TERRESTRIAL CARBON FLUXES IN INDIA WITH A FOCUS ON SPRING WHEAT AGRO-ECOSYSTEMS

by

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ABSTRACT

Anthropogenic carbon is the key driver of climate change (IPCC, 2018). Understanding the carbon cycle, with its all sources, sinks, and drivers, is central to understanding, monitoring, and mitigating climate change. That is why the carbon cycle is a major area of inquiry worldwide with particular emphasis on ecosystems because they are the largest natural sinks of carbon. Unfortunately, studies on carbon dynamics in the terrestrial ecosystems of India are limited. Most of the studies are short term and use empirical models to quantify carbon fluxes without exploring the underlying processes that affect carbon dynamics. There are almost no process studies that quantitatively investigate the external drivers and how they affect long-term trends in carbon fluxes. Furthermore, very few studies have looked at agro-ecosystems even though croplands form the dominant land use type in India. The broad goal of this thesis is to address this knowledge gap by quantitatively understanding carbon dynamics and the influence of external drivers in the Indian terrestrial ecosystems with an emphasis on spring wheat agro-ecosystems.

In the first part of this thesis, I explore the trend in net biome productivity (NBP) over India for the period 1980–2012. A state-of-the-art process-based model, the Integrated Science Assessment Model (ISAM) is used for meeting this objective. The advantage of process-based models is that, unlike empirical models, they allow us to understand the underlying processes in carbon dynamics and conduct numerical experiments to explore the role of external drivers. Results show that the terrestrial ecosystems of India have been a carbon sink for the study period. The magnitude of NBP increased from 27.17 TgC/yr in the 1980s to 34.39 TgC/yr in the 1990s but decreased to 23.70 TgC/yr in the

2000s. Environmental drivers, such as elevated atmospheric [CO_2], climate change, and land use/land cover change (LULCC), are found to be majorly responsible for changes in terrestrial carbon fluxes. The effects of these drivers on carbon fluxes of India are quantified using numerical experiments conducted with ISAM. A strong CO_2 fertilization effect is found to drive the positive trend in NBP but climate change in recent decades has offset the trend. This is because of the high loss of carbon from ecosystems due to rising temperatures and decreased precipitation.

In the second part of my thesis, I developed a dynamic crop growth model for spring wheat in India and implemented that in the ISAM. Spring wheat is the second most important crop grown in India and covers 15.69% of the total cultivated area. Developing the spring wheat model is essential for this study because ISAM and other land models do not have modules representing Indian crops. The new spring wheat model in ISAM ($ISAM_{dyn\_wheat}$) is able to capture the observed crop phenology, leaf area index (LAI), and above-ground biomass (AGBM) at the site-scale and crop production at the country-scale. Numerical experiments are conducted with $ISAM_{dyn\_wheat}$ to quantify the impact of external drivers on wheat production for India from 1980 to 2016. The results show that elevated atmospheric [CO_2] levels, water availability through irrigation, and nitrogen fertilizers have led to an increase in annual wheat production at the rates of 0.68, 0.24, and 0.31 Mt/yr respectively, from 1980 to 2016. However, elevated temperatures have reduced the total wheat production at a rate of 0.37 Mt/yr during the study period. Overall, the [CO_2], irrigation, fertilizers, and temperature forcings have led to 22Mt (30%), 8.47 Mt (12%), 10.63 Mt (15%) and -13 Mt (-18%) changes in countrywide production, respectively. The impacts of these factors spatially vary across the country thereby affecting production at regional scales. Results show that favourable growing season temperatures, moderate to high fertilizer application, high availability of irrigation facilities, and moderate water demand make the Indo-Gangetic plain the most productive wheat-growing region in India.

Finally, $ISAM_{dyn\_wheat}$ is validated against field measurements of carbon fluxes for gross primary productivity (GPP), total ecosystem respiration (TER), and net ecosystem productivity (NEP) for multiple observations in the growing season for the year 2013-14. $ISAM_{dyn\_wheat}$ performs better and shows a higher correlation with field measurements than the generic C3 model framework in ISAM. Numerical experiments conducted to study carbon fluxes in wheat ecosystems show that there is a decrease in the decadal average of all carbon fluxes from the 1990s to 2000s, mainly driven by an increase in temperature causing loss of carbon from the ecosystems.

This thesis is a timely research work that leads to three major advances in the field of carbon science in India. First, it provides a comprehensive estimate of different kinds of terrestrial carbon fluxes and the carbon sequestration potential of the terrestrial ecosystems of India. Second, this work enhances our understanding of the role of external drivers on carbon dynamics in terrestrial ecosystems. Third, the spring wheat model developed in this thesis can be used for agricultural forecasting and to conduct numerical experiments to test crop management strategies for different wheat cultivars. The accuracy of carbon flux estimates from Indian ecosystems can be improved if more such modules specific to Indian ecosystems are developed. Enhancing the terrestrial carbon sink is one of the main Nationally Determined Contributions (NDC) of India as per the 2016 Paris Agreement. Studies like this thesis can play an important role in designing appropriate strategies to meet the goals of the NDC.