Carbon sequestration potential of rubber-tree plantation in Thailand

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Abstract. Thailand has approximately 3 million hectares of latex-producing natural rubber plantations. These rubber plantations have large potential to sequester atmospheric carbon into the biomass and soil. We use eddy covariance technique to measure the net ecosystem exchange (NEE), which is the vertical net flux of CO2 above the rubber plantation, as the estimate of CO2 sequestration potential of rubber plantation. NEE of a 19-year old, latex-producing rubber plantation of a monoclonal stand of rubber trees (Hevea brasiliensis Müll. Arg.) clone RRIM 600 at Chachoengsao Rubber Research Center was observed for 4 years, starting from 2013. The results showed that annual CO2 sequestration from 2013 to 2016 ranged from 28.0 to 43.1 tons CO2 ha-1 yr-1 and averaged 36.7 tons CO2 ha-1 yr-1. In 2016, there was 2.95 million hectares of latex-producing natural rubber plantations in Thailand producing 4.342 million tons of natural-rubber latex. Thus, the estimated CO2 sequestration potential of these plantations was approximately 108 million tons of CO2. In addition, it was estimated that rubber plantation in Thailand sequestered approximately 24.9 kg of CO2 to produce each kilogram of natural-rubber latex. This large carbon sequestration potential associated with natural latex production information shows that natural latex is very friendly to the environment. These observations have important implications not only for the potential management of carbon sequestration in Thailand, but also for the establishment of marketing strategy to enhance the natural rubber competitiveness, especially in comparison to the less environmental-friendly synthetic rubber.

1. Introduction
Rubber (Hevea brasiliensis Müll. Arg.) is one of the most economically important tree crops in tropical area throughout the world. Rubber plantations provide natural rubber latex and rubber wood for several downstream industrials. There are approximately 3 million hectares of latex-producing natural rubber plantations in Thailand, providing primary income for approximately 6 million people.

In addition to providing latex and wood, these rubber plantations have large potential to sequester atmospheric carbon into the biomass and soil [6], [7], [8], [11], [12], [13]. However, the potential role
of these plantations in sequestering carbon in the soil and plant biomass in relations to latex produced, which could be the most important indicator to illustrate the environmental-friendliness of natural rubber latex, has not been fully evaluated.

The vertical net flux of CO₂ above the ecosystem, often called the net ecosystem exchange (NEE), includes net ecosystem production (NEP) and inorganic sources and sinks for CO₂. NEP, which is defined as the difference between the organic carbon (C) fixed by photosynthesis in an ecosystem (gross primary production, or GPP) and released by total ecosystem respiration (the sum of autotrophic and heterotrophic respiration, or Rₑ), represents organic C available for storage within the system or loss from it by export or non-biological oxidation [5]. Inorganic sources and sinks, such as weathering reactions, precipitation or dissolution of carbonates, and atmosphere–water equilibrations, are likely to be minor terms in the CO₂ exchange such as in a forest ecosystem [5]. Eddy Covariance (EC) technique has become one of the preferred micrometeorological methods for measuring the CO₂, water vapor, and energy exchange between the atmosphere and terrestrial ecosystems. The EC technique is now widely used to measure the vertical turbulent CO₂ flux between the atmosphere and biosphere as it provides continuous flux information integrated at the ecosystem scale, and annual carbon sink or source strength for a wide variety of ecosystems [1], [2], [9], [10]. In recent years, many studies have used EC techniques to measure NEE [3], [4], [10].

The present study addresses two main objectives: to estimate CO₂ sequestration potential of Thai rubber plantations by NEE measured using eddy covariance technique, and to quantify how much carbon dioxide is sequestered by Thai rubber plantation to produce a kilogram of natural-rubber latex.

2. Materials and methods

The research was done at the Chachoengsao Rubber Research Center located in Chachoengsao province (13°41′N, 101°04′E), Thailand. The observation site is a monoclonal stand of rubber trees clone RRIM 600. The rubber trees were 19-year-old in 2013. Tapping for latex production began when the trees were 8-year-old. The Eddy Covariance (EC) instruments were mounted at a height of 25 m on a tower. EC system consisting of a three-dimensional ultrasonic anemometer (CSAT-3, Campbell Scientific Inc., USA.) and the open-path infrared gas analyser (LI-7500, LI-COR Inc., USA) which were used to measure speed and direction of the wind and concentration of CO₂ and water vapour, respectively. An assumption of the EC technique is the flux of a given scalar parameter can be measured as an average of the covariance between the 20-Hz fluctuations in the vertical wind speed and the 20-Hz fluctuations of the scalar parameters. CO₂ flux was calculated as the mean covariance of vertical wind velocity and scalar fluctuations, with the appropriate corrections applied. The following equation presents the calculation of CO₂ flux:

$$F_{CO_2} = \rho_a \cdot w'c'$$

Where (ρₐ) is a density of the air, w' and c' are vertical wind speed and CO₂ concentration fluctuations from the means, respectively. Overbars in the equation show time averaging and primes represent fluctuations from the mean value. All raw data were collected at a rate of 20 Hz by a data logger (CR3000, Campbell Scientific Inc., USA). The 30-min mean CO₂ fluxes were calculated by using all raw data. Before covariance calculation, the time series data were de-spiking and linearly detrended. The fluxes were three-dimensional coordinate rotations to align the sonic anemometer axis along the long-term streamlines and WPL-correction. Following the sign convention in the atmospheric flux community, negative flux covariance indicates a loss of carbon from the atmosphere and gain by the ecosystem. CO₂ sequestration potential of rubber plantation was taken to be equal to –NEE, in order to indicate the positive annual net carbon gain by the rubber ecosystem.

Along with the EC measurements, standard meteorological data and soil parameters were measured continuously with an array of sensors. Quantum sensor (LI-190SB, LI-COR Inc., USA) was used to measure photosynthetically active photon flux (PPF). Solar radiation and net radiation were measured by using sunshine sensor (BF3, Delta-T Device Ltd., UK) and net radiometer (NR-Lite, Kipp & Zonen, The Netherlands), respectively. Rainfall was measured by using the tipping bucket rain
gauge (TE525, Campbell Scientific Inc., USA). Air temperature and relative humidity were measured by the temperature and relative humidity probe (HMP45C, Vaisala, Finland). Belowground parameters were measured on 3 locations in the rubber plantation. Soil temperature at depths of 1 m from soil surface was measured with a custom built chromel-constantan thermocouple. Soil volumetric water content at depths of 1 m from soil surface was measured with Water Content Reflectometer (CS616, Campbell Scientific Inc., USA.). All parameters were measured every 10s and the 30 min averaged values were recorded in data logger (CR1000, Campbell. Scientific Inc., USA.).

3. Results and discussion

From 2013 - 2016, minimum, maximum, and mean values of air temperature ranged from 12.9-15.6, 37.9-39.9, and 27.2-27.8 °C, respectively (Table 1). Soil temperature at 100 cm below surface ranged from 25.9 to 26.5º C while soil water content (SWC) at 100 cm depth ranged from 0.141 to 0.181 m$^3$ m$^{-3}$. The annual averaged relative humidity was greater than 80%. The annual cumulative rainfall showed much greater variability (24.4%), ranging from 1,023 to 1,316 mm yr$^{-1}$, than PPF (5.4%), solar radiation (4.7%) or net radiation (12.3%).

In this study -NEE, taken as proxy for annual CO$_2$ sequestration, ranged from 28.0 to 43.1 tons CO$_2$ ha$^{-1}$ yr$^{-1}$ and averaged 36.7 tons CO$_2$ ha$^{-1}$ yr$^{-1}$ (Table 2). Simple linear regression analysis (not shown) indicated that PPF, the major driver for photosynthesis, was positively correlated to annual CO$_2$ sequestration and explained 81.5% of its variations. In addition, annual CO$_2$ sequestration was positively related to annual latex yield and explained 61.5% of its variation (Figure 1).

In 2016, there was 2.95 million hectares of latex-producing natural rubber plantations in Thailand producing 4.342 million tons of natural-rubber latex. Thus, the estimated CO$_2$ sequestration potential of these plantations was approximately 108 million tons of CO$_2$. In addition, it could be estimated further that rubber plantation in Thailand has the potential to sequester approximately 24.9 kg of CO$_2$ to produce each kilogram of natural-rubber latex. On the other hand, the inverted slope of the linear regression function between annual CO$_2$ sequestration and annual latex yield in Figure 1 indicates that an increase of 22.1 kg of sequestered CO$_2$ is correlated to an increase of 1 kg latex yield. This large carbon sequestration potential, 22.1 to 24.9 kg CO$_2$ sequestered per 1 kg of natural-rubber latex production, shows that natural rubber is very friendly to the environment especially when compared to the net carbon released associated with synthetic rubber production. These observations have important implications not only for the potential management of carbon sequestration in Thailand, but also for the establishment of marketing strategy to enhance the natural rubber competitiveness, especially in comparison to the less environmental-friendly synthetic rubber.

Table 1 Annual averaged temperatures, soil water content, and relative humidity and accumulated rainfall, photosynthetically active photon fluxes, solar radiation and net radiation at Chachoengsao Rubber Research Center.

| Parameter                        | 2013  | 2014  | 2015  | 2016  | Mean  |
|----------------------------------|-------|-------|-------|-------|-------|
| Air temperature (°C)             |       |       |       |       |       |
| minimum                          | 14.3  | 12.9  | 15.6  | 13.3  | 14.0  |
| maximum                          | 38.3  | 37.9  | 38.2  | 39.9  | 38.6  |
| average                          | 27.2  | 27.3  | 27.7  | 27.8  | 27.5  |
| Soil temperature (°C) at 100 cm. depth | 26.4  | 25.9  | 26.0  | 26.5  | 26.2  |
| SWC (m$^3$ m$^{-3}$) at 100 cm. depth | 0.181 | 0.179 | 0.163 | 0.141 | 0.166 |
| Relative humidity (%)            | 81.7  | 81.5  | 80.8  | 81.4  | 81.4  |
| Rainfall (mm yr$^{-1}$)          | 1,316 | 1,282 | 1,161 | 1,023 | 1,196 |
| PPF (mol photon m$^{-2}$yr$^{-1}$)| 5,418 | 5,725 | 5,688 | 5,665 | 5,624 |
| $R_g$ (MW.m$^{-2}$ yr$^{-1}$)    | 3,169 | 3,314 | 3,258 | 3,321 | 3,266 |
| $R_n$ (MW.m$^{-2}$ yr$^{-1}$)    | 2,163 | 2,208 | 1,952 | 1,992 | 2,079 |
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Figure 1. Relationships between latex yield (T ha\(^{-1}\) yr\(^{-1}\)) and annual CO\(_2\) sequestration (T CO\(_2\) ha\(^{-1}\) yr\(^{-1}\)).

Table 2 Annual CO\(_2\) sequestration (-NEE), rubber latex yield, and estimated CO\(_2\) sequestered per kg of latex from 2013 to 2016.

| Year | Annual CO\(_2\) sequestration (T CO\(_2\) ha\(^{-1}\) yr\(^{-1}\)) | Rubber latex yield (T ha\(^{-1}\) yr\(^{-1}\)) | CO\(_2\) sequestered per kg of latex (kg kg\(^{-1}\)) |
|------|-------------------------------------------------|---------------------------------|----------------------------------|
| 2013 | 28.0                                            | 1.20                            | 23.3                             |
| 2014 | 40.6                                            | 1.89                            | 21.5                             |
| 2015 | 43.1                                            | 1.71                            | 25.2                             |
| 2016 | 35.1                                            | 1.09                            | 32.2                             |
| Mean | 36.7                                            | 1.47                            | 24.9                             |

4. Conclusion

Annual CO\(_2\) sequestration by rubber plantation ranged from 28.0 to 43.1 tons CO\(_2\) ha\(^{-1}\) yr\(^{-1}\) and averaged 36.7 tons CO\(_2\) ha\(^{-1}\) yr\(^{-1}\). Thus, it is estimated that 2.95 million hectares of latex-producing natural rubber plantations in Thailand has potential to sequester approximately 108 million tons of CO\(_2\) per year. On average, approximately 24.9 kg of net CO\(_2\) was sequestered for each kilogram of natural-rubber latex produced. This large carbon sequestration potential associated with natural latex production has important implications for the establishment of ‘environmental friendliness’ marketing strategy to enhance the natural rubber competitiveness, especially in comparison to synthetic rubber.

5. References

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