CHAPTER-1

INTRODUCTION

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Climate change is a major threat to the humans and other living organisms on the earth. The increasing atmospheric concentrations of greenhouse gases (CO_2, CH_4 and N_2O) are the main contributors to the global warming [1]. The strong relationship between increasing CO_2 concentration and global warming is the most discussed environmental issue among the scientists, policy makers, politicians and common people over the past century [2]. In response to this serious issue in the year 2015, an agreement was signed at Paris among 195 representatives of different nations to maintain the global average rise of temperature below 2°C above pre-industrial levels [3]. Accordingly, the nations targeted to limit the increase of global temperature 1.5°C above the preindustrial levels [3]. The atmospheric characteristics of the earth have been influenced by the rapid change in atmospheric CO_2 concentration [4]. Anthropogenic activity is reported to be responsible for addition of 10 billion tonnes of carbon per year to the atmosphere [5]. Fortunately, out of this total emitted carbon only half of this stays in the atmosphere and the remaining half is believed to be absorbed by terrestrial sinks like forests and oceans [6, 7]. The terrestrial carbon sink has been estimated as 2.6 PgC in the year 2010 by [8]. By regulating the use of fossil fuels it is possible to control the emission of CO_2 but it will have serious impact on the economic growth [9, 10]. Forests are considered as one of the most important and major terrestrial carbon sinks of the global carbon cycle [11, 12] as they can assimilate and store carbon for a longer duration compared to other ecosystems [13]. The carbon content of the forest ecosystem is much higher than the atmosphere [14]. The role of forests across the globe is very critical because of its gross primary productivity (GPP) is near about half of the total GPP of the terrestrial ecosystems [8]. Terrestrial ecosystems and oceans are therefore considered as major ecosystem services as without them the rate of climate change will become twice [5].The large carbon storage capacity of the tropical forests is well known to all but still there are prevailing uncertainties on the net carbon balance of the terrestrial systems [15]. The change of land use and land cover pattern are expected to release carbon in the range 0.81 to 1.14 PgC yr^{-1}[16, 17, 18] while the potential sink strengths of the forests were estimated in the same range [13, 19]. The tropical forests across the world are reported as net carbon source to the atmosphere with net emission of 425.2 ± 92 Tg C yr^{-1} [15]. But still there are lots of prevailing uncertainties over the spatial and temporal variations of these terrestrial sinks/source due to lack of measurement campaigns over the regions such as south Asia [20, 21]. Thus in the formation of annual carbon budget reliable and long term CO_2 flux data from different terrestrial ecosystem is very essential.

The natural forest cover across the globe is decreasing day by day to full fill the need and livelihood of increasing human population. Many of the natural forest ecosystems have also been converted to manmade plantation forests to full fill the need of growing human population such as timber products [22]. With the rise of temperature due to global warming, the functioning of plants and ecosystem are also expected to change which will ultimately influence the carbon assimilation capacity of the terrestrial ecosystems [23]. The Kyoto protocol has given importance on demand of proper quantification of carbon reservoirs in parallel to making policies for lowering the emission [24].

Most of the published literatures on net carbon balance studies used satellite based methods [25, 26, 27] and advanced remote sensing techniques [28, 29, 30] but they were always constrained due to geography and topography of the sites, spatial resolution and unavailability of data. Eddy covariance method is the standard and most reliable tool for the quantification of gas and energy fluxes between ecosystem and atmosphere. The flux estimated by eddy covariance technique is the measured covariance between fluctuations in concentration of a gas and vertical component of wind in high frequency. Eddy covariance method can be used for different spectrum of time (hour to years) and it can measure fluxes coming from wider area [31]. Due to the proficiency and reliability of the EC method ecosystem scientists around the globe have been using it since 1990's till date continuously for long duration of time [32] under the global network "FLUXNET".

The climate and ecosystems of India are very peculiar and diverse due to different climatic and soil conditions [33]. India stands on 8th position amongst the leading 10 biodiverse countries [34]. In India, out of the total area, 21.05 % of areas are occupied by forests and trees [35]. Therefore, it is very important to understand the carbon dynamics of Indian forests ecosystems. Although, Indian forests are reported as substantial sink of carbon [36] but the variability of the carbon sink strength of different forest ecosystems are not well documented. Carbon studies in Indian forest ecosystems are quite challenging on account of varying localities and difficulties in accessibility [12]. Systematic data on forest carbon of different region and types of forest of India are inadequate. Although the direct flux computation with the help of Eddy covariance method was being carried out over diverse forest ecosystems across the globe, the concept is still new in India. Such kind of measurement efforts covering various forest and agricultural ecosystems are very rare in Indian subcontinent which is extremely important for accurate prediction of future climate change over the globe [37, 38].

The seasonal and annual variation of CO_2 flux is a function of many biophysical factors [39]. The seasonal and inter annual variability of carbon assimilation is mainly driven by the variations of clouds and rainfall which controls the primary drivers like radiation, temperatures of soil and air, humidity and soil moisture [40, 41]. Wet and dry conditions of any ecosystem might decrease or increase the photosynthesis rate and thus affecting the carbon assimilation rate [42]. The stomates of leaves play an important role in controlling the exchange process of CO_2 and water vapour between biosphere and atmosphere [43, 44]. The process of stomatal opening and closure in plants is generally determined by humidity of the atmosphere and soil moisture content [45, 46]. On the other hand the correlation between photosynthesis and atmospheric temperature is reported to be nonlinear [47].

Carbon stocks of the terrestrial ecosystems are reported to be around 86 % including different forest types in different zones [48]. Soil is an important component of each terrestrial ecosystem. Soil organic carbon is a major component of global carbon cycle as it is the largest terrestrial reservoir of carbon [49]. Among all the terrestrial ecosystems forest has the capacity to store higher amount of SOC [50]. The amount of carbon available in terrestrial plant and soil are about 650 Pg C and 2300 Pg C respectively [51]. Globally the soil organic carbon stocks in top 1 metre of soil was estimated in the range 1460 to 1550 Gt [52, 53]. The carbon sequestration potential of the forest ecosystems of Northeast India are reported to be high [54]. The sink strength of soils is also regulated by various natural and anthropogenic sources [11].

The microbes present in the soil decompose SOC and parallelly the CO_2 is released to the atmosphere by the process of heterotrophic respiration. Soil CO_2 efflux is the sum of heterotrophic respiration and root respiration [55, 56]. Soil CO_2 efflux is the largest outgoing flux of a terrestrial ecosystem. The abiotic factors like temperatures and moistures of soil are the major driver which controls the variation in CO_2 efflux [57]. The heterotrophic respiration is highly sensitive to changes in temperature, thus small increase in temperature can trigger the decomposition rate of SOC which in turn might change a net carbon sink to a source [58]. Since, soil respiration is an important flux from soil to atmosphere, without the clear understanding of ecosystem processes related to soil respiration in different region and climatic condition, it is not possible to predict future CO_2 concentrations of the atmosphere [59]. The net primary productivity of the forests of Asia is very high due to the monsoonal impact as a result they can gather ample quantity of SOC [60, 61]. Hence, due to global warming the heterotrophic respiration component might play a crucial role on climate change [62, 63, 64].

Partitioning of net CO_2 flux in to its component fluxes gross primary productivity (GPP) and ecosystem respiration (Re) is very essential to understand the biophysical processes which controls the variation of net carbon exchange [65].

The aggregate photosynthesis of all the leaves of an ecosystem is the Gross primary production [66, 67]. Terrestrial gross primary production (GPP) is considered as the largest terrestrial flux between ecosystem and atmosphere. Terrestrial GPP of an ecosystem provides the capacity of absorbing CO_2 from the atmosphere and hence it plays a pivotal role in land carbon sequestration [68, 69]. The gross primary production of the forest primarily depends on leaf area index and photosynthetically active radiation [70]. GPP of any ecosystem is also sensitive towards the anomalies in weather, climate and nutrient availability [71, 72]. GPP cannot be measured directly due unavailability of direct measurement techniques at proper spatial resolution [73]. The presently used GPP measurement technique using leaf level photosynthesis measurement has some limitations due to environmental conditions [74]. However, it is possible to estimate GPP in an ecosystem scale from net ecosystem exchange computed with the help of eddy covariance method [75, 76].

After GPP the ecosystem respiration is considered as the second largest terrestrial carbon flux from ecosystem to the atmosphere [1]. Thus a small change in ecosystem respiration might significantly affect the CO_2 concentration level of the atmosphere [77]. Increase in ecosystem respiration with rise of temperature might have a positive feedback on global climate and warming process [78, 79]. In total ecosystem respiration 30-90 % contribution comes from soil respiration [80, 81], which has two components autotrophic respiration and heterotrophic respiration. Ecosystem respiration depends on temperatures of soil and air [82, 83]. Leaf respiration is one of the principal components of ecosystem respiration and its role in terrestrial GPP estimation is very important [84, 85]. Ecosystem respiration is major contributor of net CO_2 flux during the night time in deciduous forest sites [86]. Therefore it is very important to study the behaviour and magnitude of ecosystem respiration and its relation to different biotic and abiotic factors in the unique forest ecosystem of Northeast India for accurate documentation of regional and global carbon budgets.

Tropical forests of this earth has the highest net primary productivity among the all other terrestrial ecosystems [13, 87]. Net primary productivity is the function of different environmental factors, soil properties and CO_2 concentrations of the atmosphere [88, 89]. Net ecosystem productivity (NEP) is the difference between GPP and ecosystem respiration [90]. In long scale ecosystem carbon research the role of NEP in interpreting the carbon cycle is of great consequence [91]. NEP of any ecosystem is an indicator of potential sink/source strength of the respective ecosystem on annual scale.

The North-eastern region of India is very unique due to its unusual climate and geographical location. The forests of Northeast India are rich in biodiversity and relatively undisturbed due to different factors like ruggedness and remote location [22]. Northeast India ranked among top 25 biodiversity hotspots around the globe [92, 93]. There are several reports on carbon stock estimation of forest ecosystem of India but reports from Northeast Indian forest ecosystem are very few. Kaziranga National Park (KNP) located in Assam is a world heritage site with in Asian monsoon zone which receives very heavy rainfall during pre-monsoon, summer monsoon and during summer to autumn transition period. The frequent occurrence of flood episodes makes the forest inaccessible during monsoon. Therefore, to understand the seasonal and inter annual variability of CO_2, water vapour and energy fluxes of this unique semi evergreen forest of North-eastern India the present study was initiated during 2014. Due to extensive forest cover, rivers and mosaic of ecosystems present inside the forest, KNP can be considered as a good representative of North-eastern forests. To our best of knowledge there are hardly any literatures available on the meteorology and carbon dynamics from this kind of semi evergreen deciduous forest in Indian subcontinent using real time high frequency data. Therefore, the estimated NEP of the unexplored semi evergreen forest of KNP will give very important and valuable informations related to the regional carbon cycle.

Considering the above background we designed a study to address the prevailing scientific gap on the forest carbon cycle of Northeast India. This study was carried out over the semi evergreen forest Kaziranga national park (KNP) with the following research questions and objectives.

Research question 1: How the carbon sequestered by a terrestrial ecosystem is affected by changing season of tropical climate in a forest ecosystem with particular reference to Kaziranga national park.

Objective 1: To study the seasonal and annual variation of CO_2 flux and changes in atmospheric CO_2 concentration.

Research question 2: How the rate of CO_2 uptake and respiration of a terrestrial ecosystem varies during different stages of its growth and how these processes are influenced by changing climate parameters.

Objective 2: Investigation and analysis of the factors regulating the seasonal and diurnal variations of CO_2 concentrations and fluxes.

Research question 3: How much of atmospheric carbon is fixed by the plants in an ecosystem is portioned to biological carbon contributing to growth of the ecosystem. The Carbon released from an ecosystem and carbon fixed by the ecosystem may largely influence the net CO_2 flux. The gross carbon uptake is also expected to regulate by leaf phenology and incident PAR. To address these questions objective 3 have been designed.

Objective 3: To study the effect of photosynthetically active radiation on ecosystem gross primary productivity and net ecosystem exchange.

Research question 4: Soil organic carbon (SOC) provides a potential sink for atmospheric CO_2. Understanding the interactions between plant and SOC pools provides a key to managing the processes controlling C fluxes between plant, soil and atmosphere. As such how soil organic carbon of the forest ecosystem of KNP influence the net flux of CO_2.

Objective 4: To study the relationship of annual and seasonal variation of CO_2 flux with soil carbon dynamics.

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