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Diurnal and seasonal carbon sequestration potential of seven broadleaved species in a mixed deciduous forest in India

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HIGHLIGHTS

- Spontaneous CO_2 exchange rate was measured with LI-6400 for seven tree species.
- Carbon sequestration rate was simulated to canopy level with analytical model.
- Comparison of gas exchange attributes of broadleaved species.
- Annual carbon sequestration rate of man-made mixed forest in natural condition.

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ABSTRACT

The objective of the study was to measure annual carbon sequestration rate of mixed deciduous forest by measuring that of seven young broadleaved tree species (6 years age) as well as selection of better carbon sequestered plant species for future plantation. The diurnal net assimilation rate of Carbon dioxide (CO_2) at leaf level was measured with LI-6400 Portable Photosynthesis System at daytime on seasonal basis in a man-made forest at Budge Budge (N 22°28′ E 88°08′) of South 24 Parganas, West Bengal, INDIA. Net assimilation rate of carbon at canopy level was calculated by measuring Leaf Area Index with LAI-2200 and using analytical model with non-rectangular hyperbolic light response curve. The average net assimilation rate of CO_2 at leaf level was found maximum in *Albizzia lebbek* (8.13 μmol m^{-2} s^{-1}) and that of canopy level in *Eucalyptus spp.* (4.851 g h^{-1}). The minimum was found for *Swietenia mahagoni* (1.058 g h^{-1}). The annual carbon sequestration rate of the mixed forest in natural condition was estimated 6.01 t ha^{-1} $year^{-1}$ by consolidating the potential of all seven species.

1. Introduction

There is general consensus that the increasing concentration of greenhouse gases (e.g. Carbon dioxide, Methane, Nitrous Oxide, Sulfur Hexafluoride, Per-fluorocarbons, Hydro-fluorocarbons) have led to changes in the earth's climate and a warming of the earth's surface. Furthermore, there is agreement that human activities such as fossil fuel combustion, land-use change and agricultural practices have contributed substantially to the rise in atmospheric greenhouse gas concentrations (IPCC, 1997). Carbon dioxide (CO_2) is one of the more abundant greenhouse gases and a primary agent of global warming. It constitutes 72% of the total anthropogenic greenhouse gases, causing between 9 to 26% of the greenhouse effect (Kiehl and Trenberth, 1997). According to National Oceanic & Atmospheric Administration-Earth System Research Laboratory (NOAA-ESRL) of United States, the amount of Global CO_2 concentration in the year 2011 is 391.63 ppmv, and last 10 years average annual increase is 2.01 ppmv per year (http://www.esrl.noaa.gov). Dramatic rise of CO_2 concentration is attributed largely to human activities. Over the last 20 years, majority of emission is attributed to burning of fossil fuel, while 10–30% is attributed to landuse change and deforestation (IPCC, 2001). Increase in CO_2 concentration, along with other greenhouse gases (GHGs), raised concerns over global warming and climate changes. Forestry and afforestation in particular, is regarded as an important contributor to the offset of greenhouse

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gas emissions (Miehle et al., 2006). It stores about 80% of all above-ground and 40% of all below-ground terrestrial organic carbon (IPCC, 2001). During productive season, CO_2 from the atmosphere is taken up by vegetation (Losi et al., 2003; Phat et al., 2004) and stored as plant biomass. In 1997, during the Third Conference of Parties (COP-3) of the UNFCCC, the Kyoto Protocol was drafted which is the first international agreement that places legally binding limits on GHG emissions from developed countries. The Kyoto Protocol proposed that C reduction could take place by decreasing fossil fuel emissions, or by accumulating C in vegetation and in the soil of terrestrial ecosystems. Tropical forests have the largest potential to mitigate climate change amongst the world's forests through conservation of existing C pools (e.g. reduced impact logging), expansion of C sinks (e.g. reforestation, agroforestry), and substitution of wood products for fossil fuels (Nath and Das, 2012). The forest and landuse sector has received significant attention globally in addressing the climate change problem. However, as evidenced by the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007), mitigation potential assessment in the landuse change and forest sector has been limited by availability of information at the global-level, and by the lack of disaggregation of mitigation potential at the national and sub-national level. This is particularly true for India since very few forest mitigation assessment studies have been published (Murthy et al., 2012). Projects that increase the area of plantations have been suggested for inclusion under the Clean Development Mechanism (CDM) as defined in Article 12 of the Kyoto Protocol. However, significant uncertainties in the reliability of carbon pool and flux measurements make it difficult to determine the (net) carbon benefits of afforestation or forest management practices. As a result, further investment in and development of, the plantation industry is threatened (Van Vliet et al., 2003). The net carbon gain of a terrestrial ecosystem is composed from complex consequences of leaf area, CO_2 exchange capacity, activity of photosynthetic (leaves) and non-photosynthetic (stems and roots) organs, canopy architecture, stand biomass of plant species involved, and meteorological conditions including light incidence, air temperature, air humidity, wind speed and air CO_2 concentration (Ehleringer and Field, 1993; Baldocchi and Meyers, 1998; Baldocchi and Wilson, 2001; Baldocchi et al., 2002). As well as these instantaneous consequences of plants and their environments, spatial and temporal variations of both biotic and abiotic factors throughout the growing season control the ecosystem behavior. Due to these multiple relationships of factors governing the ecosystem function, the ecophysiological mechanisms underlying the functional role of the vegetation are always fundamental knowledge since they provide mechanistic explanations and/or parameters to the meteorological observation, satellite remote sensing and modeling prediction of the ecosystem carbon cycling which enable us to evaluate larger scale behavior of the ecosystems (Ehleringer and Field, 1993; Baldocchi and Meyers, 1998; Wilson et al., 2001; Muraoka and Koizumi, 2005). Most of the earlier carbon sequestration researches were based on the concept of static biomass carbon with a longer time scale where diurnal carbon sequestration rate (minute scale) has not been considered. Earlier works have only considered a concept of linear (proportionate) carbon sequestration as well as biomass, which is practically not feasible in the natural system. The objective of the study was to measure diurnal and annual carbon sequestration rate of young (6 years) mixed deciduous forests composed of *Acacia auriculiformis*, *Albizzia lebbek*, *Dalbergia sissoo*, *Eucalyptus* spp., *Swietenia mahagoni*, *Tectona grandis*, *Terminalia arjuna* as well as selection of better carbon sequestered plant species for future plantation.

2. Materials and methods

2.1. Study area

The study was conducted in a man-made forest of Budge Budge (N 22°28′ E 88°08′) in South 24 Parganas district of West Bengal, INDIA. The mean annual air temperature (Kolkata) for past two decades was 26.66 °C, with highest in May (30.5 °C) and lowest in January (19 °C). Mean annual precipitation during the same period was 170.3 cm (http://www.myweather2.com /City-Town/India/Kolkata/climate-profile.aspx). The study area was mainly composed of seven broadleaved deciduous species of 6 years age. Soil at the study area was silt/sandy loam in texture with a pH and bulk density of 8.25 and 1.43 g/cm^3 respectively. The soil organic carbon was found 7.6 g/kg through testing of soil sample.

2.2. Measurement of net assimilation rate of CO_2

The net assimilation rate of CO_2 (A) was measured with undamaged matured leaves ($n = 30–35$ per species) under natural condition i.e., under natural Photosynthetic Active Radiation (PAR), air temperature, humidity and CO_2 concentration. Leaves were clamped by the cuvette of LI-6400 Portable Photosynthesis System (LICOR INC., USA) with the position and direction of the blade fixed as they had been in the crown and exposed to solar radiation incident on the leaf through a transparent window at the top of the chamber (Biswas et al., 2013). A was measured at 1–2 h interval from morning to evening with the leaves of selected seven plant species in monsoon (September, 2010), winter (December, 2011) and summer (June, 2011) to get the diurnal variation of net assimilation rate of CO_2 with an air flow rate of 500 μmol s^{-1}. Ambient PAR was recorded by the LI-6400 simultaneously at the time of measurement. Leaf temperatures were 36.13 °C in September, 25.97 °C in December, and 37.45 °C in June. The average ambient CO_2 concentration was 371 ppmv in monsoon, 399 ppmv in winter and 382 ppmv in summer as measured with LI-6400. The seasonal variation of the ambient CO_2 concentration may be due to the presence of a major CO_2 source (Chimney of a thermal power plant) in the northern side of the sampling area which influences concentration of CO_2 in the ambient air due to wind flow direction. The direction of wind flow normally remains North to South in the winter, and South to North in summer and monsoon. The vapor pressure deficit (VPD, kPa) inside the cuvette was 1.854, 2.552 and 5.235 in monsoon, winter and summer respectively. Dark respiration (R_D) was measured with the sampled leaves ($n = 20–25$ per species) in the absence of sunlight to calculate the respiration at night.

Net assimilation rate of CO_2 at different values of PAR (μmol m^{-2} s^{-1}) was also measured by using artificial light source (LED-6400-02B) of LI-6400 at leaves of selected plant species to determine the net assimilation rate of CO_2 at light saturation point by drawing the light response curve (net assimilation rate of CO_2 vs. PAR) of the species. The gas exchange rate has been measured with varying PAR (0 to 2000 μmol m^{-2} s^{-1}) at 21 irradiance levels at 100 unit intervals.

2.3. Measurement of leaf area

Leaf area index (LAI) is the total one-sided area of leaf tissue per unit ground surface area (Watson, 1947). According to this definition, LAI is a dimensionless quantity characterizing the canopy of an ecosystem. It is a key parameter in eco-physiology, especially for scaling up the gas exchange from leaf to canopy level. It characterizes the canopy-atmosphere interface, where most of the energy fluxes exchange (Breada Nathalie, 2003). LAI has been measured with LAI-2200 (LICOR INC., USA) plant canopy analyzer to estimate the total leaf area of the individual plant species by multiplying