Table 1. Comparison of evaporation observation and calculation data.

	Obs.	Cal.	Diff.
08/05	1.63	1.74	-0.11
08/06	1.58	1.61	-0.03
08/07	1.58	1.59	-0.01
08/08	1.80	1.72	0.08
08/09	1.95	1.87	0.08
08/10	1.52	1.62	-0.10
08/11	1.63	1.74	-0.11
08/12	2.05	1.92	0.13
08/13	1.50	1.48	0.02
08/14	1.50	1.53	-0.03
08/15	1.94	1.81	0.13
08/16	2.19	1.89	0.30
Total	20.87	20.52	0.35

IV. Reference

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Site Info

Site Presentation
Rubber Flux, CO_2, Water and Energy Budget of Rubber Plantations in Thailand

Philippe THALER* and Poonpipope KASEMSAP**

* Cirad, France
** Kasetsart University, Thailand.

Rubber area and rubber plantation in Thailand

Rubber tree (*Hevea brasiliensis*) is a major tree crop in Southern and South-eastern Asia. It is the only commercial source of natural rubber, a polymer widely used in industrial products such as tyres, joints, shock-absorbers, and latex goods such as condoms and gloves. Although natural rubber competes with synthetic polymers, its specific properties make it irreplaceable for many applications. Moreover, during the last decades rubber wood has become an important product, and rubber wood industry (furniture, toys) has developed significantly.

World rubber area has grown at a rate of 1.67% annually, showing almost three times increase during the last four decades from 3.88 million ha in 1961 to 10.07 million ha in 2004. Though rubber is grown in more than 20 countries now, four major countries, including Thailand, Indonesia, Malaysia and India who were the pioneers to take up rubber cultivation at a commercial scale, continue to dominate the global rubber production sector with a relative share of 77% in rubber planted area and 79% of the global rubber production. These four countries have also experienced substantial transformation in the production structure with the entry of the native peasantry, eventually leading to the proliferation of smallholder systems under various socio-economic, political and institutional contexts. Therefore, the smallholder sector dominates the rubber plantation agriculture in these countries to the extent of 90% in Thailand, followed by 89% in India and Malaysia, and 83% in Indonesia (Viswanathan and Shivakoti, 2006).

The total rubber planted area in Thailand has increased from 0.4 million ha in 1961 to more than 2.0 million ha in 2003, with a concentration of area in the Southern region of the country occupying 80% (RRIT, 2003) (table 1). In 2003, a major proportion of the total area of agricultural holding in the Southern region was covered by rubber (54.1 %), followed by permanent crop/forest (29.0%) and rice (11.1%) (National Statistics Office 2003). Thus, apart from natural forest remaining in national parks, rubber plantations represent the major forest ecosystem in southern Thailand. Assessing the carbon budget of rubber plantation is thus a prior requirement to quantify local and regional carbon budgets. It is also worthy of estimating the carbon sequestration potential of rubber plantations and the possible implementation of related Clean Development Mechanism (CDM). Carbon sequestration potential of rubber plantations may provide opportunities to increase the profitability and acceptability of plantations.

Table 1. Rubber plantation area (ha) by region in Thailand (source RRIT, 2003).

	1996 (kilo-ha)	2003 (kilo-ha)	% of total area in 2003
South	1,471	1,602	79.4
East	241	210	10.4
Northeast	64	94	4.7
Other	234	113	5.6
Total	2,010	2,019	

Land use changes.

Currently two major evolutions about rubber cultivation are underway.

1. In the traditional region, almost all the appropriate land for rubber has been used. Natural forest felling is no more possible and neither desirable. In the current agricultural area, rubber cultivation has to compete with other crops, particularly with oil palm cultivation. During the last decade, the trend was toward the expansion of oil palm, replacing rubber to some extent. However, the recent increase in rubber price, and encouraging prospects, make rubber attractive again. The future share of land use between rubber and oil palm is a major issue in Thailand and in other South-eastern Asian countries. As such choice involves long term investments and perennial ecosystems, environmental issues are particularly important. Among these issues, the impact of climatic changes on the relative competitiveness of rubber and oil palm requires appropriate knowledge about the ecophysiology of both tree crops.
2. Meanwhile, rubber cultivation expands to new areas, mainly Northern and North-eastern Thailand, where it has to face less favourable climatic conditions, such as a long and dry season (up to 6 months) and relatively cold temperature in winter (in the North). In these new planting areas, the expansion of rubber occurs on previous crop area such as cassava and sugarcane, with a possible substitution of eucalypt by rubber too.

Currently there is about 209,000 ha and 95,000 ha rubber plantation in the Eastern region and North East region, respectively. Government's plans are for 1 million ha to be planted in Northern and North-eastern Thailand. Thailand aims to increase its rubber planted area by 960000 ha in 2012. Thus, it is important not only to evaluate rubber performance in such areas, but also to assess impact of rubber plantations on environment and particularly on water balance.

The Rubber Flux project

Rubber flux aims at providing a complete picture of CO_2, water and energy budget of a rubber plantation in Eastern Thailand. A synthetic presentation of the site information is available at http://www.asiaflux.net/network.html.

Beyond the evaluation of the fluxes, our purpose is to partition them among the different components of the plantation ecosystem (canopy, trunks, roots, under storey, soil) and the different functions (photosynthesis, respiration evapotranspiration) in order to understand the factors controlling the carbon, water and energy budgets of the ecosystem.

Site Description

The experiment is situated at the Chachoengsao Rubber Research Station located in Phanom Sarakham district (13° 41' N, 101°04' E, 69 m above sea level). The site is about 140 km east of Bangkok (Fig.1).

This location, although close to the Eastern region where rubber has been cultivated for a long time, is considered as climatically not optimal for rubber. The dry season last usually 4 months, from December to April (Fig. 2). Within this district, the landscape changes from the flat lands of the central plain (alluvial terrains from Chaopraya River and other rivers) to a more hilly landscape. However, the station itself is located on a relatively flat area. It covers 350 ha plantation with rubber trees of different clones and different ages, supporting experiments devoted mainly to breeding, agronomy, tapping systems.

Soils are sandy-clay-loam (Kabin Buri series) characterized by a compact lateritic layer with ferralitic concretions at around 1 m deep, which prevents most roots developing further downward.

The observation site is located in a plot at the center of the station. It is thereby surrounded by other rubber tree plots in all directions with different ages. The plot itself is 6 ha large and is planted with a monoclonal stand (clone RRIM 600, the major clone in Thailand). Trees were 12 years old in 2006. The average height was 20 m and average girth at 1.7 m was 60 cm (Fig. 3). The usual planting design is 7 m by 2.5 m (571 trees/ha) but in the considered plot inter-row distance varies between 5 to 11 m, initial planting density was 500 trees/ha and actual stand density was 454 trees/ha in June 2006. Trees are tapped for latex production for 4 years.

Rubber CO_2 Flux Experiment Design

Carbon fluxes of rubber plantation ecosystem are continuously measured by the eddy covariance method (ED). Evapo-transpiration (ET) is measured by ED and water balance together. Meanwhile, amounts of carbon (C) stored in the trees will be evaluated by measuring biomass increment of the plantation, in combination with estimations of the carbon content at the different compartments. The flux tower is a 25

Fig. 1. Location of Rubber Flux Chachoengsao.

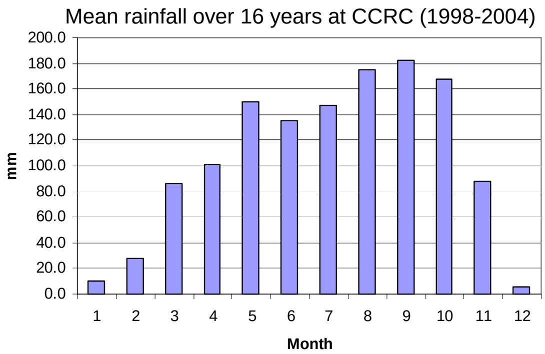

Fig. 2. Monthly mean rainfall during 1989-2004 at CRRC.

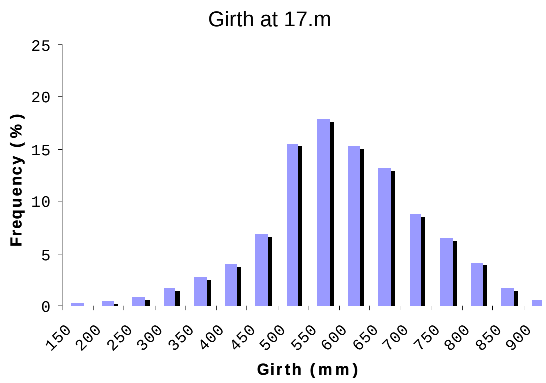

Fig 3. Distribution of trunk girth in June 2006 in Rubber Flux plot.

m high self-standing triangular structure. On the top of the tower, a hexagonal platform is used as working area and to support data loggers and power supply. The measurement height for ED is 27 m. A sheltered coaxial cable carries both power and data which can be recorded online onto a PC (personal computer) located in a shed 10 m away from the tower. An alternative way, to avoid technical problems associated with the data transfer, is to record the data on a laptop located in a water proof box on top of the tower. Electric power for the tower and equipments is supplied from the shed.

Measurements will provide the annual balance of C within plantations at different ages. Energy balance will be assessed by measurements of net radiation (Rn) and estimation of the energy partitioning among heat fluxes and heat storage.

Results obtained at the ecosystem scale by these methods will be compared to gas exchanges measured at the level of the different compartments (canopy, trunk, root system, soil, etc). Thereby, the validated CO_2 and H_2O fluxes will be used to model gas exchanges of rubber plantation ecosystem according to climate and other environmental parameters as well as crop management.

Sub-components

Eddy-covariance (ED)

ED methodology was adapted from a similar experiment developed by our research group on another tropical tree crop plantation, coconut tree, in Vanuatu islands. Details of the methods are described in Roupsard *et al* (2006). Three-demensional (3-D) sonic anemometer Young 81000V 20 Hz is used together with an open path gas analyser (LI-7500; LI-COR, Inc., Lincoln, Nebraska, USA). Raw data are collected and pre-processed by the “Tourbillon” software (INRA-Bioclimatologie, Bordeaux, France) for a time-integration period of 300 s. Raw data are post-processed using EdiRe software (University of Edinburgh, UK) into half-hourly values. All data are despiked according to variance filters, planar fit is applied (parameters are calculated monthly), and vapour is corrected for buoyancy.

For short periods (2 months), a double ED systems will be installed, above and below the canopy, to estimate contribution from the understorey to fluxes.

Climate

Weather station measures semi-hourly net radiation (Rn), photosynthetically active radiation (PAR), diffuse PAR (PAR_{diff}), reflected PAR ($PAR_{reflected}$), global radiation (Rg), air temperature (Ta), relative humidity (Rh), wind speed, wind direction, rainfall, vertical profile of air temperature (TCs).

Net Primary Productivity (NPP)

Standing biomass dynamics will be assessed by tree survey in the plot. As we are in a monoclonal plantation, DBH and height measurements, monitored on a large sample (± 500 trees), will provide an accurate estimation of biomass, based on existing allometric relationships.

Litter-traps are used to assess fall of leaf, branches, flowers and fruits. There are currently 20 litter-traps. Litter-bags will be used to compute the time-course of litter mass remaining (LMR) and the decomposition constants (k). Phenology of leaf, flowers and fruits is surveyed. In our conditions complete leaf-shedding occurs in January-February, followed by a rapid re-foliation. Together with the use of hemispheric photography, this will allow good assessment of leaf area index (LAI) dynamics. A specific sub-programme aims at comparing several methods and software for the acquisition of canopy parameters (including LAI) from hemispheric pictures.

Fine root biomass dynamics will be assessed from the growth measurement in cores or trenches, whereas root lifespan and turnover will be obtained from root observation glasses. Allometric rules from previous data will be used to calculate biomass increment.

Water balance, water status in soil and trees

16 home-made Granier probes (heat dissipative) are installed on a representative sample of the tree stand, selected according to trunk diameter, to measure sap-flow. Sap-flow is computed semi-hourly in order to provide calculation of transpiration that could be compared with evapo-transpiration measured by ED. Leaf water potential (predawn and diurnal time-course) is assessed periodically throughout the canopy in relation to climate and soil water content. Hydraulic conductance will be computed thereby. We particularly focus on contrasting periods, such as beginning of rainy season (May) and end of rainy season (November).

Soil temperature profiles are measured in three trenches located according to planting design, using copper-constantan thermocouple probes buried down to 1 m, and a 10TCRT thermocouple reference thermistor (Campbell Scientific, Inc., Logan, Utah, USA). Soil volumetric water content (θ) is measured using 21 water content reflectometers (CS615 probes, Campbell Scientific), buried horizontally in the vertical walls of the same trenches and calibrated against the gravimetric method, using the measured soil dry bulk density.

Energy balance

Soil heat flux (G) will be assessed using soil water content, soil temperature profile and soil mineral and organic composition (from previous data). Heat storage in trunks (Qt) is measured using thermocouples. Heat storage in air (Qa) is measured using thermocouples (air profile). Sensible heat flux (H) and latent heat flux (LE) are obtained from the ED measurement

Leaf photosynthesis

An important related topic is the parameterization of Jarvis and Farquhar models of stomatal conductance and leaf photosynthesis, using the LI-6400 photosynthesis system (LI-COR). This is performed on trees of different ages, including those of the flux tower plot. Measurements within the canopy are processed from a crane cradle along a vertical transect (Fig. 4, 5 and 6). At the same time, leaf nitrogen content, leaf chlorophyll content, leaf water potential, light interception and LAI are measured along this transect. This would finally be integrated to model canopy CO_2 and water exchanges.

Soil respiration

This important component of carbon budget assay will be implemented in 2008. We plan to transfer a system and expertise that we developed to measure continuously trunk respirations for this soil respiration measurement. In order to unravel heterotrophic respiration from root respiration we will compare soil respiration from undisturbed soil and from trenched plots.

Partnership

This operation is a component of a project under Thai-French cooperative programme for higher education and research, namely 'Improving the Productivity of the Rubber tree'.

Fig. 4. The 25 m high, self standing tower, view at leaf-shedding.

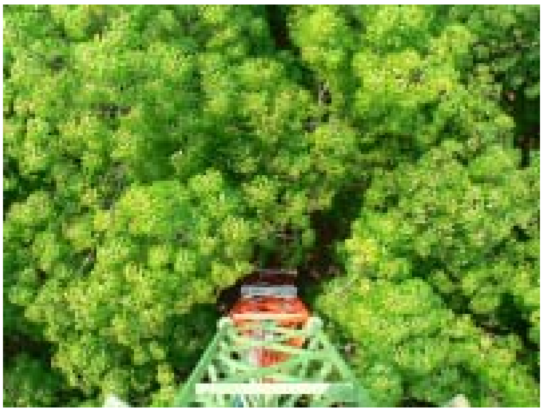

Fig. 5. View of rubber canopy from the tower.

Fig. 6 Leaf gas exchanges measurements with a crane.

There are two main Thai partners and two main French partners.

Kasetsart University, Bangkok Thailand, is the main Thai University in agriculture and environment. Coordinator of the project is Sornprach Thanisawanyangkura, faculty of Science, Department of Botany. Main scientist involved in the project is Poonpipope Kasemsap, Faculty of Horticulture. Several PhD and MS students are doing their research work within the Rubber Flux project.

Chachoengsao Rubber Research Center (CRRC), where the experiment is located, is one of the two largest research stations of the Department of Agriculture (DOA) devoted to rubber in Thailand. The main scientist involved is Arak Chantuma.

CIRAD, French Agricultural Research Centre for International Development, is an agency specialized in cooperative research in agriculture and environment. The main scientist involved is Philippe Thaler, Functioning of Plantation Ecosystem research unit, helped by Dr Olivier Roupsard, currently responsible for the Coco Flux site in Vanuatu.

INRA, French National Centre for Agricultural Research provides expertise thanks to Jean-Marc Bonnefond, a key member of the INRA-Ephyse research unit already involved in several flux research sites within the Euroflux network.

Schedule

The flux tower has been built in January 2006. The site is still under installation and setting up. Processed flux data cannot be provided yet. However, complete weather, soil water content and sap flow are already monitored.

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Site Info

Continuous Observation at a Sub-Arctic Black Spruce Forest in Interior Alaska

Masahito UEYAMA and Yoshinobu HARAZONO

International Arctic Research Center, University of Alaska Fairbanks

Introduction

Climate change in northern high latitude was remarkable in past few decades (Hinzman *et al*., 2005). To improve our understanding how the arctic ecosystems would respond to the recent arctic warming, we started year-round continuous observation at a sub-arctic black spruce forest in interior Alaska since fall 2002 (Nojiri *et al*., 2003). Fluxes of energy, water, and CO_2 were measured by the eddy covariance method, whereas CH_4 flux was measured by using the modified gradient method (Ueyama *et al*. 2006a, b). Since the black spruce is a climax forest of boreal biome in North American continent, it is particularly important to estimate the carbon fluxes of black spruce forests for evaluating the regional carbon budget.

Site description

The research site is located at a typical taiga forest in Fairbanks Alaska (64°52'N, 147°51'W, elevation 120 m; Figure 1). Since the climate in interior Alaska is continental,