Article

Estimate of soil organic carbon and greenhouse gas emissions in para rubber (*Hevea brasiliensis* MÜll. Arg) plantation by DNDC model in Upland Area Northern, Thailand

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Received 17 May 2014; *Accepted 24 June 2014*; *Published online 1 December 2014*

Abstract

The process-oriented model DNDC describing biogeochemical cycling of C and N and greenhouse gases (GHGs) fluxes carbon dioxide (CO_2), nitrous oxide (N_2O), nitric oxide (NO) in para rubber plantation was applied to simulate carbon sequestration and GHGs emissions in a para rubber plantation of small watershed in the lower part of northern Thailand. The results indicated that the simulated gross primary production (GPP) and soil organic carbon (SOC) of the para rubber plantation was strongly affected by temperature. The annual total GPP was 2,765.8 kg C /ha/yr, and net primary production (NPP) was 2,032.4. The SOC in 0-10 cm. were 4,983 kg C /ha/yr for 2011.The simulated seasonal variation in CO_2 emissions generally followed the seasonal variations in temperature and precipitation. The annual total CO_2 emission was 976.53 kg C /ha/yr for 2011, the simulated annual total N_2O emissions from the plantation's soil was 10.51 kg N $ha^{-1}yr^{-1}$ for 2011, the annual total NO emissions were 0.87 kg N /ha/yr for 2011, and the annual Dissolved Organic Matter (DOM) leaching was 0.23 kg C /ha/yr.

Keywords carbon dioxide; nitrous oxide (N_2O); nitric oxide (NO); GHGs emissions; para rubber plantation.

Computational Ecology and Software
ISSN 2220-721X
URL: http://www.iaees.org/publications/journals/ces/online-version.asp
RSS: http://www.iaees.org/publications/journals/ces/rss.xml
E-mail: ces@iaees.org
Editor-in-Chief: WenJun Zhang
Publisher: International Academy of Ecology and Environmental Sciences

1 Introduction

Para rubber is a tropical tree crop which is mainly grown for the industrial production of latex. Like oil palm it requires a high and year-round rainfall with little or no dry season and stable high temperatures; soils should not be particularly rich, but must be deep and well drained. Both crops are often grown in the same ecological areas, and in many cases oil mills and rubber treatment plants from part of one and the same industrial complex. Thailand is the world leading producer and exporter of para rubber (herein called rubber) with production capacity of 3.1 – 3.2 million tons per year, with 88-90 percent of total production capacity exported to foreign markets. The country also has high potential for expanding the production area and raising production capacity. In year 2009, rubber plantations in Thailand covered 2.70 million ha across Thailand with the majority (2.10 million ha) in the traditional areas in the southern (2.61 million ha) and eastern 14.68 million ha) region and the remaining 0.60 million ha are planted in new areas in the northeastern (0.45 million ha), northern (0.09 million ha) and central (0.05 million ha) region.

Global warming is a present problem and spreading throughout the world (Wu and Zhang, 2012), encouraging all nations to take various measures to reduce global warming under the KYOTO protocol. The protocol is a part of the United Nations Framework Convention on Climate Change (UNFCC), enforced in 2005. Even if Thailand is a non-annex 1 member country that can reduce greenhouse gas emission through the clean development mechanism, the appropriate approach is to plant para rubber plantation in place of deforestation in Thailand. Because rubber trees have a production life of 20 years, the plantation can be considered as forest plantation as a rubber tress increase in biological mass as they age and has a high capacity for carbon stock storage (Mandal et al., 2013).

Predicting the responses of environmental drivers and their effect on carbon and nitrogen dynamics in para rubber plantation ecosystems presents a number of challenges, largely because the primary responses lead to secondary effects which from a complicated network of feedbacks and indirect responses, often operating at a number of spatial and temporal scales (CUI et al., 2005). To predict carbon characteristics and GHGs emissions in para rubber plantation ecosystems, we need to quantify the effects of environmental factors on photosynthesis, respiration, decomposition, nitrification and denitrification and the effects of plantation ecological features (e.g. Canopy, litter the floor and soil fertility) on soil temperature, moisture, Eh, pH and substrate concentration. Based on the biogeochemical cycling of C and N in para rubber plantation ecosystems In this study, the DNDC model was used to derive the estimates of carbon sequestration and GHGs emissions in the para rubber plantation ecosystems on small watershed northern, Thailand.

2 Methodology

2.1 Model description

The DNDC model has developed at the University of New Hampshire since 1992 that is a process-oriented simulation tool of soil carbon and nitrogen based on biochemical cycles that is one of the most successful biogeochemical models in the world (Qiu et al., 2005). The model consists of two components and six interacting, the first component includes soil climates, crop growth and decomposition sub-model. It predicts soil environmental factors driven by ecological factors like climate, soil, vegetation and anthropogenic activity. The second components utilize the resulting soil environmental factors as inputs to nitrification, denitrification and fermentation sub-model. The model contains six interacting sub-model which describes the generation, decomposition and transformation of organic matter, and output the dynamics of the components of SOC and fluxes of greenhouse gases. It integrated two existing model: PnET-N-DNDC, an upland forest model biogeochemical model, and Wetlands-DNDC, a hydrology-driven model (Miehle et al., 2006). The PnET-N-DNDC was a process-oriented model which could simulate C and N dynamics, and trace gas emissions in upland forest ecosystems (Li et al., 2000). Wetland-DNDC, which was developed for predicting C and N biogeochemistry and in forested wetland ecosystems, was constructed by incorporating hydrological features into the PnET-N-DNDC model. The basics adopted by the Wetland-DNDC model are to simulated forest growth, soil biogeochemistry and hydrological processes (LI et al, 2004). So the Forest-DNDC could be run in the upland mode same as the PnET-N-DNDC did, or in the wetland mode. In our study, the Forest-DNDC (Version Forest DNDC 1.0.0.1) was run in the upland mode. To simulated carbon sequestration and GHGs emissions for a specific site in daily resolution, the Forest-DNDC requires the following input parameters: site latitude, ambient CO_2 concentration, N concentration in rainfall, daily climate data (precipitation, minimum and maximum temperature), soil properties (texture, clay content, humus type and so on), and forest or plantation properties (forest types and age, above ground and underground biomass, plant physiology parameters) the model will used default values. The Forest-DNDC is currently parameterized for 15 tree species / genera, such as pine, hardwoods, tropical forest, beech, plantation and so on, this study used plantation mode.

2.2 Study site description and simulation scenarios

The para rubber plantation is located in Phitsanulok province, lower northern, Thailand between 1852151 47Q 0678961 to 1852290 47Q 1852290 (Fig. 1). The study site is located in the Huai Lam Radon sub watershed where a part of the Wang Thong watershed. The study area covers forest in the Thung Salaeng Luang National Park and adjacent some para rubber tree plantation. This study area is located in the lower northern of Thailand, the altitude approximate 700-860 m. The geological formation of the study area is composed of sedimentary rock and metamorphic rock (Boonyanuphap et al., 2007). The climate is tropical and sub-tropical with three distinct seasons such as: winter, summer and rain. March to June are the hottest month mean maximum temperature (29°C), and November to February are the coldest months mean minimum temperature (17°C), and the mean temperature is 22°C. The maximum rainfall occurs during the monsoon season May to October with mean rainfall 1,300-1,700 mm. Monthly rainfall and temperature during study represent in Fig. 2 and site characteristics descript in Table 1. Study duration of April 2010-March 2011.

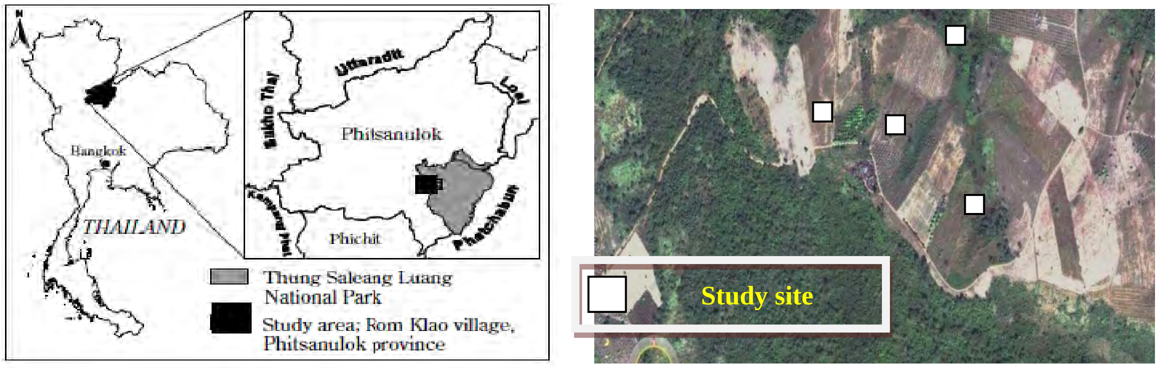

Fig. 1 Study site para rubber plantation is located in Phitsanulok province, lower northern, Thailand.

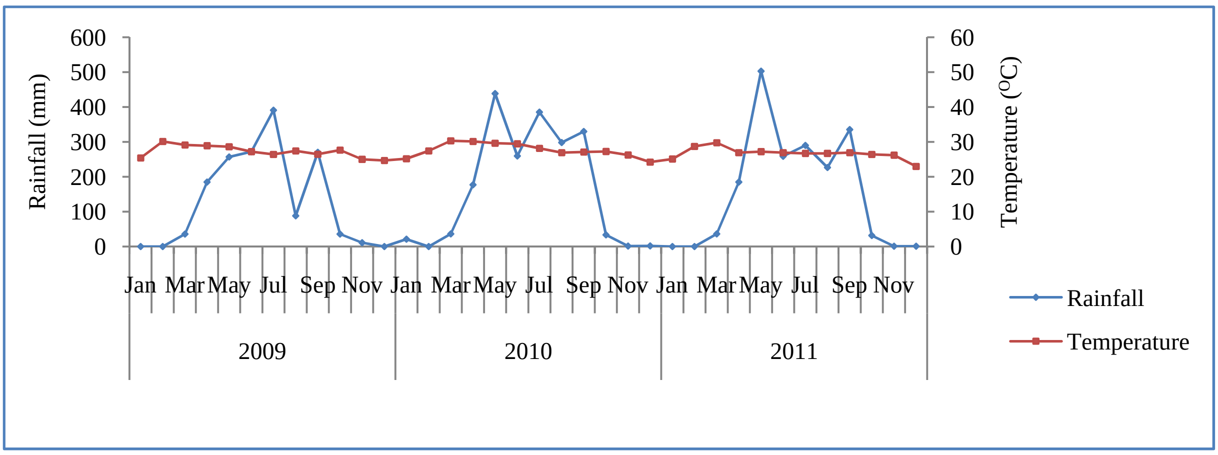

Fig. 2 Monthly rainfall and temperature from April 2009 to March 2011 at study site.

2.3 Model validation

The model validation is to test the degree of agreement between simulated values and measured values and measured values. The Forest DNDC has been validated by many kinds of forest types in some countries. The results showed that the simulated and measured values were generally in agreement in terms of magnitude and seasonal variations. In this study the daily soil CO_2 emissions were measured at the para rubber plantation for one year from April 2011 to March 2012 for model validation (Fig. 3). The modeled soil CO_2 emissions corresponded well to the trends and temporal variations of the measured and measured fluxes of soil CO_2 showed good agreement (R^2 = 0.875). We had few soils NO and N_2O emissions data observed in para rubber plantation for model validation.

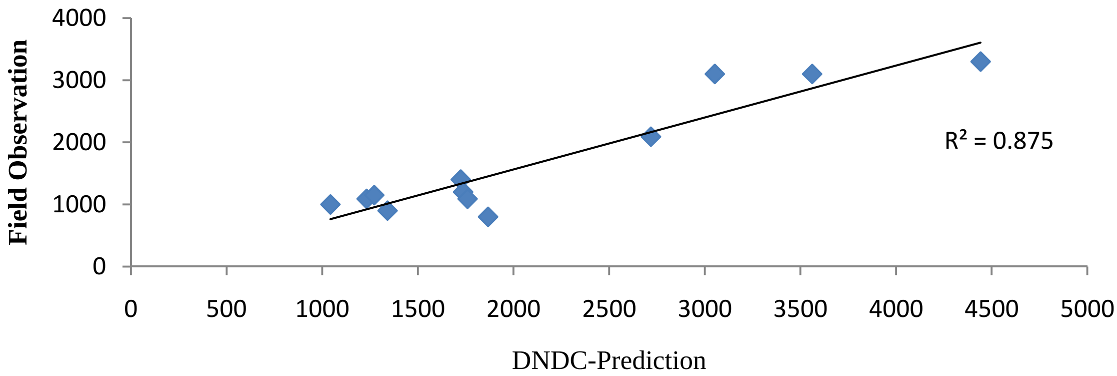

Fig. 3 Comparison between the simulated and field observation daily soil CO_2 emissions from April 2011 to March 2012.

3 Results

3.1 Carbon sequestration

In para rubber plantation the carbon input is the photosynthetic fixation of CO_2 by tree canopy. The carbon outputs are all in the form of respired CO_2, coming either from plant tissues due to growth or maintenance respiration, or from litter and soil organic carbon pools as the results of heterotrophic respiration. The process of photosynthesis and respiration are the functions of several environmental and plant variables, including solar radiation, air temperature and humidity, availability of water and nutrients, leaf area, and foliar nutrition. The annual total GPP was 2,765.8 kg C ha^{-1} yr^{-1} , and net primary production (NPP) was 2,032.4. The SOC in 0-10 cm. were 4,983 kg C ha^{-1} yr^{-1} for 2011 (Fig. 4).

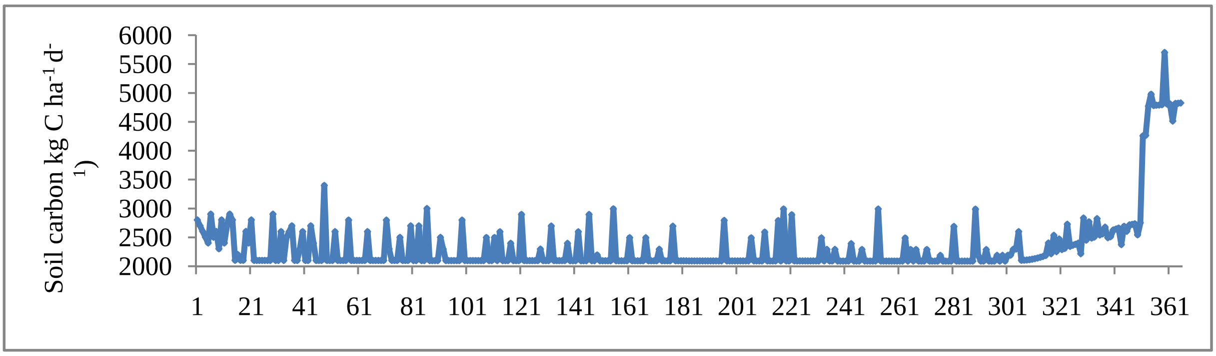

Fig. 4 Soil carbon sequestration in para rubber plantation for 2011.

3.2 CO_2 emission

Soil CO_2 emissions results from soil organic matter decomposition and root respiration in para rubber plantation soil. The CO_2 emissions rate from para rubber plantation soil reflects the variations in temperature, moisture and other environmental factors. To estimate losses of gaseous CO_2 from soil carbon pools, the Forest-DNDC simulated soil microbial respiration and root respiration. Fig. 4 shows the simulated total soil CO_2 emission from para rubber plantation in 2011. The seasonal variations of CO_2 in temperature and precipitation. The modeled daily CO_2 emissions remained low in winter and high in summers. The modeled annual total CO_2 emission was 976.53 kg C $ha^{-1}yr^{-1}$.

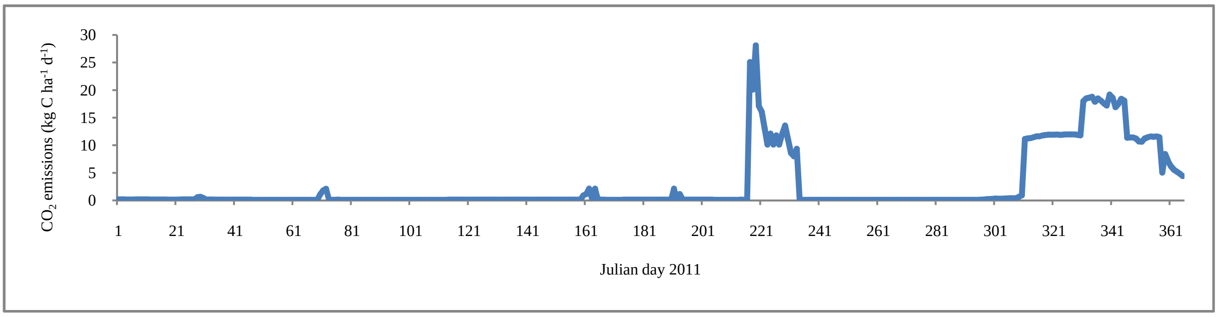

Fig. 4 Simulate daily soil CO_2 emissions from a para rubber plantation in 2011.

3.3 N_2O and NO emission

The production of N_2O and NO in soil is due to the microbial process of nitrification and denitrification. The nitrification is an oxidative process through which NH_3/NH_4^+ is oxidized into NO_2^-/NO_3^-. This process requires availability of molecular oxygen. In contract, the denitrfication is a reductive process, which mainly occurs in soil anaerobic zones. With the depletion of oxygen in soil, some microbes can use NO_3^- / NO_2^- to sequentially produce NO, N_2O and finally N_2. To handle the problem of simultaneously occurring aerobic and anaerobic process in the adjacent microsite, the DNDC uses a kinetic scheme, called “anaerobic balloon”. Based on the O_2 diffusion from the atmosphere into the soil and O_2 consumption during heterotrophic and autotrophic respiration, the O_2 concentration is assumed to be reciprocally proportional to the anaerobic fraction within this soil layer (Li et al., 2004; Kesik et al., 2005). Chemodenitrification, i.e., chemical decomposition of NO_2^- to NO, is considered as other sources of NO production in soil. This chemical reaction is controlled by the concentration of nitrite in the soil, soil pH and temperature, and it occurs only when soil pH is < 5.0 (Li et al, 2000). Fig. 5 shows the modeled daily soil N_2O and NO emissions from the para rubber plantation soil. The simulated N_2O emission was 10.51 kg N $ha^{-1}yr^{-1}$ for 2011, and the annual total NO emission was 0.87 kg N ha^{-1} yr^{-1} for 2011.

3.4 Dissolved Organic Matter (DOM)

Dissolved Organic Matter (DOM) in land use is one of the largest reservoirs of organic matter on the earth's surface holding approximately as much carbon as is available in atmospheric carbon dioxide (Hudges, 1992). The modeled daily DOM from the para rubber plantation soil. The simulated DOM leaching was 0.23 kg C $ha^{-1}yr^{-1}$ for 2011.

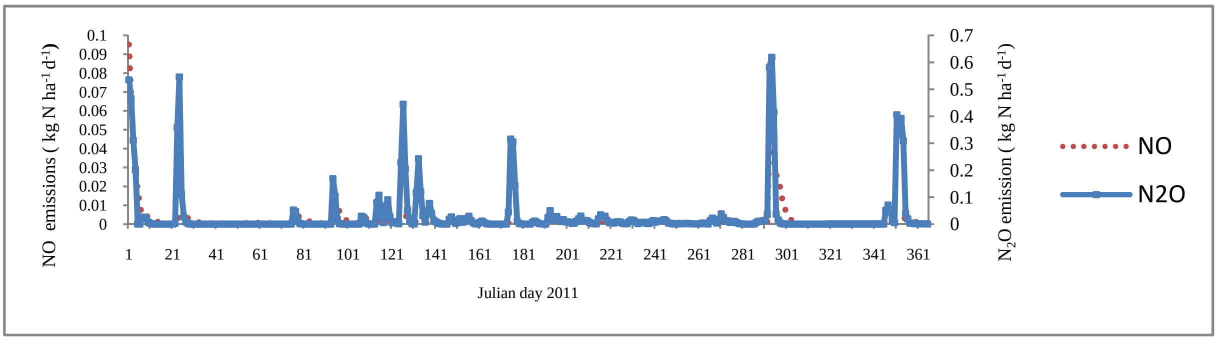

Fig. 5 Simulated daily soil N_2O and NO emissions from para rubber plantation soil in 2011.

4 Discussion and Conclusions

To quantify the carbon characteristics and soil GHG (greenhouse gases) emissions of para rubber plantation is a scientific challenge that needs comprehension understanding of the para rubber process, soil chemical process, and the biogeochemical process. Fortunately, the latest developments in biogeochemistry, spatial data acquisition and computing techniques have provided potentials to integrate the research effort across the scales in apace and time. In the last decade many biogeochemical models were developed and utilized to simulated carbon budgets, carbon and nitrogen exchanges or GHGs emissions from many kinds of forest, plantation, agriculture and agroforestry. In this study the process oriented biogeochemical model DNDC, was used to simulated the carbon fluxes, carbon dynamics, soil CO_2, N_2O and NO emissions for plantation of para rubber. The results indicated that the simulated GPP of the para rubber plantation was strongly affected by temperature. The annual total GPP was 2,765.8 kg C ha^{-1} yr^{-1} , and net primary production (NPP) was 2,032.4. The SOC in 0-10 cm. was 4,983 kg C ha^{-1} yr^{-1} for 2011. The simulated seasonal variation in CO_2 emissions generally followed the seasonal variations in temperature and precipitation. The annual total CO_2 emission was 976.53 kg C $ha^{-1}yr^{-1}$ for 2011, the simulated annual total N_2O emissions from para rubber plantation soil was 10.51 kg N $ha^{-1}yr^{-1}$ for 2011, and the annual total NO emissions were 0.87 kg N ha^{-1} yr^{-1} for 2011, and the annual DOM (Dissolved Organic Matter) leaching was 0.23 kg C $ha^{-1}yr^{-1}$.

Acknowledgements

The research was supported by a CHE-Ph.D-SW-NEWU scholarship from the Commission on Higher Education, and by Uttaradit Rajabhat University. The Department of National Parks, Wildlife and Plant Conservation is thanked for giving permission to access and collect data from the study area.

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