CHAPTER I

INTRODUCTION

# INTRODUCTION   **Page no.**

1.1 Overview

Carbon is the fourth most abundant, non-metallic, element in the universe with atomic number six. It is a key component of the atmosphere, sea, land, and all living things on earth. The name "carbon" actually comes from the latin word *carbo*, meaning charcoal (West, 2008). It is the backbone of all kinds of structural and functional compounds necessary for life. Carbon exists throughout the planet in several reservoirs and in a variety of forms (The Royal Society, 2005). The most important reservoirs are atmosphere, lithosphere, biosphere and oceans. Most of the carbon in the atmosphere exists as carbon dioxide (CO_2). It also occurs in other forms as carbon monoxide (CO) and methane (CH_4). Oceans contain carbon in the form of bicarbonate or carbonate ions (Korhonen et al., 2002). There are three forms of carbon present on earth viz., 1) elemental 2) inorganic and 3) organic (Schumacher, 2002). The primary sources for elemental carbon in soils and sediments are as incomplete combustion products of organic matter (i.e., charcoal, graphite, and soot), from geologic sources (i.e., graphite and coal), or dispersion of these carbon forms during mining, processing, or combustion of these materials (Schumacher, 2002). Inorganic carbon in the soil occurs largely in carbonate minerals, such as calcium carbonate ($CaCO_3$) and dolomite ($CaMg\ (CO_3)_2$) (Nieder and Benbi, 2008). The naturally occurring organic carbon (OC) forms are mainly derived from the decomposition of plants and animals. In soils a wide variety of OC forms are present, ranging from freshly deposited litter such as leaves, twigs, and branches to highly decomposed forms such as humus (Buringh, 1984). Plant litter and microbial biomass are the major parent materials for soil organic matter (SOM) formation (Kogel-Knabner, 2002; Kramer and Gleixner, 2006). The three forms of carbon (elemental, organic and inorganic) are recycling between the reservoirs such as ocean, biosphere, atmosphere and living things by photosynthesis, respiration, burning, burial of organic matter, decomposition, and weathering processes (West, 2008).

1.2 Carbon cycle

Carbon circulates in a system that consists of the atmosphere, vegetation, soil and the oceans. This circulation is mainly comprised of two different processes: the exchange of carbon between the atmosphere and the sea and the binding and release of carbon in conjunction with photosynthesis and respiration in terrestrial ecosystems (Korhonen et al., 2002).

Figure 1: Global carbon cycle and fluxes between the reservoirs
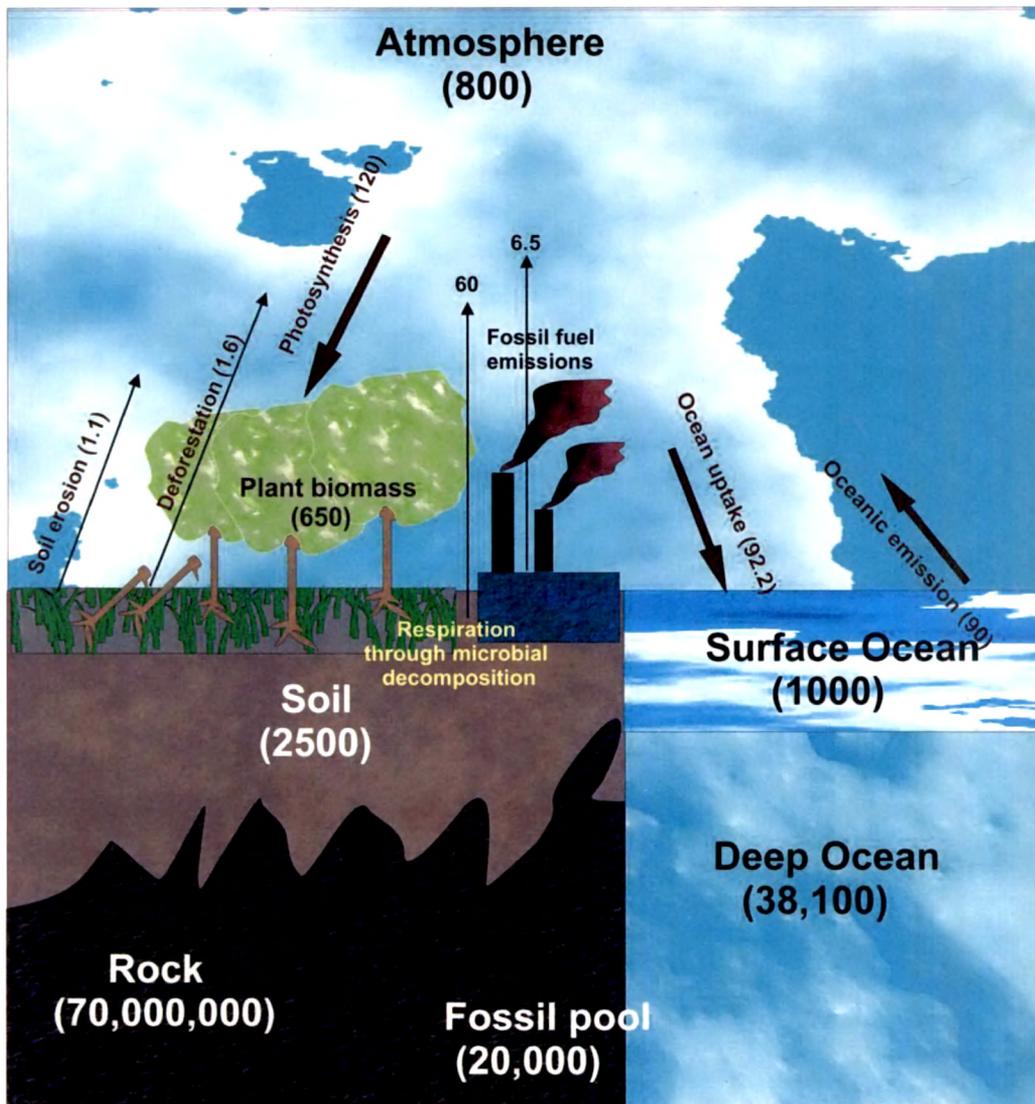
All numbers in the figure are in petagrams (Pg=10^{15}g) (Source: Schimel, 1995; Zimov et al., 2006; Lal, 2004 and U.S. Department of Energy, 2005).

1.2.1 Ocean

Ocean is one of the largest reservoirs of carbon. The atmosphere and the ocean have powerful exchange of carbon. The total exchange of carbon between atmosphere and oceans is controlled by two principal processes viz., the solubility (or physical) pump and the biological pump (U.S.Department of Energy, 2005). The solubility pump is driven by physical processes. Depending on local climatic conditions, CO_2 can dissolve from air into sea or be released by the sea into the air (Korhonen et al., 2002). CO_2 dissolves in the cold surface waters around the north and south poles. When these cold waters sink, they carry the carbon deep into the oceans where it can be stored for hundreds of years (West, 2008). Because of their ability to store carbon, the oceans are known as a carbon sink (Sabine et al., 2004; Battle et al., 2000). Sabine et al. (2004) estimated the natural oceanic sink of 118 ± 19 Pg C between 1880 and 1994, and the sink capacity is likely to increase to 5 Pg C yr^{-1}. The two main forms of carbon in the sea are carbonate (CO_3^-) and bicarbonate ions (HCO_3^-). Bicarbonate ions are created when CO_2 molecules dissolved in seawater undergo a chemical reaction and combine with hydrogen (West, 2008). About 88% of the inorganic carbon in the sea is made up of bicarbonate ions (West, 2008). Carbon transfers relatively slowly from the surface layers of the sea to the depths (Siegenthaler and Sarmiento, 1993).

The biological pump begins with the photosynthesis of phytoplankton (diatoms, dinoflagellates and cyanobacteria) converting about as much atmospheric carbon to organic carbon in the ocean as plant photosynthesis does on land and end with either the conversion of organic matter to CO_2 at different depths or with the deposition of a small fraction of organic material into sediments on the ocean floor (U.S.Department of Energy, 2005). Dead organisms from photosynthetically active top water column sink into depths and, settle on the ocean floor (U.S.Department of Energy, 2005). The surface and deep water ocean water holds 10,000 and 38,000 Pg of carbon respectively (Figure 1). Warm surface waters in oceans easily release

carbon dioxide into the atmosphere when warm waters rise to the surface, mainly near the equator (West, 2008).

1.2.2 Terrestrial ecosystems

Atmospheric CO_2 enters terrestrial ecosystem by the process of photosynthesis. Photosynthesis is a natural process by which plants fix CO_2 to produce carbohydrates, which are then used in different metabolic pathways (Jimenez and Lal, 2007). The principal reaction (photosynthesis) that converts atmospheric CO_2 into biomass is given in the following equation.

$$6CO_2 + 12H_2O + light\ energy \longrightarrow C_6H_{12}O_6 + 6H_2O + 6O_2$$

This carbon is stored in plant components including trunks, branches, leaves and roots (Kishwan et al., 2009). The incorporation of these materials into the soil via the action of different soil organisms, especially the functional group of soil ecosystem engineers (Jones et al., 1994; Kemmitt et al., 2008) and inhabitants of the litter, together with the carbon exudates from roots that are utilized by microbial populations, constitute the natural pathways of incorporating biomass carbon into the soil. The biomass carbon enters the soil through the decomposition, a key process in the carbon cycle due to its two interrelated sub-processes, i.e., mineralization and humification (Jimenez and Lal, 2007). Mineralization is the process by which organic molecules are converted into inorganic forms assimilable by plants, and humification is the process by which soil organic matter levels are maintained (Jimenez and Lal, 2007). Humification efficiency ranges from 10 to 20% (Lal, 2004b). During mineralization CO_2 is emitted from respiration activities of soil microorganisms (Jimenez and Lal, 2007). Estimates of the contribution of root respiration to total CO_2 efflux from soil range from 10-90% (Hanson et al., 2000). Of the 120 Pg CO_2-C absorbed by photosynthesis, 60 Pg is returned back to the atmosphere through plant respiration and decomposition of soil organic matter or soil respiration (Lal, 2008).

1.2.3 Atmosphere

Atmosphere contains a mixture of gases. Table 1 shows the various gases present in a volume of air near the earth's surface. Notice that nitrogen (N_2) occupies about 78 percent and oxygen (O_2) about 21 percent of the total volume. Other gases (including CO_2) are also present in the atmosphere as trace amounts (Table 1).

Table 1: Composition of the atmosphere near the earth
(Adopted from Ahrens, 2001)

Permanent gases			Variable gases			
Gas	Symbol	Percent (by volume) Dry Air	Gas (and particles)	Symbol	Percent (by volume)	Parts per Million (ppm)*
Nitrogen	N_2	78.08	Water vapor	H_2O	0 to 4	-
Oxygen	O_2	20.95	Carbon dioxide	CO_2	0.037	368*
Argon	Ar	0.93	Methane	CH4	0.00017	1.7
Neon	Ne	0.0018	Nitrous oxide	N_2O	0.00003	1.3
Helium	He	0.0005	Ozone	O_3	0.0000004	0.04†
Hydrogen	H_2	0.00006	Particles (dust, soot, etc.)	-	0.000001	0.01-0.15
Xenon	Xe	0.000009	Chlorofluorocarbons (CFCs)	-	0.00000002	0.0002

*For CO_2, 368 parts per million means that out of every million air molecules, 368 are CO_2 molecules.
†Stratospheric values at altitudes between 11 km and 50 km are about 5 to 12 ppm.

Currently atmosphere contains 800 Pg of carbon (U.S. Department of Energy, 2005). Before the industrial revolution the amount of gases in the atmosphere is relatively stable, but after the industrial revolution the composition of the atmosphere got altered (Malhi and Phillips, 2005) especially by green house gases (GHGs). Water vapour (H_2O), CO_2, Methane (CH_4), Nitrous oxide (N_2O), Chloroflurocarbons (CFC), Hydroflurocarbon (HFC), Perflurocarbons (PFC) and sulphur hexafluorides (SF_6) are the primary GHGs in the atmosphere (IPCC, 2001). An increase in the concentration of GHGs leads to an increased infrared opacity of the atmosphere, and therefore to an effective radiation into space from a higher

altitude at a lower temperature. This causes a radiative forcing, an imbalance that can only be compensated for by an increase in the temperature of the surface-troposphere system. This is the enhanced greenhouse effect (IPCC, 2001). CO_2 is the principal anthropogenic greenhouse gas that affects the earth's radiative balance (IPCC, 2001; Broadmeadow et al., 2003). The amount of CO_2 present in the atmosphere (although small, 0.037%) plays a crucial role to maintain the earth surface temperature (IPCC, 2001). The atmospheric concentration of CO_2 has historically oscillated between about 180ppm during glacial periods and 280ppm during interglacial periods (Falkowski et al., 2000). Due to burning of fossil fuels, cement production, deforestation and agricultural development, the atmospheric CO_2 concentration increased from the pre-industrial level of about 280ppm (parts per million) to 391.19ppm in 2011 (NOAA, 2011)). CO_2 is increasing at the rate of 0.4% or 1.5ppm year^{-1}, CH_4 which has increased from 0.80 to 1.74ppm and increasing at the rate of 0.75% or 0.015ppm year^{-1}, and N_2O which has increased from 288 to 311ppb (parts per billion) and is increasing at the rate of 0.25% or 0.8ppb year^{-1}(Lal, 2004a). Recent report (IPCC, 2007) confirmed that the arctic and antarctic ice sheets are melting due to the increasing levels of CO_2 in the atmosphere.

The anthropogenic CO_2 that did not accumulate in the atmosphere must have been taken up by the ocean, by the land biosphere, or by a combination of both (Sabine al., 2004). Greenhouse gases effectively absorb infrared radiation emitted by the earth's surface, by the atmosphere itself from these same gases, and by clouds. Atmospheric radiation is emitted to all sides, including downwards to the earth's surface. Thus, greenhouse gases trap heat within the surface–troposphere system (IPCC, 2001). Earth surface temperature has increased by 0.74°C since 1850 and it's expected to increase by another 1.1°C to 6.4°C by the end of this century (Stern, 2007). Because temperature affects almost all aspects of terrestrial carbon processes, increasing earth's surface temperature likely enhances ecosystem carbon fluxes, potentially feeding back to a buildup of atmospheric CO_2 concentration and

climate dynamics (Luo, 2007). The need to identify options for mitigating atmospheric concentrations of CO_2 is widely recognized.

1.3 Kyoto protocol

The United Nations Framework Convention on Climate Change (UNFCCC), adopted in 1992 in Rio de Janeiro, was the first international treaty that set out to address the problem of climate change by working to prevent anthropogenic emissions that contribute to climate disturbances (Reilly et al., 2002). The main aim at climate convention was "the stabilisation of greenhouse gases in the atmosphere at a level that will prevent dangerous anthropogenic interference with the climate system" (IGBP Terrestrial carbon working group, 1998). The convention on climate change classifies the countries in two groups: the annex I countries (considered to be developed in 1990 or in transition towards a market economy) and non-annex I countries (considered to be developing countries in 1990) (1PCC, 2001). The third conference of the parties to the UNFCCC (CoP 3) convened in Kyoto, Japan, in 1997 (Reilly et al., 2002). It legally binds the 38 most industrialized countries (annex I countries) to meet emission reduction targets by cutting their total emissions for six greenhouse gases such as CO_2, CH_4. N_2O, HFC, PFC and SF_6 by at least 5% from 1990 levels (Cirman et al., 2009). No commitments were specified for non-annex I countries. These reductions must be effected during the period 2008-2012 (Cirman et al., 2009). Annex I countries are allowed to achieve some emissions reductions by investing in energy and tree planting projects (reforestation and afforestation) that cut green house gases emissions in developing countries through the "Clean Developmnt Mechnism (CDM)" (Santilli et al.,2005). According to the Kyoto protocol (KP), carbon sequestration in terrestrial sinks can be used to offset green house gas emissions (Jandl et al., 2007).

1.4 Carbon sequestration

Carbon sequestration implies capture and storage of atmospheric CO_2 into long lived pools in ocean, geologic basalts, vegetation and soil by biotic and abiotic strategies (Lal, 2004a). Abiotic strategies involve separation, capture, compression, transport, and injection of CO_2 from industrial plant flue gases and effluents of industrial processes deep into geological basalts and ocean (IPCC, 2005; Lal, 2004a). The capture and/or injected CO_2 is reacted with water to form carbonic acid ($H_2CO_3^-$) and subsequently the carbonic acid is encountered to form carbon bearing ionic minerals, finally further break down of these minerals could precipitate new carbonate minerals that would fix capture and /or injected CO_2 in its most secure state over thousands to millions of years (Kumar, 2007). These strategies of sequestration of carbon are still in infancy, and for implementation of abiotic strategies to sequester carbon are required lots of money, chemicals and equipments, because these strategies are totally based on new engineering techniques. However, oceans are absorbing CO_2 from the atmosphere and this is causing chemical changes by making them more acidic (that is, decreasing the pH of the oceans). In the past 200 years the oceans have absorbed approximately half of the CO_2 produced by fossil fuel burning and cement production (Ravens et al., 2005). The pH of our ocean surface waters has already fallen by about 0.1 units from about 8.16 to 8.05 since the beginning of the industrial revolution around 200 years ago (The Royal Society, 2005). If global emissions of CO_2 from human activities continue to rise on current trends then the average pH of the oceans could fall by 0.5 units (equivalent to a threefold increase in the concentration of hydrogen ions) by the year 2100 (Ravens, et al., 2005). Ocean acidification, as the phenomenon is called, over time will create major negative impacts on corals and other marine life, with anticipated adverse consequences for fishing, tourism, and related economies (Feely et al., 2009). However, many of the ecological, chemical, and geological elements of the deep sea and, therefore, the effects of injecting carbon dioxide into the ocean, are widely unknown (Nieder and Benbi, 2008).

Geologic sequestration involves a direct injection of carbon dioxide into an underground geologic formation at high pressure and at great depth (Nieder and Benbi, 2008).Geological storage of CO_2 is accomplished by injecting it in dense form into a rock formation below the earth's surface. Porous rock formations that hold or (as in the case of depleted oil and gas reservoirs) have previously held fuids, such as natural gas, oil or brines, are potential candidates for CO_2 storage. Suitable storage formations can occur in both onshore and offshore sedimentary basins (natural large-scale depressions in the earth's crust that are filled with sediments) (IPCC, 2005). Once injected into the storage formation, the fraction retained depends on a combination of physical and geochemical trapping mechanisms. First, CO_2 dissolves in the in situ water. Once this occurs (over time scales of hundreds of years to thousands of years), the CO_2 laden water becomes more dense and therefore sinks down into the formation (rather than rising toward the surface). Next, chemical reactions between the dissolved CO_2 and rock minerals form ionic species, so that a fraction of the injected CO_2 will be converted to solid carbonate minerals over millions of years (IPCC, 2005). The risks due to leakage from storage of CO_2 in geological reservoirs fall into two broad categories: global risks and local risks. Global risks involve the release of CO_2 that may contribute significantly to climate change if some fraction leaks from the storage formation to the atmosphere. In addition, if CO_2 leaks out of a storage formation, local hazards may exist for humans, ecosystems and groundwater (IPCC, 2005). These are the local risks.

In contrast to oceanic and geologic carbon storage techniques, the terrestrial carbon sequestration in biotic strategies are based on natural process of photosynthesis and transfer of fixed atmospheric CO_2 into vegetative biomass and SOM pools (Kishwan et al., 2009; Lal, 2008). SOM is a heterogeneous mixture consisting of plants, animals and microbial materials in all stages of decay combined with a variety of decomposition products of different ages and levels of

complexity (Buringh, 1984). SOM is a major storehouse of carbon on a global scale (Feng et al., 2001). The accumulation of SOM, of which about 58% is carbon, occurs during ecosystem development as a result of interactions between biota (e.g., autotrophs and heterotrophs) and environmental controls (e.g., temperature, moisture) (Post et al., 2001). As the trees grow, they absorb CO_2 through photosynthesis and incorporate a portion of this carbon into their body structure. Thus, carbon sequestration by growing forests has been shown to be a cost-effective option for mitigation of global climatic change (Andrasko, 1990, Brown et al., 1996). The biological management of carbon in tackling climate change has therefore essentially two components: the reduction in emissions from biological systems and the increase in their storage of carbon. These can be achieved in three ways: existing stores could be protected and the current high rate of loss reduced; historically depleted stores could be replenished by restoring ecosystems and soils; and, potentially, new stores could be created by encouraging greater carbon storage in areas that currently have little, for example through afforestation (Trumper et al., 2009). At the same moment, carbon sequestration (by growing forests) can be appropriate from both an ecological, environmental and a socioeconomic point of view. The environmental perspective includes the removal of CO_2 from the atmosphere, the improvement of soil quality, and the increase in biodiversity (Batjes and Sombroek, 1997, Batjes, 1999, Lal et al., 1999). Socioeconomic benefits can be reflected through increased yields (Sombroek et al., 1993) and monetary incomes from potential carbon trading schemes (McDowell, 2002). Carbon sequestration projects could also enhance local participation and understanding of sustainable forest management practices (Tschakert, 2001). Sequestration of carbon in terrestrial ecosystems is a low-cost option that may be available in the near-term to mitigate increasing atmospheric CO_2 concentrations.

1.5 Terrestrial ecosystems and carbon stocks

Terrestrial ecosystems include different types of land surface with vegetal cover and soils. Different ecosystem types store different amounts of carbon depending on their species compositions, soil types, climate and other features (Trumper et al., 2009). In terrestrial ecosystems the smallest land areas are occupied by tundra and temperate grassland ecosystems, and the largest land area is occupied by tropical forest. The most productive ecosystems are temperate and tropical forests, and the least productive are deserts and tundras. Cultivated lands, together with grasslands and savannas utilized for grazing are referred to as agro ecosystems, are of intermediate extent and productivity (Kucharik et al., 2001; Oelbermann et al., 2004; Amthor and Huston, 1998). Tropical forests cover approximately 17% of the terrestrial biosphere, yet they account for a 43 % of global net primary productivity (NPP) and 27% of carbon stored in soils (Melillo et al., 1993; Clark et al., 2001). In terrestrial ecosystems, forest ecosystems contain more carbon per unit area than any other land types (accounting for 60% of total carbon in terrestrial ecosystems) and their soils are of major importance for carbon storage (FAO, 2001). The total amount of carbon stored (vegetation biomass and soil) in terrestrial ecosystems is large (~2542.3 Pg C) (Table 2). Forest vegetation and soils constitute a major terrestrial carbon pool with the potential to absorb and store CO_2 from the atmosphere (Lal, 2005; Kaul et al., 2010). Forest ecosystems are open systems and exchange carbon, energy and materials with other systems including adjacent forests, aquatic ecosystems and the atmosphere. Thus, a forest ecosystem is never in equilibrium (Lorenz and Lal, 2010).

Table 2: Global estimates of land area and carbon stocks in living plants and soils for various ecosystems

Ecosystems	Area (Mha)	Biomass carbon (Pg)	Soil carbon up to 1 m (Pg)	Total (Pg)
Forest				
Boreal	900	22.0	135.0	157.0
Temperate	750	92.0	90.0	182.0
Tropical	1480	244.2	123.0	367.2
Temperate woodlands	200	16.0	24.0	40.0
Chaparral	250	8.0	30.0	38.0
Tropical	2250	65.9	263.0	328.9
Temperate grasslands	1250	9.0	295.0	304.0
Tundra, arctic and alpine	950	6.0	121.0	127.0
Deserts	3000	7.2	191.0	198.2
Lake and streams	200	0	0	0
Wetlands	280	12.0	202.0	214.0
Peat lands	340	0	455.0	455.0
Cultivated and permanent crops	1480	3.0	117.0	120.0
Perpetual ice	1550	0	0	0
Urban	200	1.0	10.0	11.0
Total	**15,080**	**486.4**	**2056**	**2542.3**

Note: Pg=petagram (10^{15}g) =Gigaton. Source: Amthor and Huston (1998).

1.6 World's forests and carbon stocks

Forest ecosystems cover large parts of the terrestrial land surface and are major components of the terrestrial carbon cycle (Lal, 2004b). Most importantly, forest ecosystems accumulate organic compounds with long carbon residence times in vegetation, detritus and, in particular, the soil by the process of carbon sequestration (Lorenz and Lal, 2010). Trees, the major components of forests, absorb large amounts of CO_2 by photosynthesis, and forests return an almost equal amount to the atmosphere by auto-and heterotrophic respiration (Lorenz and Lal, 2010). However, a small fraction of carbon remaining in forests continuously accumulates in vegetation, detritus, and soil (Lorenz and Lal, 2010). Thus, undisturbed forest ecosystems are important global carbon sinks. Forests ecosystems covering 4.1 billion hectares globally (Dixon and Wisneiewski, 1995) are a major reservoir of terrestrial carbon stock. They sequestered about 1240 Pg of carbon in their plant biomass and soil; it is 51% of total ecosystems carbon stock (Prentice, 2001). There are three principle forest biomes in the world they are boreal, temperate and tropical (Malhi et al., 1999).

Boreal forest is the second largest forest biome with an area of 1.37Mha[-1] (Landsberg and Gower, 1997) accounting for about 21% of the forested land surface (Whittaker and Likens, 1975). These forests have very cold winters but relatively warm summers. Trees can survive such a regime, though they almost all have needles rather than broad leaves. Species diversity is low, although it is higher than in tundra (Korner, 1998). Typical plant carbon density of boreal forests ranges from 40 to 60 Mg ha^{-1} (Lal, 2005). This biome accounts for 47% of the worlds forest carbon stored in soil and 11% of the carbon stored in biomass (Table 3) (Schlesinger, 1991). Like boreal forests, temperate forests, include hardwood types (e.g., oak-hickory and maple beech- birch), softwood types (e.g., southern pine, Douglas-fir, and lodge pole pine), and a few mixed types (e.g., oak-pine) (Pidwirny et al., 2007).

Table 3: Carbon stock (Pg C) in world's major forest biomes

Biome	Area (Mha)	Terrestrial carbon stock (Pg)			Carbon density (MgC ha^{-1})	
		Plants	Soil	Total	Plants	Soil
Tropical forests	1.76	340	213	553	157	1222
Temperate forests	1.04	139	153	292	96	122
Boreal forests	1.37	57	338	395	53	296
Total	4.17	536	704	1240	-	-

(Source: Prentice, 2001).

Tree covers in temperate forest promotes the accumulation of organic materials in a well-developed humus layer (Pidwirny et al., 2007). The typical plant carbon density of temperate forest is ranges from 60 to 130 Mg ha^{-1} (Lal, 2005). Temperate forests generally contain less carbon (153 Pg C) than tropical forests (213 Pg C). More than one-third of the carbon is stored in the vegetation, and nearly two-thirds in the soil (Table 3).

Tropical forests are nature's great green engines, a lush green girdle across the earth's moist equatorial regions, occupying approximately 1.76 Mha^{-1} (FAO, 2000). These include evergreen rainforests, moist deciduous and dry deciduous forests, and montane forests (Pidwirny et al., 2007). Tropical forests harbour 50% of global diversity, and hold a large fraction of the carbon held in live vegetation (Dixon et al., 1994). Tropical forests soils store many more times of carbon than in aboveground vegetation (Table 3). The typical plant carbon density of tropical forests ranges from 120-194 Mg ha^{-1} (Lal, 2005). Overall, carbon pools in tropical forests are large and diverse due to the variety of growth forms and canopy complexity especially in humid systems (De-Deyn et al., 2008). Rates of carbon

cycling are high due to favourable climatic conditions for plant growth and litter decomposition (Aerts and Chapin, 2000). Every year they cycle about 12% of the CO_2 held in the atmosphere through photosynthesis, respiration and microbial decay (Schimel, 1995). The tropical forest appears to be a net sink of CO_2 through out the year, whereas the higher latitude forests are sinks through out the growing season and source at winter (Malhi et al., 1999). Tropical forests hold 63% and 30% of world's forests plant biomass and soil carbon respectively (Table 3). Hence small shifts in the carbon cycling of tropical forests can have profound consequences for the global carbon cycle. Moreover, the turnover and response times of tropical forests are short, and hence the response to global perturbations (and adaptation to new environmental states) may be rapid (Malhi and Phillips, 2005). Globally, forest vegetation and soils contain about 1240 Pg C and nonetheless as much as two-thirds of terrestrial carbon in forest ecosystems contains soils (Dixon et al., 1994). Soil is the major and dynamic reservoir for carbon in terrestrial ecosystems and it can act as a sink or source of carbon depends on the land management activities (Lal, 2005). Obviously slight increases or decreases in the net flux of CO_2 from soils may have a measurable bearing on atmosphere (Amundson, 2001).

1.7 Global soil carbon reservoir

In the last thirty years there has been an interest in estimating the size of the global soil organic carbon pool (Bohn, 1976; Schlesinger, 1977, Post et al., 1982; Jobbagy and Jackson, 2000). There are two differing approaches to estimating this pool: (a) soil taxonomy and (b) ecosystem-based estimates (Kern, 1994). The taxonomic approach to tabulating soil carbon storage relies on the determination of the area extent and average carbon content of the major soil taxonomic groups of the world (Amundson, 2001). The two major soil classification/mapping schemes were used in global carbon tabulation are US department of agriculture soil taxonomy (USDA) and the food and agricultural organisation's (FAO) world

soil map (Amundson, 2001). Table 4 shows the world's soil taxonomy orders with soil organic carbon (SOC) content (Eswaran et al., 1993). SOC content is low in vertisols and high in histosols. In ecosystem based approach, soil organic carbon was estimated on the basis of generalised ecological life zones (Holdridge, 1947) which are distributed in relation to specific combinations of mean annual precipitation and mean annual temperature (Brown and Lugo, 1990). Table 2 shows the soil organic carbon stocks of different ecosystems of the world. They estimated global soil storage about 2542.3 Pg of carbon. There is a large error associated with estimating the mean carbon content of any ecologically or taxonomically based mapping unit (Amundson, 2001). Jobbagy and Jackson (2000) noted that average coefficient of variation is commonly≥60% for the mean carbon content of a mapping unit.

Table 4: Soil organic carbon pool of world soils

Soil order	Soil organic carbon (Pg)	
	Global	Tropical
Alfisols	127	30
Andisols	78	47
Aridisols	110	29
Entisols	148	19
Histosols	357	100
Inceptisols	352	60
Mollisols	72	2
Oxisols	119	119
Spodosols	71	2
Ultisols	105	85
Vertisols	19	11
Miscellaneous land	18	2
Total	**1576**	**506**

(Source: Eswaran et al., 1993).

The large error reflects a number of factors, such as climate variability within a map unit. In addition, variations in any other factors such as topographic position on the landscape, parent material, landscape age or biota have large effects on estimates values of soil organic carbon (Post et al., 1982; Amundson and Jenny, 1997). Jobbagy and Jackson (2000) estimated the global SOC storage in the top 3 m depth of soil was 2344 Pg C, and the first, second and third meter was 1502, 491 and 351 Pg C respectively.

1.8 Carbon stocks- Indian scenario

The global geographical area of India is 328.7 Mha (million hectares) or about 2.5% of the world total land area of the world (Lal, 2004). Of these, 161.8 Mha of arable land (11.8% of the world) of which 57 Mha (21.3% of the world) is irrigated, 68.35 Mha of forest and wood land (21.3% of the world), 11.05Mha of permanent pasture (0.3% of the world) and 7.95 Mha of permanent crops (6% of the world (Lal, 2004c). Recent Forest Survey of India (FSI) (2009) report said that forests and tree cover of the country is 78.37 Mha in 2007, which is 23.84% of the geographical area and includes 2.82% tree cover. FSI (2009) estimated the carbon stocks of forests, trees and soils (up to 30cm depth) across the country and reported at 6621 MtC (million tonnes) (1Mt=1×10 ^{3}Pg) it has increased from 6255 Mt C in the year 1995. FSI (2009) divided different types of forests (Table 4) and also estimated the SOC content of these forests. Among them tropical moist and dry deciduous forest stored more amount of SOC (Table 5) while tropical dry ever green stored very low amount of SOC stocks. The first study of organic carbon status in Indian soils was conducted by Jenny and Raychaudhuri (1960). They estimated organic carbon (OC) content in soils of cultivated lands and different types of forest with variable rainfall and temperature patterns. The first attempt in estimating OC stock in India was made by Gupta and Rao (1994). They estimated about 24.33 Pg of carbon in soils ranging from surface to an average subsurface depth of 0.44 to 1.86m with the database of 48 soil series.

Table 5: Estimates of SOC stocks of different forest types, India

| Forest type	Area (Mha)	SOC (Mt) up to 30cm	SOC (Pg ha^{-1}) up to 30cm 1×10^{-9}
Himalayan dry temperate forest	0.032	1.16	0.3625
Himalayan moist temperate forest	2.447	175.15	0.7158
Littoral and swamp forest	0.481	34.18	0.7106
Montane wet temperate forest	2.593	299.39	1.1546
Sub alpine and alpine forest	2.067	153.11	0.7407
Sub tropical broad leaved hill forest	0.303	26.24	0.8660
Sub tropical dry ever green forest	1.248	81.47	0.6528
Sub tropical pine forest	4.743	238.43	0.5027
Tropical dry deciduous forest	19.156	655.04	0.3420
Tropical dry evergreen forest	0.165	8.65	0.5242
Tropical moist deciduous forest	24.284	1335.85	0.5500
Tropical semi evergreen forest	2.946	160.93	0.5463
Tropical thorn forest	1.827	37.23	0.2038
Tropical wet evergreen forest	5.414	549.00	1.0410
Total	**67.706**	**3755.83**	**8.913**

(Source: FSI, 2009).

Bhattacharya et al. (2000) estimated the OC stock as 63 Pg in five major physiographic regions of India (northern mountains, the great plains, peninsular India, peninsular plateau and coastal plains and the islands) up to 150cm depth. Velayutham et al (2000) estimated about 20.99 Pg C up to 1.5m depth in different soil taxonomic orders (Table 6). Among different soil orders, aridisols and inceptisols stored more amount of carbon about 20.3 and 15.07 Pg respectively, followed by alfisols, vertisols, entisols, mollisols, oxisols and ultisols (Table 5). Bhadwal and Singh (2002) used three Land Use and Carbon Sequestration (LUCS) models to estimates the sequestration of carbon in different land use scenarios in India. The amount of carbon sequestered in scenario LUCS-III is estimated to be 6.937 billion tonnes, which is the highest among those sequestered in all the three scenarios. According to this scenario, the carbon sequestered in above-ground vegetation of India will be more than double by the year 2050. Lal (2004c) estimated SOC pool at 21 Pg up to 30cm depth and 63 Pg up to 150cm depth and also estimated the total potential of carbon sequestration is 0.039 to 0.049 Pg C y^{-1}.

Table 6: Soil organic carbon in different soil taxonomic orders from India

Soil order	Soil organic carbon (Pg)	
	0-30cm	0-150cm
Alfisols	4.22	13.54
Aridisols	7.67	20.30
Entisols	1.36	4.17
Inceptisols	4.67	15.07
Mollisols	0.12	0.50
Oxisols	0.19	0.49
Ultisols	0.14	0.34
Vertisols	2.62	8.78
Total	**20.99**	**63.19**

(Source: Velayutham et al., 2000).
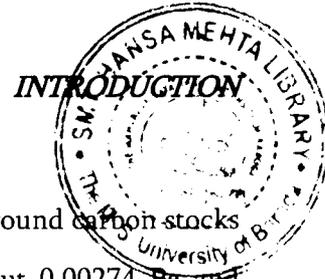
Ramachandran et al. (2007) estimated both above-and below ground carbon stocks of natural forest area of southern India. They estimated about 0.00274 Pg and 0.00348 Pg of carbon in above-ground biomass and soils respectively. Bhattacharya et al. (2008) estimated carbon stock (both organic and inorganic) of different agro climatic zones, bioclimatic systems and agro-eco sub regions of India. Bhattacharyya et al (2007) suggests that the agricultural management practices in India advocated through the national agricultural research system for the last 25 years did not cause any decline in SOC in the major crop growing zones of the country. Kumar et al. (2009) suggests that carbon sequestration through cultivation of cold resistant agroforestry species like willow and poplar can also restore degraded lands (Trans-Himalayan region) and improve SOC along with global CO_2 mitigation. A dynamic growth model (CO2FIX) was used by Kaul et al. (2010) to estimate the carbon sequestration potential of sal (*Shorea Robusta* Gaertn. f.), eucalyptus (*EucalyptusTereticornis* Sm.), poplar (*Populus Deltoides* Marsh), and teak (*Tectona Grandis* Linn. f.) forests in India. Their results indicated that poplar (8 Mg C ha $^{-1}$yr $^{-1}$) (1Mg = 1×10^{-9} Pg) and eucalyptus (6 Mg C ha $^{-1}$yr $^{-1}$) plantations had highest carbon sequestration rate followed by moderate growing teak forests (2 MgC ha $^{-1}$yr $^{-1}$) and slow growing long rotation sal forests (1 Mg C ha $^{-1}$yr $^{-1}$). Based on different forest types in India, the national average of soil organic carbon per hectare in forest soil was estimated as 183 Mg C ha $^{-1}$ (Jha et al., 2003).

1.9 Processes regulating the storage of organic carbon in soils

Carbon storage in soils is a dynamic balance between detrital inputs (Primarily litter and dead roots) and organic matter outputs in the form of CO_2 efflux from the soil (Chen et al., 2005). The size of the soil organic matter pool is determined by the rate of input of fresh organic matter, the proportion of added carbon that is humified and the rate of efflux of carbon (Kemmitt et al., 2008). The carbon stock in terrestrial ecosystems represents the difference between the input from

net primary production (in terms of quality and quantity) and the output through decomposition (Couteaux et al., 1995).

1.9.1 Litter decomposition

Plant litter decomposition is a dominant process for the flow of carbon and nutrients in most terrestrial ecosystems (Hattenschwiler et al., 2005). An understanding of plant litter decomposition is important because it is one of the important processes of global carbon cycle. Litter is broken down by two stage process. First, litter is broken down by detritovores to small pieces which can be chemically reduced (Aerts, 1997). Secondly, through the activities of microorganisms (bacteria and fungi) these small pieces of organic matter are further reduced and mineralized into basic inorganic molecules, such as ammonium, phosphate, CO_2 and water (Aerts, 1997). These can be taken up by plants or micro organisms, leached out of the system or in the case of gaseous break down products, released to the atmosphere (Swift et al., 1979; Golley, 1983). Litter decomposition is regulated by three factors: 1) climate 2) litter quality, and 3) the nature and abundance of microbial communities (Couteaux et al., 1995). Climate has a direct effect on litter decomposition due to the effects of temperature and moisture (Aerts, 1997). Temperature and precipitation on litter decomposition rates are stronger in the early stage (Berg, 2000). Although, early decomposition rates are strongly affected by litter chemical components (Berg, 2000; Gartner and Cardon, 2004). Feng et al. (2008) reported that lignin derived SOM is susceptible to enhanced degradation under warmer temperatures. Thus climate is affecting the storage of SOC through litter decomposition processes. The bulk of litter comprises structural components of plant cell walls (cellulose, hemi-cellulose and lignin) and hence carbon is always in much larger concentrations than nutrients (Johansson, 1995). In addition to structural polymers, litter also contains water soluble fractions, such as simple sugars and aminoacids, oils, waxes, simple and complex phenolic compounds, cutins (Alexnader, 1977; Swift et al., 1979). Many studies demonstrated that the relationships between the litter quality

characteristics and decomposition rates for a large number of plant species (Rubino et al., 2007; Cornwell et al., 2008). The C:N ratio is accepted as a general index of quality (Seneviratine, 2000). Mineralization rate tends to decrease with increasing C:N ratio. The early stages of decomposition are dominated by the easily decomposable carbohydrates, while at later stages lignin exerts the major control on decomposition rate (Corbeels, 2001). Soil microbes play a pivotal role in litter decomposition processes. They release degradative enzymes that attack dead OM, breaking it down into digestible units that they can take up (Agren, 2010). It is mentioned that at most of the times two different groups of microbes (autochthonous and zymogenous) participate in decomposition/ mineralization (Kemmitt et al., 2008; Fontaine et al., 2004) processes. These two groups of microbes will active depends upon the availability of substrates (Fontaine et al., 2004). Zymogenous group of microbes flourish with the availability of fresh inputs and mainly metabolises the labile fractions (cellulose and hemicelluloses). They become dormant when the fresh supply stops (Kemmitt et al., 2008). Autochthonous group of microbes will survive even if the fresh supply is stopped. They mainly metabolise the recalcitrant fraction of soil organic matter (Winogradsky, 1924; Langer et al., 2004; Kemmitt et al., 2008). After all these actions, the remaining soil organic matter becomes stable for longer periods of time. Thus microbial community types affect the SOC storage via litter decomposition process.

1.9.2 Soil respiration

Soil respiration is an ecosystem process that releases carbon dioxide by root respiration, microbial respiration and fauna respiration (Luo and Zhou, 2006). Soil respiration is intimately associated with nutrient processes such as decomposition and mineralization (Luo and Zhou, 2006). Moreover, soil respiration plays a critical role in regulating atmospheric CO_2 concentration and climate dynamics in the earth system (Luo and Zhou, 2006). Thus, it becomes relevant to the mitigation of climate change and the implementation of international climate

treaties in terms of carbon storage and trading. In recent years, much attention has been paid on soil respiration because it is recognized as a major soil carbon efflux and one of the key components of the carbon cycle in terrestrial ecosystems (Raich and Schlesinger, 1992; Raich and Potter, 1995). It was reported that soil respiration could represent 40–90% of the forest ecosystem respiration (Schlesinger and Andrews, 2000). On a global scale, soil respiration produces 80.4 Pg CO_2-C annually, which is approximately 10 fold greater than that from fossil fuel combustion and deforestation sources combined (Raich et al., 2002). The annual flux of CO_2 from global soils to the atmosphere (which roughly equals the amount of carbon fixed by plants) is only slightly less than the annual CO_2 exchange between the oceans and the atmosphere (Sundquist, 1993). Obviously slight increases or decreases in the net flux of CO_2 from soils may have a measurable bearing on atmospheric CO_2 levels (Amundson, 2001). Even small changes in soil respiration may greatly influence atmospheric carbon and heat balance (Veenendaal et al., 2004; Kane et al., 2005). This, soil respiration is the main pathways for carbon moving from the ecosystem to the atmosphere and can strongly influence net carbon uptake from the atmosphere or net ecosystem production (NEP) the balance between photosynthesis (GPP) and ecosystem respiration (Ryan and Law 2005).

Boreal forests and tundra have the largest store of labile organic matter and the greatest predicted rise in temperature (Luo and Zhou, 2006). Organic carbon accumulated in the soil over previous, colder periods is now decomposing and being released through soil respiration as the soil warms in response to climate change (Malhi, 1999). Tropical regions have large pools of SOM with relatively rapid turnover times (Trumbore, 2000). Carbon fluxes in the tropical regions are also larger than those in temperate and northern forests (Raich and Schlensinger, 1992). It is well known that the activity of soil microorganisms increases with temperature, a relationship that shows an approximate doubling of activity for each 10°C increase in temperature (Kirschbaum 2000). Global warming potentially

stimulates great losses of soil carbon in the tropics (Trumbore et al. 1996). Thus, understanding soil respiration in different regions is critical in predicting regional and global carbon cycles.

1.10 Importance of SOC

In most soils (with the exception of calcareous soils) the majority of carbon is held in the form of SOC (Batjes and Sombroek, 1997). Soil contains about 1.5 to 3 times more organic carbon than that of vegetation and about twice as much carbon than is present in the atmosphere (Post et al., 1982; Batjes, 1996; Jobbagy and Jackson, 2000). Any changes in terrestrial SOC stocks can ultimately lead to climate feed back. SOC is a major indicator of soil quality and sustainability, influencing the physical, chemical and biological parameters (Reeves, 1997). SOC is vital for ecosystem function, having a major influence on soil structure, water-holding capacity, cation exchange capacity, and the soils ability to form complexes with metal ions and to store nutrients (vanKeulen, 2001). In addition to this SOC plays an important role in supplying plant nutrients, improving soil aggregation and water retention and supporting soil biological activity (Dudal and Deckers, 1993). Soil organic matter is not only a major regulator of various processes underlying the supply of nutrients and the creation of a favourable environment for plant growth but also regulates various processes governing the creation of soil-based environmental services (Vanlauwe, 2004).

OC storage in soils mainly depends on climate (Schimel et al., 1990), altitude (Dixon et al., 1994), topography (Yimer et al., 2006), soil texture (Bosatta and Agren, 1997; Hassink et al., 1997; Ratnayake et al., 2008) and vegetation types (Jobbagy and Jackson, 2000; Chen et al., 2005). The rate of accumulation of SOC in soils is totally dependent on the quantity and quality of organic matter input. The quantity and quality of organic matter input into soils is varying from species to species under different climatic conditions (Fierer et al., 2005). Thus, variations in vegetation cover types have significant effects on the storage of SOC (Dinakaran

and Krishnayya, 2008). Paul et al (2002) reported that tree species have different impacts on soil carbon pools and dynamics. The information about the affects of different types of vegetal/land cover on SOC storage and dynamics is very sketchy in tropical lands.

1.11 Influence/s of land cover on SOC

The type of vegetation covering the earth's surface is called as land cover (IPCC, 2003). Globally, many studies on SOC dynamics agreed that the amount and relative distribution of SOC is mainly associated with vegetation cover than climate (Jobbagy and Jackson, 2000). Gill and Burke (1999) reported that dominant plant life forms or community type (e.g. trees, shrubs, grasses and herbs) changes have an influence on soil carbon content. This is because plant life forms alter litter chemistry, patterns of detrital input. Other studies also reported that plant life form typically differs in the depth and distribution of their root systems (Jackson et al., 1996; Nepstad et al., 1994) which influences the amount and distribution of soil carbon (Matamala et al., 2003). Plant species have the potential to influence soil carbon pools and their dynamics through variation in carbon inputs (that is, net primary production) and by influencing carbon losses, including SOM decomposition (Hobbie et al., 2007). Among tree species, O-horizon (organic horizon) pool sizes are largely controlled by the difference between inputs via litter fall and outputs via litter decomposition (Olson, 1963) and thus should exhibit marked differences among species that vary in those attributes (Binkley and Giardina, 1998). Hobbie et al. (2007) studied the influence of tree species on soil carbon and nitrogen dynamics in a common garden of replicated monocultures of fourteen angiosperm and gymnosperm, broadleaf and needle leaf species in southwestern Poland. Also they reported that tree species contribute to variation in SOM dynamics, even in the mineral soil horizons. Tropical forests contain more than half of the earth's terrestrial species (Myers et al., 2000). But the effect of different tree species on soil carbon sequestration is not

yet clear in tropics. Thus, understanding carbon sequestration in different types of vegetal cover is indeed important in tropical ecosystems.

1.11.1 Teak cover

Teak, scientifically called *Tectona grandis* Linn f (family: Verbenaceae), is one of the most valuable timber tree species of the world (Shukla, 2009). It occurs naturally between 9° to 26° N latitude and 73° to 140° E longitude in the tropical and sub-tropical regions of south and south-east Asia which include peninsular India, Myanmar, Thailand and Laos (White, 1991). Teak is a large deciduous tree species that mature plants can reach 30 to 40m height and 2m diameter (Khanduri et al., 2008). Teak occurs in moist and dry deciduous forests below 1000m elevation and is one of the several species constituting mixed forest stands (Pandey and Brown, 2000). It can grow in a wide variety of soils, tolerate a wide range of climates, and have best growth under the conditions that the minimum monthly temperature is above 13°C and the maximum monthly temperature is below 40°C (Khanduri et al., 2008). Teak is one of the most important tropical hardwood species in the international high-quality timber market (Derwisch et al., 2009). Teak is native to India, Myanmar (Burma), Thailand and Laos, but this broad leaved tree species grows now a days in the whole intertropical region (excluding desert areas of Africa) (Bermejo et al., 2004). It has been growing naturally in Java, where it was probably introduced some 400-600 years ago (Troup, 1921, Kadambi, 1972, White, 1992). Early introductions of teak outside Asia were made in Nigeria, with the first plantations being of Indian origin in 1902 and subsequently of Burmese origin (Horne, 1966). It is one of the most extensively planted tree species in the tropics, constituting about 25 million hectare plantation area worldwide (Behaghel, 1999). The area of teak plantations in tropical Africa is about 4.5% of total area of teak plantations and the rest are in tropical America, mostly in Costa Rica and Trinidad and Tobago (Pandey, 1998). The plantation forests of 5.3 million ha teak in Asian Pacific region have been managed under 35

to 80-year rotations, yielding 5 to 20 m^3 $ha^{-1}year^{-1}$, while 31,0000 hectare plantations in Africa are harvested at 20-year rotations, yielding between 4 and 13 m^3 $ha^{-1}year^{-1}$ (Bhat and Hwan Ok Ma, 2004). Teak was introduced in Central America less than a century ago (de Camino et al. 1998). By the year 2000, approximately 223,000 ha of teak plantations were established in Central America (Pandey and Brown, 2000). Perez and Kanninen (2003) examined the distribution of total aboveground biomass of teak plantations in different regions in Costa Rica and its relationship with diameter, age and stand density. Carbon can be stored in the production of high quality timber such as teak (*Tectona grandis* Linn. f.) (Derwisch et al., 2009). Kraenzel et al. (2003) measured the above and below-ground biomass and the tissue carbon contents of 20-year-old teak plantation in Central Panama. In the last decade, its high value as timber of excellent appearance and mechanical resistance, and the appearance of strong markets for teak products which parallels an increasingly declining stock of natural stands, have attracted particular attention to the potential of teak plantations as a high return investment possibility (Ball et al., 2000). In recent years private investors established several teak plantations in the Province of Chiriqui (Western Panama) for carbon sequestration and timber production (Derwisch et al., 2009). Because carbon sequestration rates and the total amounts of carbon stored in tropical ecosystems are highly noticeable.

In India, which is one of the major teak producing countries, its natural zone of distribution is discontinuous and is mostly confined to the peninsular region below 24 degree latitude (Chakrabarti and Gaharwar, 1995). The total area of natural teak forests in India has been estimated to be 9.77 Mha (million hectare), which is about 13% of the total forest area of the country (Keswani, 2001). The localities where most important teak forests are found are Andhra Pradesh, Madhya Pradesh, Maharashtra, Tamil Nadu, Karnadaka and Kerala besides Uttar Pradesh, Gujarat, Orissa and Rajasthan (Chakrabarti and Gaharwar, 1995). It also has been raised mainly by plantation in Assam, Dadra and Nagar Haveli,

Meghalaya, Gujarat, West Bengal, Utter Pradesh and Haryana. However, in India, the history of teak planting dates back to the year 1842 when the first teak plantation was attempted at Nilambur in Kerala state (Prabhu, 2003). Presently, there is more than 1.5 mha area under teak plantations in India (Shukla, 2009). Teak plantations are being raised at an average annual rate of about 50,000 ha (Subramanian et al, 2000). Teak is one of the most important species growing in tropical forests of India. Area under teak cultivation makes it an important land over to study carbon sequestration.

1.11.2 Bamboo cover

Bamboo is the vernacular or common term for members of a particular taxonomic group of large woody grasses (subfamily:Bambusoideae, family: Poaceae) (Scurlock, 1999). Bamboo, popularly known as giant grass, with more than 1575 species in 75 genera in the world, occurring in a great variety of soil and climatic conditions, plays an important role in providing livelihood, ecological and food security of the man kind (Gupta, 2008). Bamboo forest is an important forest type in tropical and subtropical areas, with a total area of 23.455 Mha at present (Lobovikov et al., 2007). Although the total forest areas in many countries have drastically decreased, bamboo forest area has progressively increased (Zhou et al., 2005). China with over 500 species in 39 genera, has the richest bamboo resources in the world in terms of number of species, area and reserve of bamboo, and has long been known as the "Kingdom of Bamboo" (Zhou et al., 2005). There are about 1500 traditional uses of bamboo broadly classified into household, industry, weapons, energy, transportation, fisheries, agriculture, medicine and construction (Dubey et al., 2008). In recent years, bamboo culm is used as the raw material for the manufacture of pulp and plywood (Yang et al., 2008). Bamboo's role in stabilizing river or water reservoir embankments has also been widely recognized (Yang et al., 2008). Many species of bamboo are beautiful in appearance, and this has come to be appreciated by gardeners, interior designers and landscape artists

who use it to beautify the environment (Yang et al., 2008). Besides, bamboo is known to be one of the fastest growing plants in the world, with a growth rate ranging from 30 to 100cm day^{-1} in growing season (Zhou et al., 2005). A culm can reach its full height in a matter of two to three months (Zhou et al., 2005). Bamboos are a significant structural component of many forest ecosystems and play a major role in ecosystem dynamics through their distinctive cycles of mass flowering and subsequent die-off, which may increase the importance of fire (Keeley and Bond, 1999). Its biological characteristics make it a perfect tool for solving many environmental problems, such as erosion control (Austin et al., 1970) and CO_2 sequestration. Bamboo is an important part of forest ecosystem and an important carbon source and carbon sink on the earth (Li et al., 2003). The potential carbon sequestration of *Dendrocalamus strictus* forest can contribute to settings levels of possible compensation to countries that are obliged to conserve forest beyond its own needs (Bijaya, 2008). Bamboos are tall, perennial, arborescent and common grasses, which not only provide direct production benefits but also indirect environmental benefits in the form of abating global warming and climate change through conserving atmospheric CO_2 (Bijaya, 2008).

India is second to china in bamboo resources with about 24 genera and 134 species (Nath et al., 2008). It covers an area of about 10.03 Mha that constitutes about 12.8% of the total area of forest cover in India (Chand and Sood, 2008). Areas particularly rich in bamboo are the North-eastern regions, Western Ghats, Bastar region of Madhya Pradesh and Andaman and Nicobar Islands (Nath et al., 2008). In many parts of India especially the north east, bamboo shoots form a part of traditional cuisine whether fresh, dried, shredded or pickled (Nath et al., 2008). This is another potential land cover to look at its ability in regulation of SOC.

1.11.3 Mixed tree species cover

Forest areas are dominated by one or more tree species of neither deciduous nor evergreen species is called mixed forest. Tropical forests often are referred to as one of the most species-diverse terrestrial ecosystems (Kumar et al., 2004). In addition, a mixture of species, each with different nutrient requirements and different nutrient recycling properties, may be overall less demanding on site nutrients than pure stands (Binkley et al., 1997; Folster and Khanna, 1997). Mixed plantations can produce more biomass per unit area because competition among individuals is reduced and the site is used integrally (Montagnini et al., 1995). The roots of different species may occupy different soil strata allowing more complete utilization of soil and water resources (Lamb and Lawrence, 1993). More solar energy can be captured because different species have different light requirements and crowns are broadly distributed in the vertical plane (Guariguata et al., 1995). Benefits from the use of mixed plantation may result from better site use, improved tree nutrition, and less insect or pest damage (Brenes and Montagnini, 2006). There is continued interest in mixed-species plantations amongst landowners and researchers in tropical and subtropical regions (Kanowski et al., 2005; Piotto et al., 2004). Mixed plantations yield more diverse forest products than monospecific stands, helping to diminish farmers risks in unstable markets (Montagnini, 2000). Mixed designs can be more productive than monospecific systems (Sayyad et al., 2006). More complex plantation mixtures of 5–70 species have been used for ecological restoration of degraded lands (Kelty, 2006). These mixtures can also improve economic return through greater individual-tree growth rates and provision of multiple commercial or subsistence products (Kelty, 2006). An earlier study (Piotto et al., 2004) reported that mixed plantations with native species would contribute more to sustainable management, because while single-species plantations do not provide a great range of goods and services when compared to the natural forest, mixed plantations are likely to increase this range of benefits. There may be also financial gains from combining fast-growing species

that can be harvested earlier in a rotation, with more valuable species that need

longer rotations (Brenes and Montagnini, 2006). In a mixed deciduous forest of

central India as many as 80-100 tree species associate with teak (Bhatia, 1958).

There is a lack of information about carbon sequestration in mixed species cover of

tropical forest in India.

1.12 Importance of this study

The above mention literature presented clearly indicates that   plant species have

the potential to influence soil carbon pools and their dynamics through variation

in carbon inputs (through litter fall, SOM decomposition and carbon losses (soil

respiration). Understanding variations in SOC content across different depths of

soils with different vegetal cover is very important. Thus understanding and/or

measuring the carbon sequestration in any ecosystem is quite challenging task.

The UNFCCC requires parties to report on all sources and sinks of carbon,

including vegetation and soil (Coomes et al., 2002). In addition, signatories of the

Kyoto protocol (from Annex 1 countries) will be obligated to monitor 'the net

changes in greenhouse gas emissions resulting from direct human induced land use

change and forestry activities' although there is still uncertainty about which

carbon stocks need to be accounted for, or the degree of precision required

(Coomes et al., 2002).

Current growth rates in economy and commitment to environment protection of

our country makes its necessary to estimate the SOC content and sequestration

pattern of different types of land cover. Gujarat is economically a fast growing

state of our country and the forest and tree cover of the state is 23,010 km^2, which

is 11.74 of the geographical area while reserved, protected and unclassified forests

constitute 74.61%, 2.53% and 22.86% of the total area respectively (FSI, 2009). As

per FSI (2009) classification, the state has 23 different forest types which belongs

to four forest type groups viz., tropical moist, tropical dry deciduous, littoral and

swamp and tropical thorn forests, among tropical dry deciduous forests cover about 53.16% followed by tropical thorn forests (19.36%), tropical moist forests (12.28%), littoral and swam forests (6.67%) and plantations/trees outside forests (TOF) (8.54%). The natural vegetation of the state is restricted to areas which receive adequate rainfall. Trees (mostly) which are present in the forests of Gujarat deciduous during the dry season. According to Manhas et al. (2006), teak spreads 572 km² across the Gujarat forests also he estimated the total carbon stock (from biomass) of mangrove; teak and miscellaneous forests of Gujarat were about 13.14 and 19.92 Mt in 1984 and 1994 respectively. There is a need of study especially carbon sequestration in different types of land cover in Gujarat to understand the effects of land cover on carbon sequestration process. Keeping the above information as a background the study was initiated in central Gujarat with the following objectives: **(1) to estimate the organic carbon in different types of land cover and (2) different pools of soil organic carbon.**