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Original Article

Preliminary assessment of land–air energy transfers in tropical forest and agro-ecosystems

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Abstract

This study aims to show preliminary results of meteorology and surface energy transfers in tropical forests and agro-ecosystems and their associations with vegetation canopy and soil water content. Field observations were conducted at the selected vegetation sites and adjacent sparse vegetation sites in the Northeast of Thailand from the summer season to early rainy season. The study results showed that diurnal variations on spatial soil temperature gradient between bare soil and vegetation soil was significant but not much for air temperature and humidity. Influenced by season and cropping cycle, soil water content (SWC) could induce greater spatial air temperature and humidity differences and moderated the spatial soil temperature gradient. Among various vegetation covers, diurnal patterns on energy transfers and associations between SWC and latent heat were clearly different and they suggest substantial microclimate changes associated with the conversion of forests into croplands.

Keywords: latent heat, sensible heat, agro-ecosystem, soil water content

1. Introduction

The northeastern region of Thailand is influenced by semi-arid tropical climate and predominantly covered by croplands, consisting mainly of rice, corns and sugarcanes which can be counted for approximately 60.5% of its entire area. Rice is normally grown once a year during the rainy season, therefore called as rain-fed rice, which covers the area of ~6 M hectare in the whole region (Ministry of Agriculture and Cooperatives, 2014). A typical crop calendar for rain-fed rice starts from transplanting in mid- to late-May, followed by heading in mid- to late-October and harvesting in late November (Sawano *et al*., 2008). Other important crops in this area include sugarcanes, cassavas and corns. Their cropping cycles are from 10 to 12 months and they can be grown without irrigation due to sufficient soil water content in the dry season (Moroizumi *et al*., 2009; Watanabe *et al*., 2004). Furthermore, approximately 0.45 M hectare in this region has currently been used for Para rubber plantation and ~2.65 M hectare is suitably available for the future expansion (Saengruksawong *et al*., 2012). Owing to its long productive life of ~20 years, carbon storage in Para rubber plantations has been comparable to that in forest ecosystems (Saengruksawong *et al*., 2012).

Several studies also report effects of agricultural land uses on changes in evapotranspiration and energy fluxes, both of which influence hydrological cycle, weather and climate (Raddatz, 2007). Surface energy fluxes include latent heat (used for a change in water phases without a change in temperature), sensible heat (used for a change in temperature regardless of the effects of evapotranspiration) and soil heat storage (Kimura & Shimizu, 1994). LeMone *et al*. (2007) measured horizontal distribution of sensible and latent heat fluxes in USA and reports effects of land cover on the heat

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fluxes. The lower latent heat flux was found over sparse vegetation or bare soil and higher over green vegetation covers. The sensible heat flux, however, was higher over the bare soil (LeMone *et al*., 2007). This results to negative latent–to–sensible heat flux ratio, varying from -2.48 for the wet surface to -1.09 for the dry surface (LeMone *et al*., 2007). The negative heat flux ratio, however, was not consistent with the conclusion made by Wilson *et al*. (2002), concerning positive sensible-to-latent heat flux ratio of approximately 0.42 for deciduous forest and higher (0.89) for grassland (Wilson *et al*., 2002).

Influenced by agro-ecosystems, the climate in the Northeast of Thailand could link to vegetation type, spatial cropping pattern, seasonal plant phenology and crop management practice, including tillage and irrigation. Rain-fed ecosystem is suitable for lowland rice. Rice plants are normally soaked and grown in water for approximately five months, inducing high water evapotranspiration (Maruyama & Kuwagata, 2010). Seasonal plant phenology also influences different evapotranspiration and soil water content (Tyagi *et al*., 2000; Watanabe *et al*., 2004). Once crops have been harvested, the air above soil surface is expected to be warmer associated with drier and warmer surface soil (Cooley *et al*., 2005). Crop residue management and tillage options strongly affect soil water dynamics and energy exchange between air and land, thus influencing surface temperature and humidity (Alvarez & Steinbach, 2009; van Donk *et al*., 2010; Verhulst *et al*., 2011). Irrigation, associated with agricultural intensification, played a key role in increasing moisture flux in the Indian continent (Douglas *et al*., 2009). It induces surface cooling and changes in regional circulation and precipitation patterns (Douglas *et al*., 2009). Raddatz (2007) reviewed available publications and concluded that agriculture could induce deep moisture convection, leading to changes in mesoscale circulations over Canada. Nevertheless, the association between agricultural land covers and surface meteorology in tropical Southeast Asia has been very limited (Raddatz, 2007).

This study aims to show preliminary results on diurnal meteorological patterns over different tropical vegetation fields in the selected sites in Southeast Asia and to assess effects of plant canopy on meteorological patterns and surface energy partitioning. Effects of soil water content on the energy fluxes are also discussed. The result obtained from this study could lead to development of adaptation measures for climate changes in the tropical agro-ecosystems.

2. Methodology

2.1 Study sites

Four sites situated in the Northeast of Thailand had been selected to represent different tropical agro-ecosystems, including mixed deciduous forest in Maha Sarakham, Para rubber plantation in Burirum, rice paddy in Kalasin and sugarcane field in Nakhon Ratchasrima. Details on land covers and dominant vegetation are shown in Table 1. The observations were taken from April to June 2015 from the local summer to early rainy season. Year 2015 is a drought year, characterized by relatively low precipitation and strong El Niño Southern Oscillation signal (National Oceanic and Atmospheric Administration [NOAA], 2015). Since the first of January 2015, average accumulative rainfall over this region as measured in June was 79.5 mm below normal and average air temperature at each site during the measurement was in the range of 30.0 to 31.1°C, which was 1.2°C and 0.7°C above the normal in May and June 2015, respectively.

2.2 Field measurement

To evaluate effects of vegetation canopy on local meteorology, air temperature and humidity under plant canopies (in mixed deciduous forest, Para rubber plantation and sugarcane field) and adjacent sparse vegetation areas were simultaneously measured. Furthermore, soil temperature and soil volumetric water content (SWC) were measured to determine latent and sensible heat transfers at soil–air interface in the vegetation fields. All measurements were simultaneously taken every 30 minutes. The sensors used for the field measurements were described below:

- Humidity/Temperature/Pressure Data Logger (RHT 50, Extech Instruments Corporation, USA), installed at ~30-50 cm above the soil surface, was employed to record surface air temperature, humidity and pressure under the vegetation canopies.
- Air temperature, humidity, absolute pressure and wind speed at 150-200 cm height were retrieved from a mobile weather station (Weatherwise instruments®), installed in the sparse vegetation areas adjacent to the vegetation canopies. Furthermore, cumulative hourly rainfall during the measuring hours was also taken from the weather station.
- The soil temperature, SWC and Photosynthetically active radiation (PAR) were continuously taken using sensors (RT-1, EC-5 and QSO-S, respectively) with datalogger (Em50 series) from DECAGON Devices, Inc., USA. They were installed in the vegetation fields. The soil sensors were placed at 20-30 cm depth from the soil surface while the PAR sensor was at 20 cm height above the surface.

2.3 Latent and sensible heat flux implications

Sensible heat flux is indicated by difference in soil and air temperature at the interface and it can be written as $T_s - \theta_a$ (Kimura and Shimizu, 1994), where T_s is the soil temperature (K) and θ_a is the potential air temperature (K). The θ_a was estimated from

$$\theta_a, K = T_a \left[\frac{1,000}{P_a} \right]^{0.286} \tag{1}$$

where T_a is the surface air temperature (K) and P_a is the absolute air pressure (hPa).

Latent heat flux is implied from the difference in specific humidity (mass of water vapor in a unit mass of moist air) between soil and air at the interface and it can be written as $q_{sat}(T_s) - q_a$ (Kimura and Shimizu, 1994), where $q_{sat}(T_s)$ is the saturated specific humidity at soil temperature and q_a is the specific humidity at surface air temperature.

The saturated specific humidity at soil temperature was estimated from

$$q_{sat}(T_s), \frac{\text{Kg water}}{\text{Kg air}} = 0.62198\frac{P_{ws}}{P_a - P_{ws}} \qquad (2)$$

where P_{ws} is saturate pressure of water vapor at soil temperature, which can be estimated from T_s as

$$P_{ws}, \text{hPa} = \frac{\exp\left(77.345 + 0.00547T_s - \frac{7,235}{T_s}\right)}{100T_s^{8.2}}. \qquad (3)$$

The specific humidity at surface air temperature was estimated from

$$q_a, \frac{\text{Kg water}}{\text{Kg air}} \approx \frac{RH\left[\exp\left(\frac{17.67(T_a - 273.16)}{T_a - 29.65}\right)\right]}{26.3P_a}, \qquad (4)$$

where RH is relative humidity of surface air, in %.

3. Results and Discussion

3.1 Effects of vegetation canopy on air and soil surfaces

3.1.1 Atmospheric temperature and humidity

Figure 1 shows the differences between air temperature (a) and humidity (b) in the vegetation fields and those in the adjacent sparse vegetation areas/bare soils. In overall, meteorological conditions over the sparse vegetation exhibited comparatively higher surface air temperature (average +6.2%) and lower humidity (average -9.4%). Plant transpiration induced the higher atmospheric humidity and the lower surface temperature was resulted from lower incoming solar radiation onto the ground owing to plant canopy interception.

The spatial temperature gradient was dependent on season and location. Warmer plant-canopy temperature was observed in some other areas including Castroville, USA, in the summer and in Hopland, USA, in the spring months (Synder & Spano, 2013). This warm plant-canopy temperature in the US stations could respond to water stress, CO_2 increase, higher canopy humidity or lower wind speed (Synder & Spano, 2013). This study was conducted in high water stress period from the dry season to the early rainy season and the warmer plant-canopy temperature was not frequently observed. Nevertheless, there were few observations, mainly in the harvested sugarcane field (Sugarharvest) during daytime from 7:00 to 16:00, showing significantly higher air temperature (up to +34%) and lower humidity (up to -56%), as compared with those over the sparse vegetation.

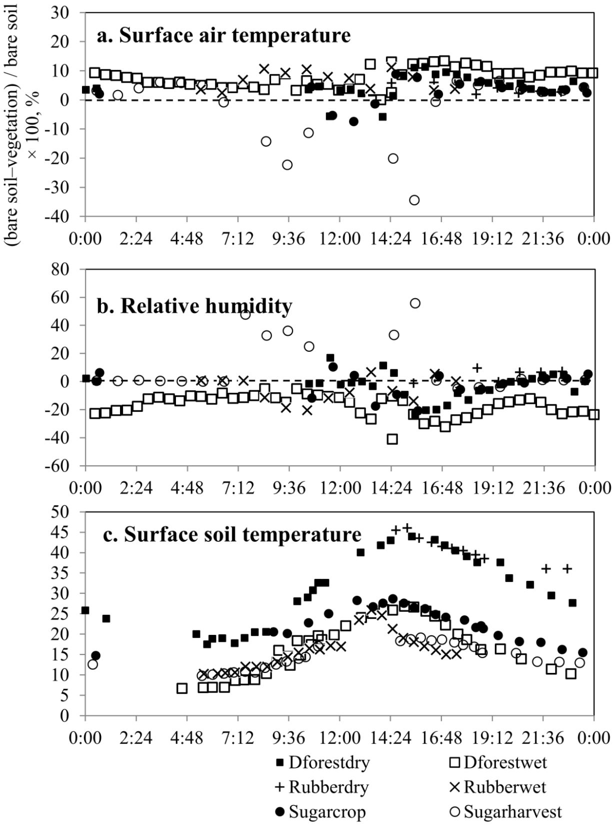

Figure 1. Diurnal distribution of spatial differences of (a) surface air temperature, (b) relative humidity and (c) surface soil temperature between under vegetation canopies and at adjacent sparse vegetation/bare soil areas for various vegetation covers.

As shown in Figure 2, the lower surface air temperature in the vegetation sites, compared with those over the sparse vegetation, was strongly correlated with its higher humidity. Linear correlation coefficients indicate similar high correlation between spatial air temperature and humidity gradients among the forest, the rubber plantation and the sugarcane field (R^2 = 0.79, 0.72 and 0.84, respectively). With the significantly high correlation, this suggested a strong interaction between spatial temperature gradient and humidity gradient. The percentage of spatial humidity gradient declined for approximately 1.3% (for sugarcane) to 2.5% (for the forest) with increases in 1% of the air temperature gradient. Nevertheless, this spatial air temperature difference did not associate well with the observed surface wind speeds (Figure 2).

3.1.2 Soil temperature and volumetric water content

From Figure 1c, surface soil temperature over the sparse vegetation areas/bare soils were greater than those in

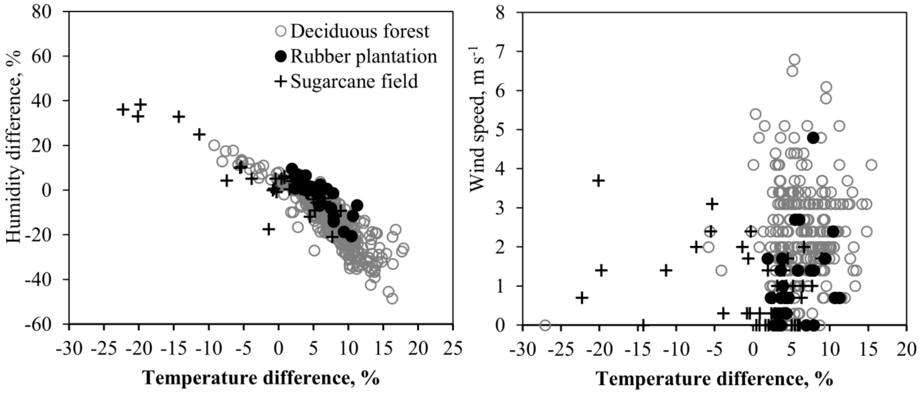

Figure 2. Scatter plots between spatial temperature difference and spatial humidity difference (left) / surface wind speed (right).

the vegetation fields. The spatial temperature gradients in Figure 1c clearly show temporal pattern, reaching the peak at ~14:30 to 16:30 and declining to the lowest point in the early morning at ~6:00. The highest solar intensity, suggested from PAR, appears around noon (Table 1). Then, soil absorbs the solar energy and later releases the energy in forms of long-wave energy and heat, resulting in higher surface soil temperature in the afternoon. There were similar soil temperature gradients (peak at 35.7% and lowest point at 16.6%) between the forest and the Para rubber plantation under dry soil condition. The significantly lower soil temperature gradient was observed under wet condition of the forest and the Para rubber plantation and their diurnal patterns were similar to those observed in the sugarcane field, with the peak at 28.7% (Sugarcrop) and the lowest point at 6.2% (Dforestwet). This could be implied that SWC has a role to play in the soil temperature.

As shown in Table 2, SWC was significantly correlated with the atmospheric humidity at the forest (*r*=0.334) and the Para rubber plantation (*r*=0.814). Increased soil moisture induces higher potential soil evaporation resulting in less energy to heat the soil (Qin *et al.*, 2012). The high correlation, however, was not observed at both rice paddy and sugarcane field. Since short growth cycles of rice and sugarcane, this discrepancy could be more or less related to evapotranspiration induced by crop canopy development.

The observed increases in SWC in the mixed deciduous forest were from 0.100-0.105 m^3 m^{-3} in the end of the dry season (April, 2015), 0.168-0.182 $m^3 m^{-3}$ in the early rainy season (June, 2015) and up to 0.278 m^3 m^{-3} during the rainy period (June, 2015). The SWC for the Para rubber plantation was not consistent with those found in the forest. The SWC was comparatively lower than the forest under dry soil condition (0.018-0.020 m^3 m^{-3}) and suddenly high at the greatest one-hour rainfall (0.426 m^3 m^{-3}). The SWC was then rapidly declining after the raining hour with the rate of approximately -0.09 m^3 m^{-3} hr^{-1} for the first three hours. This finding implies less soil water retention and higher rainwater runoff in rubber plantations than those in forests.

There were also differences in SWC observed in crop fields during the growing phase and after harvesting. SWC was measured at 0.484-0.494 m^3 m^{-3} during the phase in which rice plants were growing in the water. After the harvesting phase, the field was still composed of waterlogged soil with slightly lower SWC of 0.401-0.451 m^3 m^{-3}. This SWC values were in the similar magnitude with the saturate SWC level (>0.40 m^3 m^{-3}) estimated by Goto *et al.* (2008).

For the sugarcane field, the SWC was lower during the growing phase (0.050-0.057 m^3 m^{-3} in April) than that after harvesting (0.086-0.092 m^3 m^{-3} in June). These SWC levels were close to those reported in the work of Moroizumi *et al.* (2009) of 0.087 m^3 m^{-3} at 0.1 m depth during the dry seasons during the drought year in 2003-2004 (Hydro and Agro Informatics Institute [HAII], 2015), but significantly lower than those observed in the other dry seasons in normal years 1998 to 2000, with the lowest point of 0.109 m^3 m^{-3} at 0-0.5 m depth (Watanabe *et al.*, 2004). Low SWC in the year 2015 has been induced by long-term drought since year 2012, as of exhibited below-normal rainfall (HAII, 2015).

3.2 Implications on energy transfer and partitioning for different vegetation covers

3.2.1 Sensible heat flux transfer

Positive sensible heat flux indicates heat transferring from soil to surface air and its magnitude is estimated from degree of the difference between surface soil temperature and potential air temperature at interface (T_s - θ_a). On the other hand, its negative value indicates the degree of air-to-soil sensible heat transfer. Diurnal variation of the sensible heat flux, in Figure 3, showed greater positive fluxes (T_s - θ_a>0 and up to 6.5°C) during nighttime for the rice field and the sugarcane field than those (T_s - θ_a~0) for the forest and the Para rubber plantation. Negative sensible heat flux was typically found in the crop fields during daytime from 7:00 to 18:00. The negative fluxes over the crop fields (Sugarharvest, Ricecrop and Riceharvest) were comparatively lower than those in the

Table 1. Description of the studied sites and date of observations.

Location	Soil	Land cover	Vegetation	Site Name	Date of observation	Soil water content at 30 cm depth, m^3/m^{-3} VWC	Rainfall, mm	Hourly maximum Photosynthetically active radiation (PAR), $\mu mol\ m^{-2}\ s^{-1}$
Dun Lumpun non-hunting area, Maha Sarakham (15.77309°N, 103.02587°E, 161 m above MSL)	23.4%Clay, 28.5%Silt, 48.1%Sand	Mixed deciduous forest	Dominated by *Streblus asper* Lour., *Terminalia alata Heyne* ex Roth., and *Bambusa Bambos* (LX Voss), 32 trees (diameter > 15 cm) per 100 m^2	DForestdry	April 18th – 19th, 2015	0.100–0.105	0	102.5 at noon
					June 20th – 23rd, 2015	0.168–0.182	0	1,353.1 at 13:00
				DForestwet	June 8th–9th, 2015	0.264–0.278	20	302.1 at 14:00
					June 24th–25th, 2015	0.211–0.259	6.6	139.2 at 13:30
Rubber Research and Development Center, Burirum (15.23009°N, 103.21204°E, 152 m above MSL)	22.9%Clay, 7.8%Silt, 69.3%Sand	Para Rubber Plantation	20-years-old Para rubber (*Hevea brasiliensis*) trees with 3×7 m^2 cropping space and ~ 20 m height	Rubberdry	June 1st, 2015	0.018–0.020	0	148.3 at 13:00
				Rubberwet	June 2nd, 2015	0.105–0.426	6.3	
Rice Paddy, Kalasin (16.19513°N, 103.46616°E, 133 m above MSL)	46.1%Clay, 28.8%Silt, 25.1%Sand	Bare soil with some rice stand remains, burnt and plowed	No crop	Riceharvest	April 25th – 26th, 2015	0.401–0.451	5.4	2,120.4 at noon
		Rice paddy: transplanted and standing water	1-month crops (Phitsanulok 2) with ~33 cm height	Ricecrop	May 30th–31st, 2015	0.484–0.494	0	2,085.6 at 11:30
Agricultural Research and Development Center, Nakhon Ratchasrima (14.87837°N, 101.64748°E, 249 m above MSL)	27.0%Clay, 16.2%Silt, 56.8%Sand	Sugarcane field	10-month-old sugarcane with 150×80 cm^2 cropping space and ~230 cm height	Sugarcrop	April 26th –28th, 2015	0.050–0.057	5.1	230.7 at noon
		Harvested sugarcane field covered by dry leave and new sprouts	New sugarcane sprout shooting	Sugarharvest	June 3rd –4th, 2015	0.086–0.092	5.1	2,105.7 at 11:30

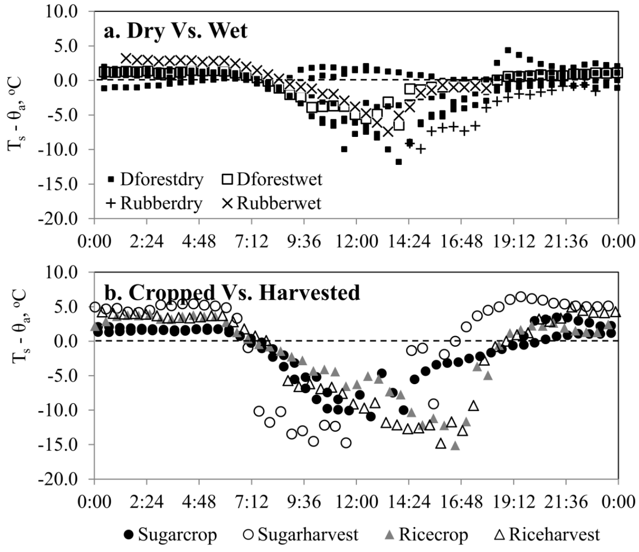

Figure 3. Diurnal variations of sensible heat flux indicator ($T_s - \theta_a$) for (a) dry and wet mixed deciduous forest and Para rubber plantation / (b) grown and harvested sugarcane and rice fields

forest and Para rubber plantation (Figure 3). The lowest $T_s - \theta_a$ was -14.7°C. This finding could imply that high degree of spatial sensible heat flux gradient between the forests/rubber plantations (comparatively lower sensible heat flux) and the adjacent croplands could drive stronger heat advection, inducing more soil evaporation over the dense vegetation and affecting hydrological cycle together with local climate. This pattern had been previously observed by Giambelluca *et al.* (2000) in Eastern Amazon and Northern Thailand.

From the correlation matrix in Table 2, the sensible heat flux was strongly associated with atmospheric humidity (r>0.87 for all vegetation covers) with linear slopes ranging from 0.20°C (Dforestwet) to 0.36°C (Rubberdry) per a unit of changed %RH. Furthermore, the sensible heat flux was negatively correlated with PAR intensity (r=-0.416 to -0.791). The linear slopes ranged from -0.008°C (Riceharvest) to -0.072 °C (Sugarcrop) per a unit of changed PAR (ìmol m^{-2} s^{-1}). From this strong relationship, it could be concluded that the positive sensible heat flux intensified under humid condition, particularly predominant at night or in a cloudy day. The negative sensible heat flux was more likely to be found under dry condition around noon in a day when the sky was clear.

Interestingly, strong association between sensible heat flux and SWC was not generally found, but in the rubber plantation (Table 2). This finding was not consistent with previous studies conducted in high latitudes showing significant connections between SWC and sensible heat flux including the works by Kimura and Shimizu (1994) in a suburb of Tokyo, Japan, Cui and Wang (2009) in the western Tibetan Plateau, and LeMone *et al.* (2007) in southeast Kansas, USA.

3.2.2 Latent heat flux transfer

The difference between saturated specific humidity at soil temperature and specific humidity of the air above the surface $(q_{sat}(T_s) - q_a)$ was used to determine degree of latent heat flux transfer. The positive value $(q_{sat}(T_s) - q_a > 0)$ indicated latent heat flux from the ground to the atmosphere and the negative value showed the opposite direction. Diurnal variation of the land–air specific humidity difference as can be seen in Figure 4, showed only positive latent heat fluxes with peaks from the late afternoon to evening (15:00 to 18:00). Nevertheless, the level of latent heat flux for dry soil ($q_{sat}(T_s) - q_a$ up to 0.0112 for Rubberdry) was slightly higher when compared with those observed in the wet soils (Dforestwet and Rubberwet) as shown in Figure 4. The diurnal variations for the dry soil (Dforestdry and Rubberdry) were similar to those of the sugarcane field and the harvested rice field. The harvested sugarcane field and transplanting rice paddy, however, exhibited ~2-3 times higher the land-air specific humidity difference, suggesting greater latent heat flux transfer. The lowest latent heat transfer ($q_{sat}(T_s) - q_a$ ~0.002) was visibly observed in the morning from 8:00 to 9:00 in the harvested rice field, the sugarcane field and the Para rubber plantation.

Table 2. Linear correlation coefficients matrix among Relative humidity (RH), soil water content (SWC), Photosynthetically active radiation (PAR), $T_s - \theta_a$ and $q_{sat}(T_s) - q_a$.

	SWC	PAR	$T_s - \theta_a$	$q_{sat}(T_s) - q_a$
Dun Lumpun non-hunting area (N = 247)				
RH	0.334**	-0.527**	0.884**	-0.627**
SWC		-0.034	0.076	-0.609**
PAR			-0.696**	0.037
$T_s - \theta_a$				-0.220**
Rubber Plantation (N = 55)				
RH	0.814**	-0.121	0.874**	-0.734**
SWC		0.082	0.627**	-0.670**
PAR			-0.416**	-0.403**
$T_s - \theta_a$				-0.338*
Rice Paddy (N = 95)				
RH	-0.104	-0.667**	0.899**	-0.513**
SWC		-0.103	0.163	0.700**
PAR			-0.791**	-0.128
$T_s - \theta_a$				-0.148
Sugarcane field (N = 123)				
RH	-0.166	-0.698**	0.897**	-0.303**
SWC		0.440**	0.097	0.751**
PAR			-0.655**	0.338**
$T_s - \theta_a$				0.123

Note: $^{**}p<0.01$; $^{*}p<0.05$

The prior latent heat flux pattern could be influenced by SWC. From the correlation matrix in Table 2, the correlation of latent heat flux with SWC was not consistent among various vegetation covers; showing a negative relationship between latent heat flux and SWC — the forest (*r*=-0.609) and Para rubber plantation (*r*=-0.670), as well as a positive relationship — the rice (*r*=0.700) and the sugarcane fields (*r*=0.751). The positive relationship between SWC and latent heat flux has been constantly reported (Kimura & Shimizu, 1994; Qin *et al.*, 2012). Moist soil has high potential evaporation which enhanced positive latent heat flux transfer and led to cooling surface soils (Qin *et al.*, 2012). For the forest and the Para rubber plantation, the land–air specific humidity difference was relatively low, when compared with those observed in the agricultural fields (Figure 4). This low latent heat flux to the air under forest and Para rubber canopies resulted from high transpiration and trapped moisture under the plant canopies. This finding indicated that latent heat flux transfer can be substantially changed as a result of forest-to-cropland conversion.

3.2.3 Relationship patterns between latent heat and sensible heat fluxes

As suggested from the plots of land–air differences in temperature and specific humidity, shown in Figure 5, negative relationships between sensible and latent heat fluxes over the vegetation fields were found when soil temperature was colder than the above air temperature (T_s-θ_a<-0.3 to -0.1°C), whereas positive relationship was found when T_s-θ_a >-0.1°C. Diurnal variation has a role to play in these diverse relationships since the colder soil condition was obviously observed during daytime (Figure 3). The negative relationship was also obtained from aircraft measurement in USA (LeMone *et al.*, 2007). In this aircraft experiment, low latent heat together with high sensible heat fluxes were found over bare soils and the latent heat flux was more sensitive to the changes in sensible heat flux over the wet soil than that over the dry soil (LeMone *et al.*, 2007).

In this study, the positive sensible–latent heat flux correlation was expected in nighttime, when soil temperature was typically warmer than the above air temperature (Figure 3). Similarly, Wilson *et al.* (2002) reported positive Bowen ratio (sensible heat to latent heat fluxes) between 0.25 to 0.5 for deciduous forest sites in USA and Europe. The highest Bowen ratio for the agricultural sites was (0.40) observed when the soybean was not fully developed (Wilson *et al.*, 2002). For Mediterranean sites, Bowen ratio, however, varied quite a lot and its negative heat flux ratio was also illustrated in the work of Wilson *et al.* (2002).

Effects of soil water content and plant phenology on sensible–latent heat flux partitioning were not clearly observed in this study. To come up with precise conclusion, it requires more observations that must look into the entire of crop phenology cycles.

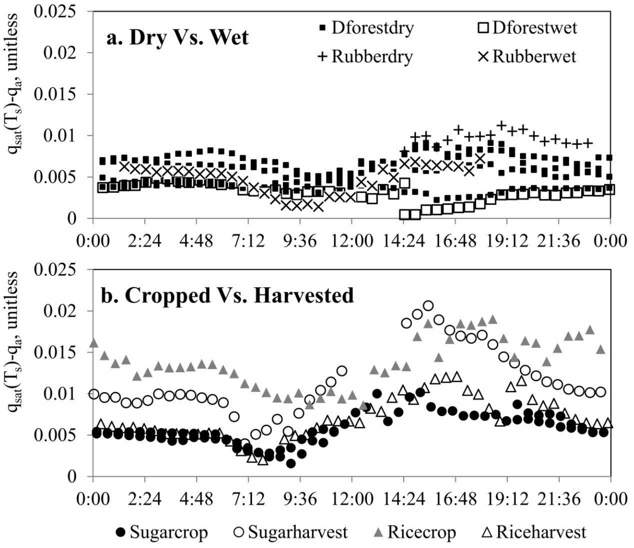

Figure 4. Diurnal variations of latent heat flux indicator ($q_{sat}(T_s)$–q_a) for (a) dry and wet mixed deciduous forest and Para rubber plantation and (b) grown and harvested sugarcane and rice fields.

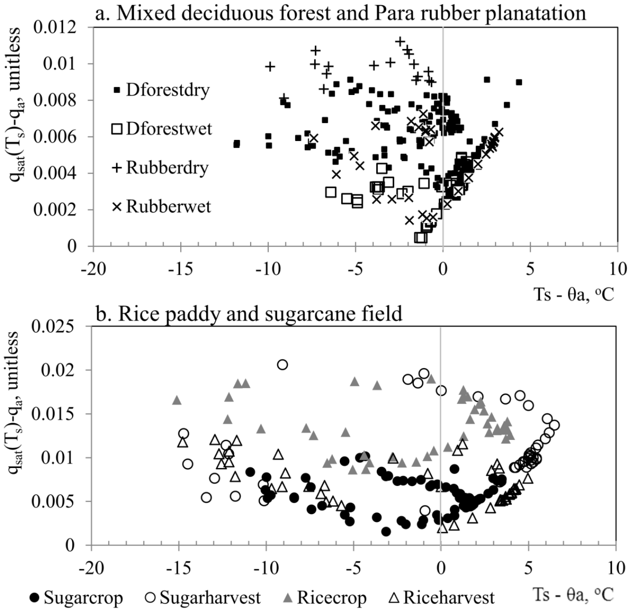

Figure 5. Scatter plots between sensible heat flux indicator and latent heat flux indicator for (a) mixed deciduous forest and Para rubber plantation and (b) rice paddy and sugarcane field.

4. Conclusions

Most parts of the Northeastern region of Thailand are classified as the area under the tropical agro-ecosystem, which influence local land–air energy transfer and micrometeorology in the region. This study aims to show preliminary results of diurnal meteorological patterns at different vegetation fields and to assess effects of plant canopy on the meteorological patterns and surface energy partitioning. Effects of soil water content on the energy fluxes were also discussed. The observations were taken in the Northeastern region of Thailand from the summer season (April, 2015) to the early rainy season (June, 2015) in a mixed deciduous forest, a Para rubber plantation, a sugarcane field and a rice paddy. Surface air temperature, humidity and pressure under vegetation canopy and adjacent sparse vegetation areas were simultaneously measured. Furthermore, soil temperature and soil water content (SWC) at 20-30 cm soil depth were measured to suggest latent and sensible heat flux transfers at soil–air interface in the vegetation fields.

Plant canopies evidently affected surface air temperature and humidity. In overall, meteorological conditions over the sparse vegetation/bare soils exhibited comparatively higher surface air temperature (~ +6.2%) and lower humidity (~ -9.4%). Lower temperature of surface air was correlated with higher humidity, indicating a strong interaction between spatial temperature gradient and the humidity gradient. These interaction patterns were largely similar among the forest, the Para rubber plantation and the sugarcane field.

Surface soil temperature over the sparse vegetation areas was greater than those in the vegetation fields. Spatial soil temperature difference reached the peak at ~14:30 to 16:30 and declined to the lowest point in the early morning at ~6:00, and this corresponded with solar radiation intensity. Wet soils likely moderated the spatial soil temperature gradient. SWC was influenced by season and cropping cycle. Furthermore, associations between SWC and atmospheric humidity varied among different vegetation types, exhibiting positive correlations for the forest and Para rubber plantation, and negative correlations for rice and sugarcane fields.

Soil-to-air sensible heat transfer was likely to be observed during nighttime and/or cloudy condition and its magnitude was greater in the rice field and sugarcane field than those at the forest and the Para rubber plantation. Conversely, the sensible heat transfer to the soil was more predominant during daytime and clear sky and its magnitude was greater in the forest and the Para rubber plantation. These differences among various vegetation covers suggest strong heat/moisture advection between forest and adjacent croplands. This sensible heat flux was positively correlated with atmospheric humidity and inversely correlated with solar radiation intensity, whereas its association with SWC was not obvious.

Latent heat transfer to the air reached its peak in the afternoon and declined in the early morning. The greater latent heat transfer was found in the rice field and sugarcane field, as compared with those in the forest and the Para rubber plantation. This latent heat flux was linearly correlated with SWC but different correlation patterns were found between the forest/Para rubber plantation (negative) and the rice/sugarcane fields (positive). This finding suggests that the latent heat flux could be substantially changed by forest-to-cropland conversion.

Correlations between the sensible and latent heat fluxes were heavily influenced by soil-air temperature difference (T_s-θ_a). The negative correlation was frequently found in daytime with cooler soil, and the positive correlation was likely found during nighttime with warmer soil. However, the effect of SWC on the surface energy flux partitioning was not clearly observed in this study.

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