, D_4 (5.32) was on par with D_3 (5.14) and D_2 (5.02). D_1 (4.87) varied significantly from D_4.

In case of interaction studies varying the land use and keeping the soil depth constant, it was observed that in the 0-10 cm depth, soil pH was highest in L_2 (5.84) and it was statistically at par with L_1(5.74) and L_5 (5.51) and not at par with L_3(5.25), L_4 (4.90), L_6 (5.21) and L_7(4.87) .In the 10-20 cm soil depth L_1(5.92) had the highest soil pH and it was at par with L_2 (5.90), L_3 (5.58) and L_5 (5.74). L_4 (5.10), L_6 (5.67) and L_7 (5.02) were significantly different from L_1.Similar results were observed in case of D_3. In 30-40 cm soil depth, the pH was found to be high. D_1 (6.45) was not statistically at par with L_3 (6.05) and L_7 (5.32) whereas it was at par with L_2 (6.13), L_4 (6.23), L_5 (6.21) and L_6 (6.36).

4.1.4. Variation in Available Soil Nitrogen (kg/ha)

Analysis of table 4.4 reveals that mean Available soil nitrogen was maximum(121.22) in Natural Forest of *Shorea robusta* which did not differ significantly from Pure Plantation of *Dalbergia sissoo* -L_5 (114.8) and Agriculture field-L_2 (108.77).Remaining land uses differed significantly. Tea garden (L_3) had Available soil N of 97.94 followed by Agri-Horticulture Agroforestry System - L_4 (89.72), Pure Plantation of *Terminalia arjuna* -L_7 (87.24) and Fallow land-L_1 (86.10).

In case of soil depth, mean soil nitrogen was highest in 0-10 cm depth-D_1 (113.2) which was significantly higher then 10-20 cm soil depth-D_2 (101.87), 20-30 cm- D_3 (90.90) and 30-40 cm soil dept-D_4 (97.33) .

Keeping land use constant and varying the soil depth, it was seen that in Fallow land, D_1 recorded highest soil nitrogen (97.44) which was significantly different from D_3 (73.45) and on par with D_2 (86.88) and D_4 (86.63). In case of Agriculture field, no soil depth exhibited significant difference. D_1 (113.45) was followed by D_2 (110.07), D_4 (107.88) and D_3 (103.69). L_3 showed similar results to L_1. In case of

Agri-Horticulture Agroforestry System, D_1 recorded the highest soil nitrogen (109.22) followed by D_2 (96.76) which was on par. D_1 differed significantly from D_3 (73.50) and D_4 (79.41). In case of L_5 all the soil depths were at par and the maximum soil nitrogen was recorded in D_3 (123.90) followed by D_1 (116.75), D_3 (109.71) and D_2 (108.84). In case of Pure Plantation of *Terminalia arjuna*, highest soil nitrogen was present in D_1 (105.59) which showed statistical similarity to D_2 (97.21) and difference with D_3 (77.33) and D_4 (68.83). In case of L_7, highest Available soil nitrogen was present in D_1 (146.70) which was significantly higher then D_2 (119.62), D_3 (112.05) and D_4 (106.50).

Table 4.4 Effect of land-use and soil depth on Available Soil nitrogen (kg/ha)

Land use	Soil depth (cm)				Mean
	0-10	10-20	20-30	30-40	
L_1	97.44	86.88	73.45	86.63	86.10
L_2	113.45	110.07	103.69	107.88	108.77
L_3	103.29	93.71	86.56	108.20	97.94
L_4	109.22	96.76	73.50	79.41	89.72
L_5	116.75	108.84	109.71	123.90	114.80
L_6	105.59	97.21	77.33	68.83	87.24
L_7	146.70	119.62	112.05	106.50	121.22
Mean	113.20	101.87	90.90	97.33	

	$CD_{(p=0.05)}$
Land use	14.45
Soil depth	5.60
Interactions : Land use x soil depth $_{1\text{---}n}$	14.80
Soil depth x landuse$_{1\text{---}n}$	19.30

Interaction studies by varying the land use and keeping the soil depth constant indicated that in the 0-10 cm depth, all the land uses were statistically different from L_7 which recorded the maximum soil nitrogen (146.70), followed by L_5 (116.75), L_2 (113.45), L_4 (109.22), L_6 (105.59) and L_3 (103.29) .The least soil nitrogen was present in L_1 (97.44). In the 10-20 cm depth also L_7 had the maximum soil nitrogen (119.62) .It was at par with L_2 (110.07) as well as L_5 (108.84). L_1 (86.88), L_3 (93.71), L_4 (96.76) and L_6 (97.21) were not at par with L_7. Analysis of table 4.4 indicates that highest soil nitrogen was present in L_7 (112.05) in case of 20-30 cm soil depth and it did not differ significantly from L_5 (109.71) and L_2 (103.69).Significant difference was seen in L_1 (73.45), L_3 (86.56) ,L_4 (73.50) and L_6 (77.33) .In the 30- 40 cm soil depth L_3 (108.20) had statistical difference with L_1 (86.63), L_4 (79.41) and L_6 (68.83).L_3 was at par with L_2 (107.88), L_5 (123.90) and L_7 (106.50).

4.1.5 Soil Organic Carbon (SOC) per cent

Perusal of data in table 4.5 reveals that among the land uses, mean carbon per cent was highest (1.459) in natural forest of Natural Forest of *Shorea robusta* (L_7) which was significantly higher then rest of the land uses. This was followed by Pure Plantation of *Terminalia arjuna* (L_6) where Soil Organic Carbon (SOC) per cent was 0.998 followed by Agri-Horticulture Agroforestry System (L_4) with 0.887 SOC per cent, Pure Plantation of *Dalbergia sissoo* (L_5) with SOC per cent 0.757 , Tea garden (L_3) having SOC per cent 0.744 and Fallow land (L_1) with SOC per cent 0.650. The least SOC per cent was found in Agricultural field (L_2) where the SOC per cent was 0.447.

Table 4.5. Effect of land-use and soil depth on Soil organic carbon per cent

Land use	Soil depth (cm)				Mean
	0-10	10-20	20-30	30-40	
L_1	0.793	0.663	0.585	0.559	0.650
L_2	0.565	0.505	0.439	0.399	0.477
L_3	1.053	0.806	0.624	0.494	0.744
L_4	1.001	0.832	0.895	0.819	0.887
L_5	1.261	0.741	0.624	0.403	0.757
L_6	1.157	1.027	0.936	0.871	0.998
L_7	1.768	1.531	1.379	1.157	1.459
Mean	1.085	0.872	0.783	0.672	

	CD $_{(p=0.05)}$
Land use	0.126
Soil depth	0.053
Interactions: Land use x soil depth $_{1---n}$	0.140
Soil depth x landuse$_{1---n}$	0.175

While considering variation in soil organic carbon percent with different soil depths irrespective of land use, it was observed that mean Soil Organic Carbon (SOC) per cent was 1.085 in 0-10 cm depth (D_1) which differed significantly from rest of the land uses. Mean soil organic carbon percent decreased with soil depth.D1 was followed by 10-20 cm soil depth (D_2) with SOC per cent 0.872 and 20-30 cm soil depth (D_3) where the SOC per cent was 0.783. The 30-40 cm soil (D_4) recorded the least mean organic carbon (0.672).

Keeping Land use constant and varying the soil depth, it was seen that in Fallow land, there was gradual decrease in the SOC per cent with increase in soil depth.D_1 recorded highest SOC per cent (0.793) which with was at par with D_2 (0.663) and differed significantly from all other land uses. The SOC per cent in D_3 (0.585) was more then D_4 (0.559). In case of Agriculture field, it was observed that D_1 (0.565) was at par with D_2 (0.505) and D3 (0.439) whereas it was significantly different from D_4 (0.339).In L_3, L5 and L_6 also the SOC per cent decreased with increase in soil depth. Agri-Horticulture Agroforestry System showed a slight variation in the trend. Here, D_1 was significantly different with D_2 (0.832) and D_4 (0.819) whereas it was at par with D_3 (0.895).In case of Natural Forest of *Shorea robusta*, D_1 (1.768) SOC per cent was significantly was higher then all of the remaining soil depths.D_2 (1.531) was followed by D_3 (1.379) and D_4 (1.157).

In case of interaction studies varying the land use and keeping the soil depth constant, it was seen that in the 0-10 cm depth, all the land uses were statistically different from L_1 which had the maximum SOC per cent (1.768), followed by L_6 (1.157), L5(1.261),L3(1.053), L4 (1.001),L1 (0.793) and L2 (0.565) in the top surface. In case of 10-20 cm depth also almost similar trend was observed. The maximum SOC per cent was in L_7 (1.531) followed by L_6 (1.027), L_4 (0.832), L_3 (0.806), L_5 (0.741), L_1 (0.663) and L_2 (0.505) respectively and all of them differed significantly from L_7. Similar results were obtained in case of D_3 and D_4. Analysis of table indicates that SOC per cent in 20-30 cm depth among different land uses was again found to be maximum in L_7 (1.379) followed by L_6 (0.936), L_4 (0.895), L_3 (0.624), L_5 (0.624), L_1 (0.585) and L_2 (0.439) respectively. In 30 - 40cm depth, L_7 (1.157) was followed by L_6 (0.871), L_4 (0.819), L_1 (0.559), L_3 (0.494), L_5 (0.403), and L_2 (0.399) respectively.

4.1.6. Soil organic carbon stock (t/ha)

Perusal of data in table 4.6 reveals that among the land uses, mean SOC stock was highest (17.69) in Natural Forest of *Shorea robusta* which possessed significant difference from the rest of land uses. This was followed by Pure Plantation of *Terminalia arjuna* (13.29), Agri-Horticulture Agroforestry System (12.14), Pure Plantation of *Dalbergia sissoo*(10.66), Tea garden (10.45) and Agricultural field (6.99).Lowest amount of SOC stock was present in Fallow land (10.05).

Table 4.6 Effect of land-use and soil depth on soil organic carbon stock (t/ha)

Landuse	Soil depth (cm)				Mean
	0-10	10-20	20-30	30-40	
L_1	11.96	10.15	9.11	8.92	10.05
L_2	8.17	7.38	6.47	5.98	6.99
L_3	14.44	11.27	8.89	7.16	10.45
L_4	13.47	11.27	12.36	11.45	12.14
L_5	17.52	10.42	8.84	5.79	10.66
L_6	15.17	13.64	12.53	11.80	13.29
L_7	21.21	18.46	16.83	14.27	17.69
Mean	14.57	11.80	10.73	9.33	

	CD $_{(p=0.05)}$
Land use	1.55
Soil depth	0.69
Interactions : Land use x soil depth $_{1---n}$	1.82
Soil depth x landuse$_{1---n}$	2.21

Considering the variation in SOC stock with different soil depths irrespective of land use, it was observed that mean SOC stock was significantly higher (14.57) in 0-10 cm depth (D_1). Mean SOC stock became less in the lower with soil depths.D_1 was followed by 10-20 cm soil depth-D_2 (11.80) and 20-30 cm soil depth-D_3 (10.73).The 30-40 cm soil depth-D_4 had the lowest (9.33) SOC stock.

In case of interaction, it was observed that in case of Fallow land, D_1 recorded highest SOC stock (11.96) which was at par with D_2 (10.15) and differed significantly from D_3 (9.11) and D_4 (8.92). For the Agriculture field, D_1 (8.17) was followed by D_2 (7.38), D_3 (6.47) and D_4 (5.98) where D_1 was not at par with D_4.Tea garden plantation displayed decrease in SOC stock with increase in soil depth. D_1 (14.44) was not at par with D_2 (11.27), D_3 (8.89) and D_4 (7.16). Agri-Horticulture Agroforestry System recorded the highest SOC in D_1 (13.47) which was at par with D_3 (12.36) and was statistically different from D_4 (11.45) and D_1 (11.27). The 0-10 cm soil depth (17.59) in case of Pure Plantation of *Dalbergia sissoo* was significantly different from D_2 (10.42), D_3 (8.84) and D_4 (5.79). In case of *Terminalia arjuna*, highest SOC stock was present in D_1 (15.17) which showed statistical similarity to D_2 (13.64) and difference with D_3 (12.53) and D_4 (11.80). In case of Natural forest of Natural Forest of *Shorea robusta*, D_1(21.21) was significantly higher then D_2 (18.46), D_3 (16.83) and D_4 (14.27).

By varying the land use and keeping the soil depth constant for the 0-10 cm depth it was seen that SOC stock was maximum in L_7 (21.21) and it differed significantly with the remaining land uses viz.L_5 (17.52), L_6 (15.17), L_3 (14.44), L_4 (13.47), L_1 (11.96) and L_2 (8.17). For the 10-20 cm soil depth. L_7 (18.46) was statistically significant from L_6 (13.64), L_3 (11.27), L_4 (11.27), L_5 (10.42), L_1 (10.15) and lastly L_2 (7.38). In the 20-30 cm soil depth, similar results were obtained. Table 4.6 reveals that for 30-40 cm soil depth L_7 (14.27) had the highest SOC stock and was statistically different from L_6 (11.80), L_4 (11.45), L_1 (8.92), L_3 (7.16), L_2 (5.98) and L_5 (5.79).

4.1.7. Relative Soil Carbon stock (t/ha) in different soil depths

Scrutiny of table 4.7 shows that in the 0-20 cm soil depth, the maximum soil Carbon stock was present in Natural Forest of *Shorea robusta* (39.67) that was followed by Pure Plantations of *Terminalia arjuna* (28.81) and *Dalbergia sissoo* (27.94), Tea garden (25.71), Agri-Horticulture Agroforestry System (24.74), Fallow land(22.11) and Agriculture field (15.55). In 20-30 cm soil depth, less soil carbon stock as compared to 0-20 cm soil depth was observed. Natural Forest of *Shorea robusta* (31.11) recorded the highest carbon stock. In *Terminalia arjuna based plantation*

(24.33), Agri-Horticulture Agroforestry System (23.81), Fallow land (18.03), Tea garden (16.05), *Dalbergia sissoo* (14.63) and Agriculture field (12.45) also the carbon stock was lower then the 0-20 cm layer. As reflected by the table 4.7, in all the land uses 0-20 cm soil depth contributed about 55 to 60 per cent of total soil carbon stock.

Table 4.7. Relative Soil Carbon stock (t/ha) in different soil depths

Land use	0-20 cm	20-40 cm	Total	Soil organic C stock % 0-20 cm
L_1	22.11	18.03	40.14	55.08
L_2	15.55	12.45	28.00	55.53
L_3	25.71	16.05	41.76	61.57
L_4	24.74	23.81	48.55	50.96
L_5	27.94	14.63	42.57	65.63
L_6	28.81	24.33	53.14	54.22
L_7	39.67	31.11	70.77	56.05

4.1.8 Variation in soil organic carbon pool inventory (Mg/ha)

Study of the data in table 4.8 shows that mean SOC pool was 176.94 in Natural Forest of *Shorea robusta* (L_7) which was significantly higher then rest of the land uses. The SOC pool inventory in other land uses viz. *Terminalia arjuna* Plantation- L_6 (132.87), Agri-Horticulture Agroforestry System - L_4 (121.38), Pure Plantation of *Dalbergia sissoo* - L_5 (108.69), Tea garden- L_3 (104.43), Fallow land- L_1 (100.47) and Agriculture field- L_2 (69.92) was much lower then L_7.

On comparing the changes in SOC pool with soil depth irrespective of land uses, it was observed that that mean SOC pool was highest in D_1 (146.92) and decreased with increase in soil depth. D_2 (118.00), D_3 (107.26) and D_4 (93.36) were found to be statistically different from D_1.

Keeping Land use constant and varying the soil depth, it was seen that in Fallow land, there was gradual decrease in the SOC pool with increase in soil depth.

D1 recorded highest SOC pool (119.6) which had significant difference with the rest of land uses. It was followed by D_2 (101.52), D_3 (91.56) and D_4 (89.19) respectively. In Agriculture field, it was observed that D_1(81.72) was at par with D_2 (73.86) and D_3 (64.73) whereas it was significantly different from D_4 (59.37).Tea garden showed a SOC Pool of 114.46 in D_1 which was not at par with the other soil depths viz. D_2 (112.71),D_3 (88.92) and D_4 (71.66).SOC pool in Agri-Horticulture Agroforestry System was maximum in D_1(134.68) and it did not differ significantly with D_3 (123.58) but was significantly different from D_2 (112.71) and D_4 (114.56).In L_5,the D_1 (175.28) was not at par with D_2 (104.19), D_3 (88.41) and D_4 (57.90).In case of L_6 also the SOC pool was less in the lower soil depths. Natural Forest of *Shorea robusta* exhibited a SOC Pool of 212.08 Mg/ha in D_1, 184.64 in D_2, 168.33 in D_3 and 142.73 in D_4. All of them were statistically different from D_1.

Table 4.8. Effect of land-use and soil depth on soil organic carbon pool inventory (Mg/ha)

Land use	Soil depth (cm)				Mean
	0-10	10-20	20-30	30-40	
L_1	119.6	101.52	91.56	89.19	100.47
L_2	81.72	73.86	64.73	59.37	69.92
L_3	144.46	112.71	88.92	71.66	104.43
L_4	134.68	112.71	123.58	114.56	121.38
L_5	175.28	104.19	88.41	57.90	108.69
L_6	151.67	136.40	125.35	118.06	132.87
L_7	212.08	184.64	168.33	142.73	176.94
Mean	146.92	118.00	107.26	93.36	

	CD $_{(p=0.05)}$
Land use	16.19
Soil depth	6.49
Interactions : Land use x soil depth $_{1---n}$	17.18
Soil depth x landuse$_{1---n}$	22.04

Interaction studies by varying the land use and keeping the soil depth constant for the 0-10 cm depth suggested that SOC Pool was maximum in L_7 (212.08) and it was not at par with L_5 (175.28), L_6 (151.67), L_3 (144.46), L_4 (134.68), L_1 (119.6) or L_2 (81.72). In case of the 10-20 cm soil depth also almost similar trend was noticed. Here also L_7 (184.64) was significantly different from rest of the land uses viz. L6

(136.40), L_3 (112.71), L_4 (112.71), L_5 (104.19), L_1 (101.52) and lastly L_2 (73.86). For 20-30 cm soil depth also similar trend was noticed and L_7 (168.33) was not at par with any of the land uses. Considering the data in the 30-40 cm soil depth it was seen that L_7 (142.73) had the highest SOC Pool and was statistically different from L_6 (118.06), L_4 (114.56), L_1 (89.19), L_3 (71.66), L_2 (59.37) and L_5 (57.90) .

4.2 Above ground biomass and carbon content

4.2.1. Total Biomass (t/ha)

Analysis of table 4.9 shows that the stem biomass was significantly higher for *Natural Forest of Shorea robusta* (1080.48) which was much higher then Pure Plantation of *Dalbergia sissoo* (287.27), Tea garden (254.81), Pure Plantation of *Terminalia arjuna* (97.70) and Agri-Horticulture Agroforestry System (13.77). Branch biomass was highest in Natural Forest of *Shorea robusta* (892.25) which was statistically significant from Pure Plantations of *Terminalia arjuna* (149.09) and *Dalbergia sissoo* (103.71), *Agri-Horticulture Agroforestry System*(14.82) and Tea garden (10.74). Leaf biomass was maximum in L_7 (5.56) that differed significantly from L_6 (4.67), L_4 (3.86), L_5 (2.17) and L_3 (0.65). The whole tree biomass was maximum in Natural Forest of *Shorea robusta* (1978.29) which was significantly higher then any other land use. It was followed by Pure Plantation of *Dalbergia sissoo* (393.15), Tea garden (266.14), Pure Plantation of *Terminalia arjuna* (251.46) and Agri-Horticulture Agroforestry System (32.45).Tea garden (15.34) had maximum biomass followed by Agriculture field (10.81) and Agri-Horticulture Agroforestry System (3.55). In both Fallow land and Agriculture field, Stem, Branch , Leaf and Whole tree biomass was zero. The grass/ herb/ shrub biomass was maximum in case of Natural Forest of *Shorea robusta* (1.75) followed by Fallow land(1.31).In the table 4.9 it is reflected that total biomass of Natural Forest of *Shorea robusta* (1980.04) showed significant difference with Pure Plantation of *Dalbergia sissoo* (393.15), Tea garden (281.49), Pure Plantation of *Terminalia arjuna* (251.46), Agri-

Horticulture Agroforestry System (36.00) and Agriculture field (10.81) The least total above ground biomass was observed in case of Fallow land (1.31).

Table 4.9 Influence of land use on Total above ground Biomass (t/ha)

Landuse	Stem	Branches	Leaves	Whole tree	crop	Grass	Total
L_1	0.00	0.00	0.00	0.00	0.00	1.31	1.31
L_2	0.00	0.00	0.00	0.00	10.81	0.00	10.81
L_3	254.81	10.74	0.65	266.14	15.34	0.00	281.49
L_4	13.77	14.82	3.86	32.45	3.55	0.00	36.00
L_5	287.27	103.71	2.17	393.15	0.00	0.00	393.15
L_6	97.70	149.09	4.67	251.46	0.00	0.00	251.46
L_7	1080.48	892.25	5.56	1978.29	0.00	1.75	1980.04
CD $_{(p=0.05)}$	90.64	27.07	0.49	103.65	0.97	0.08	103.19

4.2.2 Biomass (t/ha/year)

Perusal of data in table 4.10 revealed that the stem biomass per year was highest for Natural Forest of *Shorea robusta* (36.02) which was statistically at par with Pure Plantation of *Dalbergia sissoo* (31.92) and significantly different from Pure Plantation of *Terminalia arjuna* (25.80) and Agri-Horticulture Agroforestry System (1.35). For the branch biomass, the maximum value was obtained in Natural Forest of *Shorea robusta* (29.74) which was not at par with any of the land use viz. Pure Plantation of *Terminalia arjuna* (16.57), Pure Plantation of *Dalbergia sissoo* (11.52), Agri-Horticulture Agroforestry System (1.48) and Tea garden (1.07). Pure Plantation *Terminalia arjuna* recorded the maximum leaf biomass per year (0.52) and it exhibited significant difference with Agri-Horticulture Agroforestry System (0.39), Pure Plantation of *Dalbergia sissoo* (0.24), Natural Forest of *Shorea robusta* (0.19) and Tea garden (0.07). The whole tree biomass was significantly higher for Natural Forest of *Shorea robusta* (65.94). It was followed by Pure Plantation of *Dalbergia sissoo* (43.68), Pure Plantation of *Terminalia arjuna* (27.94), Tea garden (26.61) and Agri-Horticulture Agroforestry System (3.25).

Table 4.10 Influence of land use on above ground Biomass (t/ha/year)

Landuse	Stem	Branches	Leaves	Whole Tree	crop	Grass	Total
L_1	0.00	0.00	0.00	0.00	0.00	1.31	1.31
L_2	0.00	0.00	0.00	0.00	10.81	0.00	10.81
L_3	25.80	1.07	0.07	26.61	1.53	0.00	28.32
L_4	1.35	1.48	0.39	3.25	3.56	0.00	6.84
L_5	31.92	11.52	0.24	43.68	0.00	0.00	43.68
L_6	10.86	16.57	0.52	27.94	0.00	0.00	28.10
L_7	36.02	29.74	0.19	65.94	0.00	0.06	66.00
CD $_{(p=0.05)}$	9.77	1.85	0.05	11.03	0.80	0.01	10.89

4.2.3 Carbon stock (t/ ha)

Scrutiny of table 4.11 reveals that in case of carbon stock in Stem, Sal was significantly higher (486.22) then all of the other land uses. It was followed by Pure Plantation of *Dalbergia sissoo* (129.27), Tea garden (114.64), Pure Plantation of *Terminalia arjuna* (43.96) and Agri-Horticulture Agroforestry System (6.19). In case of Branch carbon stock also, Natural Forest of *Shorea robusta* (401.51) was significantly higher then all the other land uses viz. Pure Plantations of *Terminalia arjuna* (67.09) and *Dalbergia sissoo* (46.67), Agri-Horticulture Agroforestry System (6.67) and Tea garden (4.83). For the carbon stock in leaf, Natural Forest of *Shorea robusta* (2.50) was followed by Pure Plantation of *Terminalia arjuna* (2.11), Pure Plantation of *Dalbergia sissoo* (0.97), Tea garden (0.29) and Agri-Horticulture Agroforestry System (0.15). Considering the whole tree carbon stock, it was seen that L_7 (890.23) was significantly higher then L_5 (176.99), L3 (119.76), L_6 (113.16) and L_4 (13.01) respectively. Tea garden (6.90), Agriculture land (4.87) and Agri-Horticulture Agroforestry System (1.60) contributed to the crop carbon stock. Grass carbon stock was 0.59 t/ha in Fallow land and in case of Natural Forest of *Shorea robusta*, Grass/herbs/Shrubs contributed 0.79 t/ha.

Table 4.11 Influence of land use on Total Carbon stock (t/ha) in above ground biomass

Landuse	Stem	Branches	Leaves	Whole tree	crop	Grass	Total
L_1	0.00	0.00	0.00	0.00	0.00	0.59	0.59
L_2	0.00	0.00	0.00	0.00	4.87	0.00	4.87
L_3	114.64	4.83	0.29	119.76	6.90	0.00	126.66
L_4	6.19	6.67	0.15	13.01	1.60	0.00	14.62
L_5	129.27	46.67	0.97	176.99	0.00	0.00	176.92
L_6	43.96	67.09	2.11	113.16	0.00	0.00	113.16
L_7	486.22	401.51	2.50	890.23	0.00	0.79	891.02
CD $_{(p=0.05)}$	40.80	12.18	0.22	46.69	0.44	0.00	19.45

4.2.4 Carbon stock (t/ ha/ yr)

Perusal of table 4.12 revealed that the stem carbon stock per year was significantly higher in case of Natural Forest of *Shorea robusta* (16.21) followed by Pure Plantation of *Dalbergia sissoo* (14.36), Tea garden (11.46), Pure Plantation of *Terminalia arjuna* (4.89) followed by Agri-Horticulture Agroforestry System (0.62). In both Fallow and Agriculture field, Stem, branch , leaf and whole tree carbon stock remained zero. In case of branches, the carbon stock per year was significantly more in natural forest of Natural Forest of *Shorea robusta* (13.38) as compared to Pure Plantation of *Terminalia arjuna* (7.45), Pure Plantation of *Dalbergia sissoo* (5.19), *Agri-Horticulture Agroforestry System* (0.67) and Tea garden (0.48). The leaf carbon stock per year was maximum in case of L_6 (0.23) and it was significantly different from L_5 (0.11), L_7 (0.08), L_3 (0.03) and L_4 (0.02). Natural Forest of *Shorea robusta* (29.67) recorded the maximum whole tree carbon stock/ year and it was not at par with any of the land use. Sal was followed by *Dalbergia sissoo* based plantation (19.66), Tea garden (11.97) and Pure Plantation of *Terminalia arjuna* (12.67). Agri-Horticulture Agroforestry System (1.30) recorded the lowest whole tree carbon stock /year. There was no crop biomass in question in case of L_1, L_5, L_6 and L_7 and it was obviously higher in case of Agriculture field (4.87) followed by Agri-Horticulture Agroforestry System (1.60) and Tea garden (0.68). Grass biomass was significantly higher (0.59) in case of Fallow land followed by Natural Forest of *Shorea robusta* (0.03). Finally, the total carbon stock per year in above ground biomass was maximum in case of Natural Forest of *Shorea robusta* (29.70) and it was not at par with any of the land uses viz. L_5 (19.66), L_3 (12.66), L_6 (12.66), Agriculture field (4.87), Agri-Horticulture Agroforestry System (2.90) and Fallow land (0.59).

Table 4.12 Influence of land use on Carbon stock (t/ha/yr) in above ground biomass

Landuse	Stem	Branches	Leaves	Whole tree	crop	Grass	Total
L_1	0.00	0.00	0.00	0.00	0.00	0.59	0.59
L_2	0.00	0.00	0.00	0.00	4.87	0.00	4.87
L_3	11.46	0.48	0.03	11.97	0.68	0.00	12.66
L_4	0.62	0.67	0.02	1.30	1.60	0.00	2.90
L_5	14.36	5.19	0.11	19.66	0.00	0.00	19.66
L_6	4.89	7.45	0.23	12.67	0.00	0.00	12.66
L_7	16.21	13.38	0.08	29.67	0.00	0.03	29.70
CD $_{(p= 0.05)}$	4.44	0.83	0.02	4.97	0.36	0.003	4.93

4.3 Contribution of different plant component towards biomass and carbon

4.3.1 Above ground biomass (t/ha)

From table 4.13, it can be seen that in Fallow land, Grass (1.31) and in Agriculture field, crop (10.81) added to the above ground biomass. In case of Tea garden, Total biomass (281.49), Whole tree (258.80) and Stem biomass (254.81) were at par, whereas associate crop (15.35) branch (10.74) and leaf (0.65) were statistically significant. Total above ground biomass (36.00) was significantly higher in Agri-Horticulture Agroforestry System compared to whole tree (32.45), Branch (14.82), Stem (13.77), Leaf (3.86) and Associated Crop biomass (3.55). For Pure Plantation of *Dalbergia sissoo*, Whole tree (393.15) and Stem biomass (287.28) were statistically at par. The Branch (103.71) and Leaf biomass (2.17) showed statistical significance in this case. For *Terminalia arjuna*, Total biomass (251.46) showed no statistical similarity to any other component viz. Whole tree (251.46), Branch (149.09), Stem (97.70) and Leaf (4.67). In Natural Forest of *Shorea robusta*, Total biomass (1980.04) and Whole tree biomass (1978.29) were not significantly different. However, Stem (1080.48), Branch (892.25), Leaf (5.56) and Grass/herbs / Shrubs (1.75) showed statistical significance.

Table 4.13 Partitioning of above ground biomass (t/ha) under different land-uses

Components	L_1	L_2	L_3	L_4	L_5	L_6	L_7
Stem	0.00	0.00	254.81	13.77	287.28	97.70	1080.48
Branch	0.00	0.00	10.74	14.82	103.71	149.09	892.25
Leaf	0.00	0.00	0.65	3.86	2.17	4.67	5.56
Whole tree	0.00	0.00	258.80	32.45	393.15	251.46	1978.29
Crop/associated crop	0.00	10.81	15.35	3.55	0.00	0.00	0.00
Grass/herb/shrubs	1.31	0.00	0.00	0.00	0.00	0.00	1.75
Total	1.31	10.81	281.49	36.00	393.15	251.46	1980.04
CD $_{(p=0.05)}$	0.01	1.01	52.55	2.43	118.72	23.57	43.24

4.3.2 Above ground biomass (t/ha/year)

Perusal of data in table 4.14 reflects that in case of Fallow land, only grass contributed towards the above ground biomass which was equal to 1.31.However in case of Agriculture field it was only crop that contributed to total above ground biomass which was 10.81 in this case. For Tea garden, the total above ground biomass was 28.15 which was at par with whole tree biomass (26.62) and Stem biomass (25.8) and significantly different from branch biomass (1.07), associated crop biomass (1.53) and leaf biomass (0.07). For Agri-Horticulture Agroforestry System, the total biomass (6.81) was not at par with associated crop (3.56), whole tree (3.24), Branch (1.48), Stem (1.38) and leaf biomass (0.39).It was observed that Total (43.68), Whole tree (43.68) and Stem biomass (31.92) were at par with each other and branch (11.52) and leaf biomass (0.24) differed significantly in case of Plantation of *Dalbergia sissoo*. For Plantation of *Terminalia arjuna*, Total (28.10) and Whole tree biomass (27.94) did not differ significantly. The Stem (10.86), Branch

(16.56) and Leaf biomass (0.52) were not at par. For Natural Forest of *Shorea robusta* also, Total biomass (66.00) and Whole tree biomass (65.94) were statistically at par. Stem biomass (36.02), Leaf (0.19) and grasses/ shrubs/ herbs (0.06) also contributed to the total aboveground biomass.

Table 4.14 Partitioning of above ground biomass (t/ha/year) under different land-uses

Components	L_1	L_2	L_3	L_4	L_5	L_6	L_7
Stem	0.00	0.00	25.80	1.38	31.92	10.86	36.02
Branch	0.00	0.00	1.07	1.48	11.52	16.56	29.74
Leaf	0.00	0.00	0.07	0.39	0.24	0.52	0.19
Whole tree	0.00	0.00	26.61	3.24	43.68	27.94	65.94
Crop/associated crop	0.00	10.81	1.53	3.56	0.00	0.00	0.00
Grass/herb/shrubs	1.31	0.00	0.00	0.00	0.00	0.00	0.06
Total	1.31	10.81	28.15	6.81	43.68	28.10	66.00
CD $_{(p=0.05)}$	0.01	1.01	4.96	0.26	13.19	2.62	1.44

4.3.3 Above ground Carbon stock (t/ha)

Table 4.15 shows that the Fallow land and Agriculture field contributed through grass (0.59) and crop (4.87) respectively to the above ground Carbon stock. In case of Tea garden, total carbon stock (126.66), whole tree (119.76) and stem (114.64) displayed no significant difference but statistical significance was observed in case of Branch (4.83), leaf (0.29) and associated crop (6.90) in Carbon stock. The Total aboveground carbon stock (14.62) in Agri-Horticulture Agroforestry System was not significantly different from Whole tree (13.01), Branch (6.67), Stem (6.20), Associated crop (1.60) and leaf carbon stock (0.38). For Plantation of *Dalbergia sissoo*, Total (176.92), Whole tree (176.92) and Stem carbon stock (129.27) were at par and Branch (46.67) and leaf carbon stock (0.98) differed significantly. Whole tree biomass (113.16) displayed statistical dissimilarity with Branch (67.09), Stem (43.96) and leaf carbon stock (2.10) in *Terminalia arjuna* Plantation. In case of Natural Forest of *Shorea robusta*, Total carbon stock (891.02) was not significantly different to whole tree (890.23). Also the Stem (486.22), Branch (401.51), grass /herb/shrub (0.79) and leaf (2.50) contributed to the total above ground carbon stock.

Table 4.15 Partitioning of above ground Carbon stock (t/ha) under different land-uses

Components	L_1	L_2	L_3	L_4	L_5	L_6	L_7
Stem	0.00	0.00	114.64	6.20	129.27	43.96	486.22
Branch	0.00	0.00	4.83	6.67	46.67	67.09	401.51
Leaf	0.00	0.00	0.29	0.38	0.98	2.10	2.50
Whole tree	0.00	0.00	119.76	13.01	176.92	113.16	890.23
Crop/associated crop	0.00	4.87	6.90	1.60	0.00	0.00	0.00
Grass/herb/shrubs	0.59	0.00	0.00	0.00	0.00	0.00	0.79
Total	0.59	4.87	126.66	14.62	176.92	113.16	891.02
CD $_{(p=0.05)}$	0.005	0.45	22.78	0.97	53.43	10.61	19.46

4.3.4 Above ground Carbon stock per year (t/ha/yr)

Scrutiny of table 4.16 shows that Grass (0.59) and Crop (4.87) in the Fallow land and Agriculture field respectively added to the above ground Carbon stock every year. In case of Tea garden, Total carbon stock(12.66),Whole tree (11.98) and stem (11.47) were at par and differed significantly from Associated crop(0.68),Branch (0.48)and leaf (0.03) carbon stock. For Agri-Horticulture Agroforestry System, Total carbon stock per year (2.90) was significantly higher then all other components viz. Associated crop (1.60), Whole tree (1.30), Branch (0.67) and Stem (0.62) and leaf (0.02) carbon stock per year. Total (19.66), Whole tree (19.66) and Stem (14.36). Carbon Stock per year was statistically at par in case of Pure Plantation of *Dalbergia sissoo* but significant difference was observed in case of Branch (5.19) and leaf (0.11) carbon stock per year. For *Terminalia arjuna*, Whole tree carbon stock per year (13.66) was significantly higher then Branch (7.45), Stem (4.90) and leaf (0.23) respectively. In case of Natural Forest of *Shorea robusta*, Total carbon stock per year 29.75 and Whole tree carbon stock per year 29.70 were at par but differed significantly from Stem (16.21), Branch (13.38), Leaf (0.08) and Grass/ herbs/ shrubs (0.03).

Table 4.16 Partitioning of above ground Carbon stock per year (t/ha/yr) under different land-uses

Components	L_1	L_2	L_3	L_4	L_5	L_6	L_7
Stem	0.00	0.00	11.47	0.62	14.36	4.90	16.21
Branch	0.00	0.00	0.48	0.67	5.19	7.45	13.38
Leaf	0.00	0.00	0.03	0.02	0.11	0.23	0.08
Whole tree	0.00	0.00	11.98	1.30	19.66	13.66	29.70
Crop/associated crop	0.00	4.87	0.68	1.60	0.00	0.00	0.00
Grass/herb/shrubs	0.59	0.00	0.00	0.00	0.00	0.00	0.03
Total	0.59	4.93	12.66	2.90	19.66	13.66	29.75
CD $_{(p=0.05)}$	0.005	0.50	2.28	0.11	5.93	2.10	0.68

4.4 Total biomass and carbon under different land uses

4.4.1 Total Plant and Soil Carbon stocks (t/ha)

Analysis of table 4.17 shows that the Maximum plant carbon stock was present in Natural Forest of *Shorea robusta* (624.02) which was followed by Pure Plantation of *Dalbergia sissoo* -L_5 (176.92), Tea garden- L_3 (126.66), Pure Plantation of *Terminalia arjuna*- L_6 (113.16), Agri-Horticulture Agroforestry System-L_4 (14.62) and Agriculture field - L_2 (4.87). The least plant C stock was present in Fallow land-L_1 (0.59). In case of the soil C stock up to 0- 40 cm soil depth, it was observed that SOC stock was higher in L_7 (70.77) as compared to other land uses viz. L_6 (53.14), L_4 (48.55), L_5 (42.57), L_3 (41.76), L_1 (40.14) and L_2 (40.14). Table 4.17 also reveals that the total carbon stock was also highest in case of Natural Forest of *Shorea robusta* (694.79). Natural Forest of *Dalbergia sissoo* (219.49) recorded the next highest value followed by Tea garden (168.42), which was closely followed by Pure Plantation of *Terminalia arjuna* (166.3). Agri-Horticulture Agroforestry System (63.17), Fallow land (40.73) and Agriculture field (32.87). The Soil: Plant ratio was high for L_1 (68.03). In

L_2 and L_4 the ratios were 5.75 and 3.32 respectively. In all the remaining land uses viz. L_6 (0.47), L_3 (0.33), L_5 (0.24) and L_7 (0.11) the ratio was low.

Table 4.17 Total Plant and Soil Carbon stocks (t/ha) of different land use systems

Land use	Plant C stock	Soil C stock (0-40 cm)	Total	Soil: Plant
L_1	0.59	40.14	40.73	68.03
L_2	4.87	28	32.87	5.75
L_3	126.66	41.76	168.42	0.33
L_4	14.62	48.55	63.17	3.32
L_5	176.92	42.57	219.49	0.24
L_6	113.16	53.14	166.3	0.47
L_7	624.02	70.77	694.79	0.11

CHAPTER- 5

DISCUSSION

DISCUSSION

The results obtained in the present study are discussed under the following headings:

5.1 Physico-chemical properties of soil.

5.2 Above ground biomass and carbon content.

5.3 Contribution of different plant parts and vegetation towards biomass and carbon content.

5.1 Physico-chemical properties of soil

The results presented in table 4.1 reveals that soil bulk density ranged from 1.20 to 1.59 gm/cm^3. It was found that as the soil depth increases, the bulk density also increased. Among seven Land use system taken, the maximum bulk density was 1.55 gm/cm^3 in Fallow land and least 1.21gm/cm^3 in Natural Forest of *Shorea robusta*. The results obtained in the present study are in conformity with the results given by Baruah and Barthakur (1997). They reported that bulk density generally has inverse relationship with the amount of carbon present in soil. Table 4.5 provides the data on soil organic carbon per cent which shows inverse trend being highest in case of Natural Forest of *Shorea robusta* (1.459 per cent) and minimum in case of Agriculture field (0.477 per cent) and maximum in surface layers (1.085 per cent) and minimum in sub surface soils (0.672 per cent in 30-40 cm depth).

Soil moisture content varied from 12.70 to 38.70 per cent and it was found that in general as the soil depth increased, the soil moisture per cent also increased. The average soil moisture per cent was highest in Agriculture field (35.33 per cent) and lowest in case of Fallow land (15.78 per cent).The higher moisture content in case of

Agriculture field is attributed to the land management practices adopted particularly irrigation as the crop grown was Paddy in present case .The least moisture content in Fallow land is because of the absence of any vegetation. This is also proved from the fact that the land use taken under the present study having tree components were having more moisture content compared to Fallow land. In case of Tea garden, a completely different trend was observed and the moisture per cent decreased in the lower horizons which may be owing to impeded drainage for low-lying positions and / or due to impermeable layer.

Table 4.3 revealed that the pH ranged from 5.02 to 6.45. It was highest in Fallow land (6.09) and lowest in the Natural Forest of *Shorea robusta* (5.09).It generally increased with increase in soil depth. Chavan *et al.* (1995) and Contractor and Badnur (1996) have reported low soil pH under forest plantation. Lower soil pH found in land uses having tree component is due to presence of high organic matter (Table 4.5) and leaching of bases and enhancement of weathering process giving rise to high Al levels. The results obtained were in accordance with Chakravarty and Barthakur (1997).

Available soil nitrogen ranged from 73.45 kg / ha to 146.70 kg/ha .Maximum Available nitrogen was present in Natural Forest of *Shorea robusta* (121.22 kg / ha) and least in Fallow land (86.10 kg / ha).It also decreased with increase in soil depth but it was more in D_4 in some cases .which may be attributed to leaching of nitrogen due to high rainfall in the area. The higher amount of available nitrogen in case of natural forest and tree based land use systems may due to addition of more organic material through residual root and leaf fall in the surface soils and its rapid mineralization. Total N in soils is closely associated with organic matter and its content depends on nature of vegetation, climate, topography and texture of soil and its decomposition. Gupta *et al.*, (2001) reported that organic carbon, N and C: N ratio values were lowest in barren land and highest in forest. High Available N in Agriculture land may be due to continuous N fertilizer addition and rapid turn over of organic matter by tillage operation.

Soil organic carbon stock ranged from 6.47 t/ha to 21.21 t/ ha .The maximum soil carbon stock was present in Natural Forest of *Shorea robusta* (17.69 t/ha) followed by Pure Plantation of *Terminalia arjuna* (13.29 t/ha), Agri-Horticulture System (12.14 t/ha), Pure Plantation of *Dalbergia sissoo* (10.66 t/ha), Tea Garden (10.45 t/ha), Fallow land (10.05 t/ha) and Agriculture field (6.99 t/ha).The present results are in conformity with the results obtained by Ladegaard *et al.* (2005) who reported that SOC stocks differed significantly between tree species. Jha et al. (2003) also reported that miscellaneous forest has the maximum SOC storage capacity compared to pure plantation. Total soil organic carbon stock (t/ha) in 0-40 cm soil depth was highest in Natural Forest of *Shorea robusta* (70.77 t/ha) and lowest in Agriculture field (28 t/ha). Rhoades *et al.* (2000) reported that Total soil C was 23 t/ha lower in the upper 30 cm following 50 year of sugarcane production (24 percent decrease) compared to old-growth forest. The net change (-0.4 t ha^{-1} $year^{-1}$) in soil C consisted of 1.3 t/ha annual losses of original forest C and 0.9 t/ha annual gains of C from sugarcane. After 15 years beneath pasture, soil C was 11 t/ha less in the upper 30 cm than beneath forest (12 percent decrease). Total SOC stock in 0-40 cm ranged from 28 t/ha to 70.77 t/ha being lowest in Agriculture field and highest in Natural Forest of *Shorea robusta*.The results are in conformity with Das (1975) and Banerjee *et al.* (1986) who have reported 40.2 t/ha to 79.2 t/ha soil carbon in top 30 cm soil of tropical moist deciduous forest of India.

Soil organic carbon pool ranged from 59.37 Mg/ha to 212.08 Mg/ha .The maximum soil organic carbon pool was in Natural Forest of *Shorea robusta* (176.94 Mg/ha) followed by Pure Plantation of T*erminalia arjuna* (132.87 Mg/ha) , Agri-Horticulture System (121.38 Mg/ha), Pure Plantation of *Dalbergia sissoo* (108.69 Mg/ha), Tea Garden (104.43 Mg/ha), Fallow land (100.47 Mg/ha) and Agriculture field (66.92 Mg/ha).The SOC pool decreased with increase in soil depth .Lal (2004) had estimated SOC pool of 21 Pg upto 30 cm depth and 63 Pg up to 150 cm depth. Oelbermann et al., (2004) while quantifying SOC pool in 19 year old *Gliricidia sepium* alley cropping system, observed 16-23 per cent higher SOC Pool as compared to sole crop. Chabbra *et al.* (2002) estimated the total soil organic carbon pool in Indian forest as 4.13 Pg in top 50 cm, 6.81 Pg in top 100 cm soil depth.

5.2 Above ground biomass and carbon content

Table 4.9 reveals that the total biomass was maximum in Natural Forest of *Shorea robusta* (1980.04 t/ha) and lowest in case of Fallow land (1.31 t/ha). Carbon stock was also highest in Natural Forest of *Shorea robusta* (891.02) followed by Pure Plantation of *Dalbergia sissoo* (176.92 t/ha), Tea Garden (126.66 t/ha), Pure Plantation of *Terminalia arjuna* (113.16 t/ha), Agri- Horticulture AF System (14.62 t/ha), Agriculture field (4.87 t/ha) and Fallow land (0.59 t/ha). The biomass / year was highest in case of Natural Forest of *Shorea robusta* (66 t/ha /yr) and least in Fallow land (1.31 t/ha /yr). Carbon stock per year was maximum in Natural Forest of *Shorea robusta* (29.70 t/ha/ year) and lowest in Fallow land (0.59 t/ha/ year). In general stem contributed more then branches and least contribution was made by the leaf except in case of Agri- Horticulture System and Pure Plantation of *Terminalia arjuna* where branch had contributed more then stem. Mutuo et al 2005 reported that in humid tropics the potential of agroforestry (tree-based) systems to sequester C in vegetation can be over 70 Mg C ha^{-1}, and up to 25 Mg ha^{-1} in the top 20 cm of soil. In degraded soils of the sub-humid tropics, improved fallow agroforestry practices have been found to increase top soil C stocks up to 1.6 Mg C ha^{-1} y^{-1} above continuous maize cropping. Swamy and Puri (2005) compared carbon sequestration potential of *Gmelina arboria* planted as sole and in Agrisilviculture system.They reported that Total C storage in abandoned agricultural land before planting was 26.3 Mg ha^{-1}, which increased to 33.7 and 45.8 Mg ha^{-1} after 5 years in plantation and agrisilviculture system, respectively. They reported that competitive interactions played a significant role in agrisilviculture system. Plantations were more efficient in sequestering C than agrisilviculture system on abandoned agricultural land. In similar way, Silfver (2003) conducted a study in Ethopia to examine the effect of land use change on carbon and nitrogen storage in soils. Two different land uses were studied: a Eucalyptus forest plantation and a farmland under maize production. It was shown that Eucalyptus on set-aside farmland had significantly higher soil carbon concentrations at 10 and 60 cm depth. Planting Eucalyptus on set-aside farmland also showed a significant increase in the total organic nitrogen concentration at 50 and 70 cm depth. Moura-Cousta (1996) compared carbon sequestration potential of plantation, agroforestry and Rainforest up to 20-30 years. They reported that plantation of fast growing species sequestered 100-200 t/ha of Carbon, Agroforestry sequestered 90-150 t/ha and maximum amount of carbon sequestered was 300-400 t/ha in Rainforest. Freedman and Keith (1996) reported that carbon content of plants on agricultural land is less than 5 per cent of a forest, while that of agricultural soil is typically 60 to 80 percent that of forest soil. Winjum *et al.* (1992) estimated the amount of C sequestered per unit area for five major forestry practices: reforestation (artificial regeneration), afforestation (similar to reforestation, but done on land that has not supported forests for 50 years), natural regeneration, silviculture, and agroforestry. According to him, median tropical forest carbon ($tCha^{-1}$) was highest for Natural reforestation(119 $tCha^{-1}$) followed by agroforestry (95 $tCha^{-1}$), reforestation (65 $tCha^{-1}$), Silviculture (34 $tCha^{-1}$) and lastly afforestation (29 $tCha^{-1}$). Houghton *et al.*(1991) considered three methods of forestry practices for C sequestration: plantations, agroforestry, and protection/regeneration. In case of Asia, protection sequestered maximum C (7 GtC), followed by plantation (3 GtC) and agroforestry (1 GtC). In Latin America, carbon sequestration was maximum in agroforestry (16 GtC) followed by plantation (9 GtC)and protection (7 GtC).In Africa, plantation sequestered maximum amount of carbon(15 GtC) followed by agroforestry(6 GtC) and protection (3 GtC).

5.3 Contribution of different plant parts and vegetation towards biomass and carbon content

Biomass content in Stem was highest in Natural Forest of *Shorea robusta* (1080.48 t/ha) and least in Agri-Horticulture Agroforestry System (13.77 t/ha). Highest Branch biomass was in Natural Forest of *Shorea robusta* (892.25 t/ha) and least in Tea Garden (10.74 t/ha). Maximum amount of leaf was in *Shorea robusta* (5.56 t/ha) and least (0.65 t/ha) in Tea Garden. Grass was observed only in Fallow land whereas in Natural Forest of *Shorea robusta* undergrowth was of grass/herbs / shrubs contributing biomass of about 1.75 t/ha. Crop contribution was in case of Tea Garden, Agri-Horticulture Agroforesty System and Agriculture field. Similar trend was observed while estimating carbon stock except for carbon stock in leaves of Tea Garden and Pure Plantation of *Dalbergia sissoo*. Biomass (t/ha/year) and carbon stock (t/ha/yr) showed maximum values in Natural Forest of *Shorea robusta* (66.00 t/ha/yr, 29.70t/ha/yr) followed Pure Plantation of *Dalbergia sissoo*, Tea garden, Pure Plantation of *Terminalia arjuna*, Agriculture field, *Agri-Horticulture System* and Fallow land (1.31t/ha/yr, 0.59 t/ha/yr) respectively. Variation in biomass and carbon stock under different land use had been discussed under sub head 5.2.Higher biomass and hence more carbon stock in natural forest is because of the efficient utilization of space due to presence of grasses, shrubs and trees on same patch of land and higher SOC also leads to increased rate of growth of plants. In general stem contributed more then branches and least contribution was made by the leaf except in case of Agri-Horticulture Agroforestry System and Pure Plantation of *Terminalia arjuna* where branch had contributed more then stem. This is because of the fact that *Mangifera indica* is trained and pruned in such a way that the crown surface area increases which leads to more fruiting and hence more branch biomass and restricted stem dimension. In case of Pure Plantation of *Terminalia arjuna,* Branch biomass was more because of grazing pressure in the initial stages of the plantation which had led to profuse side branches.

CHAPTER- 6

SUMMARY AND CONCLUSIONS

SUMMARY AND CONCLUSION

The present study entitled "Carbon sequestration estimates of various land uses in Terai Zone of West Bengal" was conducted during 2004-2006. The amount of carbon stored in above ground biomass and carbon sequestered in soil under seven different land uses were studied. The land uses selected were Fallow land, Agriculture field, Tea Garden, Agri- Horticulture Agroforestry System, Pure Plantation of *Dalbergia sissoo*, Pure Plantation of *Terminalia arjuna* and Natural Forest of *Shorea robusta*. The experimental site was in Terai Zone of West Bengal, which is located at northern fringe of the state.

Estimation of carbon sequestration in soil was done by taking samples from four soil depths viz. 0-10, 10-20, 20-30 and 30-40 cm under different land uses selected. Soil organic carbon per cent, Carbon stock (t/ha), Organic carbon pool inventory (Mg/ha) were calculated. Soil organic carbon stock ranged from 6.47 t/ha to 21.21 t/ ha and the Soil organic carbon pool ranged from 59.37 Mg/ha to 212.08 Mg/ha. The maximum SOC stock and pool was present in Natural Forest of *Shorea robusta* (17.69 t/ha, 176.94 Mg/ha) and least in Agriculture field (6.99 t/ha, 66.92 Mg/ha) respectively. In general the organic carbon decreased with increase in soil depth. Soil bulk density ranged from 1.20 to 1.59 gm/cm^3. It was found that as the soil depth increases, the bulk density also increased. The pH was highest in Fallow land (6.09) and lowest in the Natural Forest of *Shorea robusta* (5.09). It generally increased with increase in soil depth. Available soil nitrogen ranged from 73.45 kg / ha to 146.70 kg/ha. Maximum Available nitrogen was maximum in Natural Forest of *Shorea robusta* (121.22 kg / ha) and least in Fallow land (86.10 kg / ha) that decreased with increase in soil depth.

Above ground carbon sequestration potential was estimated by quantifying biomass under various land uses. Further, above ground biomass was partitioned into seven categories viz. Stem, Branch, Leaf, Whole tree, Crop/ associated crop, Grass/ herb/ shrubs and total biomass. The total biomass was maximum in Natural Forest of *Shorea robusta* (1980.04 t/ha) and lowest in case of Fallow land (1.31 t/ha). Thus the Carbon stock was also highest in case of Natural Forest of *Shorea robusta* (891.02 t/ha) and least in Fallow land (0.59 t/ha). The contribution of different plant parts and vegetation towards biomass and carbon content was also observed in different land uses. Biomass content in Stem was highest in Natural Forest of *Shorea robusta* (1080.48 t/ha) and least in Agri-Horticulture Agroforestry System (13.77 t/ha). Highest Branch biomass was in Natural Forest of *Shorea robusta* (892.25 t/ha) and least in Tea Garden (10.74 t/ha). Maximum biomass of leaves was in *Shorea robusta* (5.56 t/ha) and least (0.65 t/ha) in Tea Garden. The grass was observed only in Fallow land whereas, in Natural Forest of *Shorea robusta*, undergrowth was of grass/ herbs/ shrubs contributing biomass of about 1.75 t/ha. Crop contribution was in case of Tea Garden (15.35 t/ha), Agri-Horticulture Agroforestry System (3.55 t/ha) and Agriculture field (10.81 t/ha). Total carbon stock (Plant + Soil) was highest in case of Natural Forest of *Shorea robusta* (694.79 t/ha) and lowest in Agriculture field (32.87 t/ha).

It is concluded from the study that carbon sequestration potential of disturbed land viz. Fallow land and Agriculture field is only 5.86 per cent and 4.73 per cent respectively as compared to natural forest of *Shorea robusta*. However, Agroforestry systems viz. Tea garden and Agri-Horticulture Agroforestry systems contributed 24.24 per cent and 9.09 per cent carbon, whereas, pure plantation of *Dalbergia sissoo* and *Terminalia arjuna* contributed 31.59 per cent and 23.93 per cent carbon respectively as compared to Natural forest of *Shorea robusta*. Though natural forest sequester more carbon and hence are best option for reducing atmospheric carbon, however, they cannot be extended to large areas due to population pressure and high demand of land for agriculture purposes. Therefore, Agroforestry systems seem to be the best alternative to minimize atmospheric carbon and simultaneously fulfill social and economic needs.

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