Chapter 1

General Introduction

Carbon (C) is the basis of life on earth. The term carbon cycle or carbon budget means the cyclic pathway of carbon through our atmosphere between pools of carbon near the earth’s surface to the water and sediments in the ocean. Currently, an imbalance has been seen in the global carbon budget due to climate change that is attributed to excessive usage of fossil fuels viz. coal, petroleum and natural gas.

Carbon is available in the earth’s atmosphere as carbon dioxide (CO₂) and methane (CH₄). These gases along with water vapour act as important greenhouse gases (GHG). They absorb the infrared radiation coming from the sun and trap it in the earth’s atmosphere thereby keeping the atmosphere warm. A rise in the concentration of these greenhouse gases will ultimately affect the earth’s energy budget. This energy budget is responsible for the global circulation of heat and water through the atmosphere and the patterns of temperature and precipitation is experienced as weather and climate. An alteration in the global carbon budget will thus ultimately affect the earth’s energy budget thereby having consequences on climate and climate change. Carbon dioxide has been considered as the single largest forcing agent of climate change according to the Strategic Plan of U. S. Climate Change (CCSP, 2003).

Global C can be partitioned into five large pools: oceanic (38,000 Pg C, where Pg = petagram = 10¹⁵ g [42,000 billion tn]); geologic (5,000 Pg [5,500 billion tn]); pedologic, or soils-based (2,460 Pg [2,710 billion tn]—1,500 Pg [1,650 billion tn] in SOC and 950 Pg [1,050 billion tn] in SIC); atmospheric (800 Pg [887 billion tn], increasing at the rate of ~4.1 Pg C yr⁻¹ [4.5 billion tn yr⁻¹] [IPCC, 2007]); and biotic C (550 Pg [606 billion tn]) (Houghton 2007; Lal 2004, 2006). Approximately 9 Pg (9.9 billion tn) of C is presently released to the atmosphere each year from burning fossil fuels and industrial activity, and another ~1.5 Pg (1.7 billion tn) is released from deforestation and land use change (Global Carbon Project 2009). Evidently, atmospheric
carbon dioxide and oxygen data confirm that the terrestrial biosphere became a net carbon sink in 1990s (IPCC, 2001).

Although links between land use/cover changes and flux of carbon to the atmosphere are commonly acknowledged, uncertainties exist concerning the magnitude of such fluxes. Therefore, the estimates of the global CO$_2$ release from biomass reductions and land clearing are being reported to vary between 8 and 44% of total anthropogenic CO$_2$ emissions (Schimel, 1995; Cook et. al., 1990). More accurate estimates of global or continental CO$_2$ emission from land use/cover change can only be obtained from extrapolation of reliable local estimates (Cairns et. al., 1996). Therefore, comprehensive information on the spatial and temporal distribution of land use and land-cover change is a prerequisite for understanding the carbon flux.

Carbon budgeting involves both input and output of carbon between the atmosphere and the biosphere of the planet earth while significant amount of the carbon is sequestered permanently in soil leading to carbon accumulation. The C cycling is thus an important pathway in an ecosystem that determines the above ground productivity and also soil biological activity. It is further crucial in agro–ecosystem where soil fertility vis-à-vis nutrient availability is dependent on soil organic matter whose major constituent is C.

The consequences of unbalanced C budget is not yet fully understood till date, however, it is assumed to be beyond climate change alone. For in stance, experiments have proved that in many of the plant species, a rise in the level of CO$_2$ would result in higher rates of photosynthesis manifesting greater productivity. But at the same time, uncertainty prevails over the fact that whether increasing concentrations of CO$_2$ will actually increase the productivity of plants and enhance agricultural crop yield in the near future as the climatic conditions will also change along with it. Also increased level of CO$_2$ is primarily responsible for increasing acidity of the ocean surfaces which in turn is fatal for corals and other marine organisms that require calcium for building their skeletons and shells.

Photosynthesis by green plants capture and convert CO$_2$ into organic form, which is the way elemental carbon enters into the terrestrial ecosystems, including agricultural
systems. Some of this carbon enters the soil and add to the soil organic carbon (SOC) and inorganic carbon pools and ultimately returned back to the atmosphere. CO$_2$ assimilation by green plants depends on various factors such as soil fertility, climatic conditions, management practices etc. Three major thrusts of GHG mitigation research in agriculture are

1. Developing management practices to enhance the assimilation of atmospheric CO$_2$ by vegetation,

2. Managing the movement of C from the plants/animals into the soil, and

3. Altering the cycling of SOC to increase its residence time.

Carbon sequestration into soil organic matter (SOM) is considered to be among the best option for storing C in terrestrial ecosystems. Besides help in offsetting CO$_2$ emissions, C sequestration provides multiple benefits like improved soil quality, soil structure and aggregate stability, water holding capacity and capacity to reduce toxic elements (Morgan et al., 2010).

Recently, understanding of soil organic C dynamics and its distribution at a regional level has been considered as an essential step when quantifying regional and global C budgets. The estimation of SOC is a way of indirect assessment of C sequestration to complement direct measurements. It may also help in the identification of areas with a large potential for increased soil organic carbon (SOC) sequestration as well as making it possible to predict and understand future changes due to changing climate, altered land use and different land management practices. To be successful, these budgeting models however need to incorporate both human and environmental factors while predicting the regional soil organic carbon pool changes.

SOC plays a vital role in the maintenance of the health of soil system, the media for plants growth. Decomposition by microbes of soil organic matter (SOM) releases nitrogen (N), phosphorous (P) and other essential elements for use by the plant roots. During the process of decomposition, microbes also produce resins and gums that bind the soil particles together into stable aggregates. The improved soil structure can hold more water, allows air and plant roots to move easily between them. Organic C is also the source of nutrition for a variety of organisms in the soil. Availability of organic C
decides the microbial diversity in the soil, their nutrients recycling, improving soil structure and suppressing some of the plants diseases. It is also known to lessen the effect of toxic substances by absorption of toxic heavy metals and degradation of harmful pesticides.

SOC makes up about two-thirds of the C pool in the terrestrial biosphere; annual C deposition and decomposition to release carbon dioxide (CO₂) into the atmospheric constitutes about 4% of this SOC pool. Cropland is an important, highly managed component of the biosphere. Among the many managed components of cropland are the production of crop residue, use of tillage systems to control crop residue placement/disturbance, and residue decomposition. Accumulation of SOC is a C sink (a net gain from atmospheric CO₂) whereas a net loss of SOC is a C source to atmospheric CO₂.

Carbon storage and sequestration in agricultural soils is considered to be an important issue in the study of terrestrial C cycling and global climatic change. The baseline C stock and the C sequestration potential are among the criteria for a region or a state to adopt strategies or policies in response to commitment to the Kyoto Protocol. Paddy soils represent a large portion of global cropland. However, little information on the potential of C sequestration and storage is available for such soils. For instance paddy soils represent a large portion of global cropland. However, little information on the potential of C sequestration and storage is available for such soils.

In India, it has been estimated that nearly 20 percent of the country’s total greenhouse gas emission results from agricultural processes. Thus a change in the management practices of agro-ecosystems may lower the production of these gases. Agricultural systems contribute to carbon emissions through consumption of direct and indirect fossil fuel. Increasing use of fertilizers, mechanical irrigation and other mechanized power, all of which are energy intensive practices, the result is that industrialized agriculture has become progressively less energy efficient. In addition to CO₂, methane and nitrous oxide are two other agricultural GHGs significantly contributing to climate change. Methane emission from agricultural systems occur primarily from livestock through enteric fermentation and from wetland systems like
rice, with emission rates being sensitive to N, water availability, soil pH, and amounts and forms of SOC. Nitrous oxide emissions from agriculture are largely the result of N fertilizer additions. However, the practices adopted by farmers in the agricultural fields largely influence the dynamics of C and other nutrients in soil vis–a–vis crop production.

The Apatanis (an indigenous tribe), settled in the higher elevation of Arunachal Pradesh (the present study area), live with limited land under agriculture and hence use the land efficiently to sustain productivity. Here, year after year same crops are continuously grown i.e. paddy which needs long period of standing water and eventually able to successfully involve agri–pisciculture. After harvest, the water is drained and left as fallow. The leftover stubble, after harvesting crops, is also burnt to clear away the land. All this process again adds to the amount of carbon in the soil. More carbon hence expectedly accumulated in the soil. As we know carbon being insoluble is water, gets locked up in the soil over time. This affects percolation of surface water. Though carbon is abundantly present in the soil, but the bioavailability of the element is reduced. Under such scenario, organic agriculture offers a unique combination of environmentally-sound practices with low external inputs while contributing to food availability (Zundel et al., 2007). Even in developing countries it has been seen that people are opting for organic agriculture as they are becoming more and more conscious of health and environment. Recent studies have highlighted the substantial contribution of organic agriculture to climate change mitigation and adaptation (Scialabba and Muller-Lindenlauf, 2010, Niggli et al., 2009).

Agricultural practices also exacerbate climate change. The Intergovernmental Panel on Climate Change (IPCC, 2004) stated that agriculture contributes 13.5 percent of global greenhouse gas emissions. According to Greenpeace, if calculating both direct and indirect emissions from the food system, agriculture’s contribution could be as high as 32 percent. The future of agricultural production relies on both designing new ways to adapt to the likely consequences of climate change, as well as changing agricultural practices to mitigate the climate damage that current practices cause, all without undermining food security, rural development and livelihoods which is also popularly known as “climate resilient agriculture”.

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Climate change and food security are related because climate change can directly affect a country’s ability to feed its people. However, research shows climate change will not equally affect all countries, and will likely have the biggest impact in equatorial regions such as sub-Saharan Africa. This means that countries already struggling with food security are likely to find they struggle still harder in the future. The IPCC projects that yield from rain-fed farming in some African countries could be reduced by up to 50 percent by 2020. Meanwhile, countries such as the United States are experiencing changing agricultural land use patterns due to climate change.

In wet-paddy cultivation systems, integrating aquaculture assures higher productivity and year round employment for farmers. For instance the plots utilized for rice–cum–fish culture by the ‘Apatanis’ is mainly based on organic fertilization with varieties of animal excreta such as poultry dropping, pig excreta, cow dung and wastes of plants such as rice husks, waste product of local beer and ashes from household burnt and remains of burnt straws after the harvest is over. And compost fertilizer like decomposed straws, weeds and stalks. They utilize varieties of domestic waste products to their paddy field to enhance crops productivity which in turn enhance soil fertility as well as feed to fishes. Therefore, an understanding of the valley land agro-ecosystem function of the Apatanis becomes significant in a hilly environment (Ramakrishnan, 1992).

Over all, soil C is an important determinant of site fertility due to its role in maintaining soil physical and chemical properties (e.g. aggregate stability, cation exchange capacity) (Reeves, 1997). Restoration of soil quality through soil organic carbon (SOC) management has remained the major concern for tropical soils. To make this successful, the comprehensive knowledge on SOC stocks forms an essential prerequisite in future land resource management programmes. While important factors controlling SOC levels include climate, hydrology, parent material, soil fertility, biological activity, vegetation patterns and land use, SOC is sensitive to impact of human activities viz. deforestation, biomass burning, land use changes and environmental pollution. To sustain the quality and productivity of soils, knowledge of SOC in terms of its amount and quality is essential.
A good farming practice can decrease CO₂ evolution from soil into the atmosphere and enhance soil fertility and thus productivity (Lal, 2004). This is more important in tropical and subtropical region where soils are inherently low in organic C content and production system is fragile (Mandal et al. 2005). Studies have shown that such an increase in soil organic C (SOC) levels is directly linked to the amount and quantity of organic residues return to the soils (Rasmussen et al. 1980). In addition to manuring and also fertilization (Hartwig and Ammon, 2002), cropping sequence (Kuo et al., 1997), duration and timings of ‘fallowing’ etc. (Halvorson et al. 2002) can also affect the SOC stocks. Further, soil aggregation dynamics also influence SOC sequestration and cycling (Tisdall and Oades, 1982).

Soil carbon turnover and storage are controlled in large part by climate (Jenny, 1980), but the heterogeneous nature of SOM complicates analyses of the relationship between decomposition and climate. Reportedly soils contain thousands of different low to high molecular weight compounds that vary dramatically in their resistance to decomposition, with fractions of SOM that vary in turnover time from days up to thousands of years (Kononova, 1975, Schlesinger, 1977, Van Veen and Paul, 1981). The most labile pools comprise only a small fraction of the total, but because they turn over so rapidly, day to day soil CO₂ efflux is dominated by their dynamics (Schimel et al., 1994), while more recalcitrant pools dominate the SOM inventory (Trumbore, 1993). Correlations between climate and measurements of respiration in either field or short-term lab studies therefore may not apply to the bulk of SOM, but the response of these large pools to prolonged environmental changes will determine any major shifts in soil carbon storage.

Carbon sequestration is currently being considered as a way to mitigate the greenhouse effect and, simultaneously, combat land degradation (Lal, 2001, Olsson and Ardo, 2002). To this end, much current research is oriented towards a better understanding and quantification of carbon fluxes and stocks in a variety of ecosystems including agro–ecosystems (Post 2001). Hill agro–ecosystems in a humid tropical environment gains much more significance as they are not only production systems, but also have a wide array of intangible benefits that helps serve both ecological
synchronization of ecosystem services and also human livelihoods per se. So far, no any study has attempted to study the carbon potential of an agri–pisciculture system, particularly in the ‘Apatani’ plateau that has both cultural as well as socio–ecological principles bonded within the biodiversity rich state of Arunachal Pradesh in North–East India.

Hence, the present study is aimed at understanding carbon flux in the agro–ecosystems managed by ‘Apatani’ community with the following specific objectives:

1. To estimate the soil organic carbon (SOC) as a function of land and nutrient management practices and productivity.
2. To study the carbon flux in relation to traditional land management practices.
3. To budget the carbon for effective system management.