RESULTS AND DISCUSSION

1. Energy balance and actual evapotranspiration

1.1 Paddy field

1.1.1 Energy balance

The study of energy balance and actual evapotranspiration by using energy balance and Bowen ratio technique of Sukhothai paddy field was collected data from January 2002 to August 2004. The two years and eight months summarized data were presented in Table 2 and the annual monthly data were shown in Table 3 to 5. Results of this part can be described by each period as follow :

1) Overview throughout study period

The overview of energy balance in paddy field throughout 2 years and 8 months were found that the solar radiation (Rs) ranged between 17.0-21.9 MJ m^{-2} day^{-1} in January and April with an average of 19.3 MJ m^{-2} day^{-1}. These data are very close to those reported by Thai Meteorological Department (TMD) (2005), in which the 25 years summarized data report showed the ranged of Sukhothai's solar radiation is between 18-19 MJ m^{-2} day^{-1}. The net radiation (Rn) ranged between 11.0-16.9 MJ m^{-2} day^{-1} with 13.2 MJ m^{-2} day^{-1} by average, or approximately 70.4% of Rs. The Rn was used for latent heat (LE), Sensible heat (H) and storage in soil and water (Gs and Gw) with the average values of 9.5, 3.0, 0.4 and 0.2 MJ m^{-2} day^{-1} or 72.3, 22.9, 3.1 and 1.7 % of Rn, respectively (Table 2).

Cargnel *et al*. (1996) reported that the evapotranspiration by using Bowen ratio method express approximately 85% of Rn during or after rain, and 65% of Rn before the next season.

2) In the year 2002

The energy balance in Sukhothai paddy field throughout the year 2002 was found that the daily average of solar radiation (Rs) was 24.5 MJ m^{-2} (lowest 19.6 MJ m^{-2}in November and highest 27.4 MJ m^{-2} in March)while the daily average of net radiation (Rn) was 13.8 MJ m^{-2} or approximately 56.3% of Rs. The Rn was used for latent heat (LE), Sensible heat (H) and storage in soil and water (Gs and Gw) with the average value of 9.6, 3.5, 0.4 and 0.2 MJ m^{-2} day^{-1} or 69.9, 25.4, 3.0 and 1.8 % of Rn, respectively (Table 3).

3) in the year 2003

The results of the enegy balance showed that the solar radiation throughout the year 2003 in paddy field ranged 11.1 MJ m^{-2} day^{-1} in January and 21.2 MJ m^{-2} day^{-1}in June with an average of 17.4 MJ m^{-2} day^{-1} while the daily average of net radiation (Rn) was 13.2 MJ m^{-2} day^{-1} or approximately 76.0 % of Rs. The Rn was used for latent heat (LE)), Sensible heat (H) and storage in soil and water (Gs and Gw) with the average value of 9.7, 2.9, 0.4 and 0.2 MJ m^{-2} day^{-1} or 73.5, 21.8, 3.0 and 1.7 % of Rn, respectively (Table 4).

4) In the year 2004

The study of energy balance in paddy field throughout year 2004 were found that the average of solar radiation (Rs) was 15.8 MJ m^{-2} day^{-1} while the daily average of net radiation (Rn) was 12.5 MJ m^{-2} day^{-1} . The Rn was used for latent heat (LE)), Sensible heat (H) and storage in soil and water (Gs and Gw) The average value were 8.9, 2.9, 0.5 and 0.1 MJ m^{-2} day^{-1} or 71.2, 23.5, 4.2 and 1.2 % of Rn, respectively (Table 5).

1.1.2 Evapotranspiration

1) Overview of the study

Table 3 shows that the Bowen ratio ranged of 0.2 and 0.4 in rice planting season and off planting season, respectively. This indicated that Bowen ratio is slightly high in dry period and low in wet period. Because of the submerged water in paddy field in wet period.

Furthermore, the results found that evapotranspiration ranged from 2.8 MJ m^{-2} day^{-1} in December to 5.1 MJ m^{-2} day^{-1} in September. The annual average evapotranspiration was 4.1 MJ m^{-2} day^{-1} while rice planting season and off rice planting season was 4.5 and 3.9 MJ m^{-2} day^{-1} respectively. The result was similar in 2002 and 2003 because September is a planting season which water has storied in paddy field. Therefore, evapotranspiration was highest in September (154.5 mm) and following 154.0 mm and 154.7 mm in May and July, respectively. The evapotranspiration was high in summer season due to the high average daily of net radiation of 21.0 MJ m^{-2} day^{-1} in May and 20.1 MJ m^{-2} day^{-1} in June. There was also rainfall started from April which effected to high soil moisture. The pan evaporation ranged from 3.5 MJ m^{-2} day^{-1} in December to 6.7 MJ m^{-2} day^{-1} in April. The annual average pan evaporation was 4.7 MJ m^{-2} day^{-1} .

Rice planting season

The average variation of evapotranspiration in paddy field during 2 years 8 months of rice planting season was found that planting season started from mid of July and harvested in November with the average of 108 planting days. There was water in paddy field for the whole planting period, the average height of water was 8.5 cm. The monthly average evapotranspiration was 137.4 mm (average 4.5 mm day^{-1}). The highest evapotranspiration was 154.5 mm in September and the lowest evapotranspiration was 122.4 mm in November because in November had less rainfall and solar radiation. The highest of net radiation during planting season was found in October 19.1 MJ m^{-2} day^{-1} while in August, September and November were 18.1, 18.7 and 17.7 MJ m^{-2} day^{-1}, respectively.

2) In the year 2002

Annual average

The variation of the average evapotranspiration throughout the year 2002 was showed in Table 6. The results indicated that evapotranspiration ranged 2.2 mm day^{-1} in December to 4.9 mm day^{-1} in September with an average of 3.6 mm day^{-1} or 1,317.8 mm $year^{-1}$ while pan evaporation (Epan) ranged 3.4 mm day^{-1} in December to 5.7 mm day^{-1} in April which showed high value of solar radiation (17.1 MJ m^{-2} day^{-1}). The annual average of pan evaporation was 4.4 mm day^{-1} or 1,602.9 mm $year^{-1}$ (Table 6 and Table 3)

Results of the finding were interpreted that evapotranspiration was highest in April (165.0 mm) and following 164.3 mm in October and 161.0 mm in May therefore, during April and May were summer season. There were high average of net radiation during this period. The average of net radiation in April, May and June were 14.4, 14.3 and 14.1 MJ m^{-2} day^{-1} respectively and also rainfall amount in May was 409.7 mm (Table 2)

Rice planting season

Table 6 shown that the variation of the average evapotranspiration in rice planting season 2002. During planting season, the average height of water was 6.9 cm. The average value of net radiation was 12.5 MJ m^{-2} day^{-1}, The Rn was used for latent heat (LE), sensible heat (H) and storage in soil and water (Gs and Gw) with average values of 9.6, 3.5, 0.4 and 0.2 MJ m^{-2} day^{-1} respectively. While the daily average of evapotranspiration was 3.7 mm day^{-1} (Table 6). The highest evapotranspiration was found in September (4.9 mm day^{-1}) while the average of pan evaporation was 4 mm day^{-1} or 119.2 mm $month^{-1}$. The mature stage of growth rice in October was found that the daily average of evapotranspiration was 4.1 mm day^{-1} or 126.2 mm $month^{-1}$ while the average of pan evaporation was 3.7 mm day^{-1} or 114.7 mm $month^{-1}$.

The result shown that the highest evapotranspiration was found in September. This is because the effected of the cumulative amount rainfall that started from May and there was also rained in September which the initial stage of (108 planting days) growth rice. In this planting season, water was contained submerge in soil throughout planting period. Nevertheless, after harvesting period there was less water submerge in soil so that the lowest of soil moisture was found in December. However, soil moisture will increase in January and February, due to rainfall started.

3) In the year 2003

Annual average

Table 7 shown that the average evapotranspiration throughout the year 2003 was 4.3 mm day^{-1} while in rice planting season was 4.9 mm day^{-1}, off rice planting season was 4.0 mm day^{-1} respectively. Although the pattern and trend of evapotranspiration was similar to the year 2002, the annual average value of evapotranspiration was higher.

The result found that value of the diurnal daily average of evapotranspiration was highest in May (5.5 mm day^{-1} or 170.5 mm $month^{-1}$) while the daily average of pan evaporation was 7.1 mm day^{-1} or 214.3 mm $month^{-1}$. In September,

the daily average evapotranspiration was 5.3 mm day^{-1} while the daily average pan evaporation was 4.4 mm or 132.6 mm $month^{-1}$ and in June, there was 5 mm day^{-1} of daily average evapotranspiration while the daily average of pan evaporation was 4.9 mm day^{-1} or 147.4 mm $month^{-1}$ respectively.

The highest evapotranspiration was found in September (5.3 mm day^{-1}) due to high amount rainfall during rainy season (202.1 mm). According to the cumulative rainfall which started from May to September which effected to high soil moisture and during rice planting period therefore, high evapotranspiration was presented in this month. After harvesting period there was less soil moisture and no rainfall amount so the lowest evapotranspiration was revealed in December.

Rice planting season

The variation of the daily average evapotranspiration in paddy field during rice planting season (August-November, 2003) was found that the daily average evapotranspiration was 4.9 mm day^{-1}. The overview of variation evapotranspiration in rice planting season was similar with the data in 2002, the few difference due to the different of climatic factor (Table 7).

4) 2004 year

Table 8 was shown that the daily average evapotranspiration ranged 3.2 – 4.8 mm day^{-1} with an average of 4.4 mm day^{-1} while the average of pan evaporation was 4.8 mm day^{-1} or 143.6 mm $month^{-1}$. The trend and direction of data was similar with the variation of the data in 2002 and 2003 year while the average value was nearest 2003 year but higher than 2002 year.

1.2 Teak plantation

1.2.1 Energy balance

The study's data of energy balance and evapotranspiration in Lampang teak plantation by using energy balance and Bowen ratio technique was collected data from January, 2002 to August, 2004 (total 2 years 8 months). The summarized result was presented in Table 9 with the following explanation.

1) The overview throughout study period

The overview of energy balance in Teak plantation was found that the daily average of solar radiation (Rs) ranged between 16.0-24.6 MJ m^{-2} in August and April with an annual average at 19.0 MJ m^{-2} day^{-1}. The average daily of net radiation (Rn) was 14.8 MJ m^{-2} day^{-1} or 78.2 % of Rs. The net radiation utilized for latent heat (LE), sensible heat (H) and storage in soil (Gs) was estimated at 71.6, 23.0 and 5.4 % of Rn, respectively (Table 9)

2) In 2002

The study of energy balance in teak plantation throughout year 2002 was found that the solar radiation (Rs) ranged between 14.6 MJ m^{-2} day^{-1} in August and 25.1 MJ m^{-2} day^{-1} in April with an average of 20.1 MJ m^{-2} day^{-1}. The net radiation (Rn) ranged between 8.5 MJ m^{-2} day^{-1} in August and 20.6 MJ m^{-2} day^{-1} in June with an average of 13.9 MJ m^{-2} day^{-1} approximately 69.2 % of Rs. The Rn was used for latent heat (LE), sensible heat (H) and storage in soil (Gs) with the average value of 10.0, 3.4 and 0.5 MJ m^{-2} day^{-1} or 72.2, 24.5 and 3.3 % of Rn, respectively (Table 10)

In dry season (amount of rainfall less than 100 mm month^{-1}) Rn ranged from 10.7 to 18.9 MJ m^{-2} day^{-1} with an average of 14.3 MJ m^{-2} day^{-1}. The Rn utilized for latent heat (LE), sensible heat (H) and storage in soil (Gs) was estimated about 9.5, 4.1 and 0.7 MJ m^{-2} day^{-1} respectively while Bowen ratio ranged from 0.4 to 0.6 with 0.4 by average.

In wet season (amount of rainfall more than 100 mm month^{-1}), the daily average of Rn ranged from 8.5 to 20.6 MJ m^{-2} day^{-1} with the average of 13.6 MJ m^{-2} day^{-1}. The Rn was used for latent heat (LE), sensible heat (H) and storage in soil (Gs) of 10.6, 2.7 and 0.3 MJ m^{-2} day^{-1}, respectively, while Bowen ratio ranged from 0.1 to 0.4 and 0.2 by average.

3) In 2003

The data of energy balance in teak plantation was collected in 2003. The results obtained from this period were shown in Table 11 which can be described as follows :

The daily average of solar radiation (Rs) throughout 2003 in teak plantation was 20.4 MJ m^{-2} day^{-1} with ranged between 27.1 MJ m^{-2} day^{-1} in April and 17.1 MJ m^{-2} day^{-1} in December. The daily average of net radiation was 17.0 MJ m^{-2} day^{-1} with 83.3 % of Rs It was used for latent heat (LE), sensible heat (H) and storage in soil (Gs) estimated at 12.1, 3.8 and 1.1 MJ m^{-2} day^{-1} or 72.5, 22.7 and 4.8 % of Rs, respectively. The highest value of net radiation was 18.6 MJ m^{-2} day^{-1} in May and the lowest was 14.2 MJ m^{-2} day^{-1} in February while Bowen ratio ranged from 0.2 to 0.6 with an average of 0.3.

In dry season (amount of rainfall less than 100 mm month^{-1}) found that the net radiation ranged between 14.2 and 18.2 MJ m^{-2} day^{-1} with an average of

16.7 MJ m^{-2} day^{-1}. The net radiation utilized for latent heat (LE), sensible heat (H) and storage in soil (Gs) was 11.3, 4.2 and 1.2 MJ m^{-2} day^{-1} respectively, while Bowen ratio ranged 0.2-0.6 with an average at 0.3.

In wet season (amount of rainfall more than 100 mm $month^{-1}$) found that the net radiation ranged between 15.6 and 18.6 MJ m^{-2} day^{-1} with an average of 17.3 MJ m^{-2} day^{-1}. The net radiation was used for latent heat (LE), sensible heat (H) and storage in soil (Gs) was 68.8, 26.4 and 4.8 MJ m^{-2} day^{-1}, respectively (Table 10). The result was similar with the result of the year 2002 and 2003.

4) In 2004

The result of energy balance in teak plantation was collected from January to August 2004. It was found that the daily average of Rs was 16.8 MJ m^{-2} day^{-1} while the daily average of Rn was 13.7 MJ m^{-2} day^{-1} with 82 % of Rs. The Rn utilized for latent heat (LE), sensible heat (H) and storage in soil (Gs) was 68.8, 26.4 and 4.8 MJ m^{-2} day^{-1} respectively (Table 12). There was the same result of 2002 and 2003.

1.2.2 Evapotranspiration

1) The overview throughout study period

Table 9 showed the highest and lowest daily average evapotranspiration of 5.5 mm and 2.8 mm in April and December, respectively, .The highest Rs and Rn was in April. And also the cumulative rainfall started from January effected to high soil moisture content and high evapotranspiration value were present.

2) In 2002

The results of actual evapotranspiration and pan evaporation (Epan) shown in Table 13. It was found that the lowest average evapotranspiration was 2.1 mm day^{-1} in August and the highest was in April (5.7 mm day^{-1}) with an annual average of 3.7 mm day^{-1}. The lowest average Epan was 2.6 mm day^{-1} in December and the highest was in April (5.7 mm day^{-1}) with an annual average of 4.1 mm day^{-1}.

3) In 2003

Table 14 obtained the results of evapotranspiration and pan evaporation in the year 2003. It was found that the lowest daily average evapotranspiration was 2.6 mm in January and the highest was 6.1 mm day^{-1} in April. With an annual average of 4.2 mm day^{-1} while the lowest daily average Epan was 3.2 mm in January and highest was 0.7 mm day^{-1} in April with an annual average of 4.4 mm day^{-1}.

In dry period (January – April and November – December) was indicated that evapotranspiration ranged from 2.6 to 61 mm day^{-1} with 4.1 mm day^{-1} by average while Epan ranged from 3.2 to 5.7 mm day^{-1} with an average of 4.1 mm day^{-1}.

During the wet period (May – October) found that the lowest daily average evapotranspiration was 3.3 mm in October and the highest was 4.2 mm day^{-1} in May while the average of Epan ranged from 3.9 to 5.6 mm day^{-1} with an average of 4.7 mm day^{-1}.

4) In 2004

The actual evapotranspiration and pan evaporation (Epan) were shown in Table 15. It was found that the lowest daily average evapotranspiration was 3.0 mm in February and the highest was 5.3 mm day^{-1} in August and May with an average of 4.3 mm day^{-1} while the daily average Epan was 4.8 mm day^{-1} with the lowest in February (3.5 mm day^{-1}) and the highest in April (5.7 mm day^{-1}).

1.3 Comparison of evapotranspiration between paddy field and teak plantation

The comparison of actual evapotranspiration of paddy field and teak plantation were presented in Table 16 can be described by each period as follow :

1.3.1 Overview of study period

The evapotranspiration of paddy field was 4.1 mm day^{-1} while the averaged evapotranspiration of teak plantation was 3.9 mm day^{-1}. The evapotranspiration in teak forest area was a little less than paddy field because the paddy field has submerge water during planting season, while in teak plantation was clear and very dry in dry season.

1.3.2 Dry season (January – April, November – December)

This period is after harvesting season. The evapotranspiration of paddy field was 3.5 mm day^{-1} while the averaged evapotranspiration of teak plantation was 3.7 mm day^{-1}. The evapotranspiration in teak forest area was slightly higher because the paddy field was clear and dry. The ET of teak plantation occurred from both plant transpiration and evaporation of soil moisture (Figure 9-10).

1.3.2 Wet season (May – October)

This is a rice planting season. The average ET average of paddy field was 4.7 mm day^{-1} while in teak plantation area was about 4.1 mm day^{-1}. The study also showed that ET in paddy field was higher than in teak plantation area. Due to ET of paddy field occurred by both plant transpiration and evaporation of water in the field while in teak plantation area was covered by dense leaves and less water in soil surface (Figure 9-10).

1.4 Formulating Prediction Models

1.4.1 Paddy field

In order to establish the models for estimating daily ET_a and Bowen ratio for paddy field in Changwat Sukhothai for a particular month, the meteorological factors such as air temperature (T_a), wind speed (WS), soil moisture tension (pF), relative humidity (RH) in daily average of that particular month were employed in the regression analysis. The most suitable models were selected by all possible regression which were presented in Table 17.

In general, air temperature and relative humidity had the direct effect on the evapotranspiration in paddy field. On the contrary, when the paddy field was very dry especially from January to March, air temperature in January and relative humidity in February and March would have reverse effect to the ET. This can be explained that in case of having enough moisture for ET; the increasing of air temperature (positive value) and the decreasing of relative humidity (negative value) would increase the ET. On the other hand, when the paddy field was very dry, the decreasing temperature and increasing relative humidity would make higher air moisture and also higher ET. So, if

Table 17 Mathematical model for estimate actual evapotranspiration from climatic factors of Sukhothai paddy field.

month	model	R^2	F-ratio	MSE
January	ET_{Jan} = -1.355+1.226WS	0.32	5.83**	0.29
February	ET_{Feb} = 2.811+0.318T_a	0.5	8.99**	0.64
March	no significant	-	-	-
April	no significant	-	-	-
May	ET_{May} = 25.537-0.043RH-0.484WS	0.55	7.75**	1.44
June	no significant	0.41	-	-
July	ET_{Jul} = -7.042+0.413T_a	0.4	10.36**	0.13
August	ET_{Aug} = 10.337-0.091RH	-	6.27**	2.03
September	no significant	0.4	-	-
October	ET_{Oct} = 20.684-0.18RH	0.4	15.50**	2.02
November	ET_{Nov} = -2.102+0.275T_a	0.15	4.56**	1.45
December	ET_{Dec} = 9.079+0.352T_a-0.176RH	0.86	42.09**	0.18

Remark ** = Significant at confident level 99 %

any of these models would be applied, it must be considered not only a high r^2 but also the logical expression of all parameters in equation.

When the whole data recorded throughout the year were used in model derivation for predicting daily ET for paddy field, the significant prediction models were shown in January, February, May, July, August, October, November and December while the non significant prediction model were shown March, April, June and September. It could be said that, the air temperature, Relative humidity soil water tension and wind speed had non significant influence on ET at 95% confidence interval.

1.4.2 Teak plantation

The model formulating for evaluate the daily ET for each particular period and for annual data basis at teak plantation implied the significant influence of the meteorological factors such as air temperature (Ta), wind speed (Ws), relative humidity (RH) and soil moisture tension (pF). The suitable models were selected by all possible regression and stepwise regression. The significant models were shown in Table 18 and can be concluded as follow :

Table 18 Mathematical model for estimate actual evapotranspiration from climatic factors of Lampang teak plantation.

month	model	R^2	F-ratio	MSE
January	ETJan = 10.26-0.365Ta	0.2	2.64*	0.79
February	no significant	-	-	-
March	ETFeb = 4.546-0.039RH	0.38	7.35**	0.87
April	no significant	-	-	-
May	ETMay = 9.791-0.054RH-1.353WS	0.75	10.21**	0.2
June	ETJun = 16.77-0.151RH	0.58	40.83**	0.63
July	ETJul = -8.905+0.547Ta	0.84	47.28**	0.09
August	ETAug = -13.961+0.637Ta	0.36	9.67**	0.56
September	ETSep = 1.724+0.45Ta-0.091RH	0.77	24.17**	0.23
October	ETOct = -10.501+0.449Ta	0.39	8.32**	0.64
November	ETNov = 4.947+0.433Ta-0.117RH-0.429WS	0.84	37.00**	0.18
December	ETDec = 3.963+0.241Ta-0.023RH	0.31	6.13**	0.57

Remark * = Significant at confident level 95 %

** = Significant at confident level 99 %

In teak plantation there were non significant prediction model in February and April. The factors with affect to ET are as same as in paddy field , the results indicated that the r^2 was highest in July and November, it can said that this period have high effect on ET and climatic factor influence on ET was higher that other month.

2. Estimation evapotranspiration by using remote sensing.

In this study, The remote sensing technique had utilized for extract normalized distribution Index (NDVI), land surface temperature (LST) and surface albedo. Those were used for statistic analysis and the coefficient of determination (r^2) with evapotranspiration by bowen ratio technique. Analysis of variance (ANOVA) is significance of equation from evapotranspiration.

2.1 Normalized distribution Index (NDVI)

The basic process involved in handing remote sensing information are data acquisition and data analysis. The data acquisition is the use of sensor to record the reflected and emitted electromagnetic energy from the target. The most common vegetation indices are the simple ratio of near-infrared to visible radiance. The analysis of NDVI during August 2002 to December 2003 total 17 images were 10 days composite image data can be classified by 5 levels. The results were shown in Figure 11-13 which can be describe as follows : group 1 between -1.0 – 0.0, group 2 between 0.0 – 0.2, group 3 between 0.2-0.4, group 4 between 0.4-0.6 and group 5 between 0.6-1.0, respectively. The results found that the average of NDVI in paddy field almost 0.0-0.2 and following 0.2-0.47 respectively while in teak plantation the average of NDVI almost 0.3-0.4 and 0.4-0.6 respectively (Table 19 and Figure 11-13).

Table 19 NDVI in each satellite images of paddy field and teak plantation

Acquired Date	NDVI	
	Paddy field	Teak plantation
1. 22 August 2002	0.27	0.45
2. 15 September 2002	0.56	0.89
3. 5 October 2002	0.69	0.90
4. 20 November 2002	0.34	0.86
5. 1 December 2002	-0.11	0.10
6. 16 January 2003	-0.25	-0.23
7. 4 February 2003	-0.12	-0.22
8. 7 March 2003	-0.76	0.06
9. 17 April 2003	-0.63	0.09
10. 1 May 2003	-0.26	0.16
11. 16 June 2003	-0.46	0.24
12. 1 July 2003	-0.33	0.15
13. 16 August 2003	0.24	0.43
14. 1 November 2003	0.75	0.86
15. 16 October 2003	0.87	0.95
16. 7 November 2003	0.22	0.41
17. 23 December 2003	-0.98	0.02
Average	0.00218	0.36

The variation of the average NDVI throughout 1 satellite images was shown in Table 19. The results indicated that NDVI in paddy field is ranged -0.98 in December to 0.75 in September with an average of 0.00218 while in teak plantation the daily average NDVI was 0.36 (lowest -0.23 in January and highest 0.95 in October)

In rice planting season, Table 19 shown that the variation of the average NDVI during August 2002 to December 2003 was 0.33 while in off planting season was -

0.29, therefore in planting season there are canopy reflectance of rice that implied to more chlorophyll detected from satellite receiver more than off planting season that showed only base soil reflecting.

Furthermore, in teak plantation NDVI was higher than paddy field the daily average of NDVI during study period was 0.36. During wet and dry season the daily average of NDVI was 0.57 and -0.37 respectively, due to teak is deciduous forestit's falling leaf during dry season.

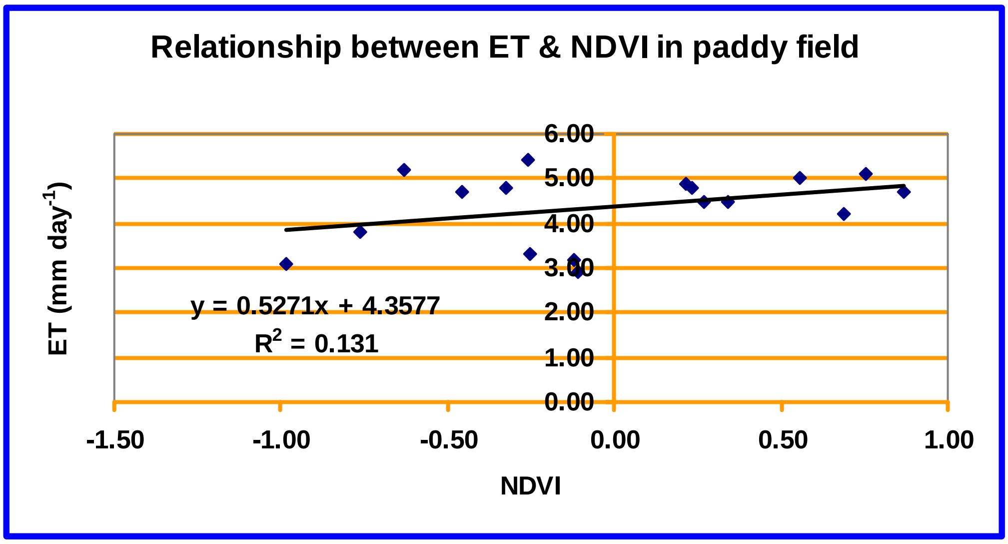
2.1.1 The relationship between NDVI and ET

The result found that the relationship between daily average ET and daily average NDVI in paddy field as no significant with determination of coefficient (r^2) was 0.131 and also in teak plantation the determination of coefficient (r^2) was 0.0192, the results indicated non significant between NDVI and ET in both sites (Figure 14)

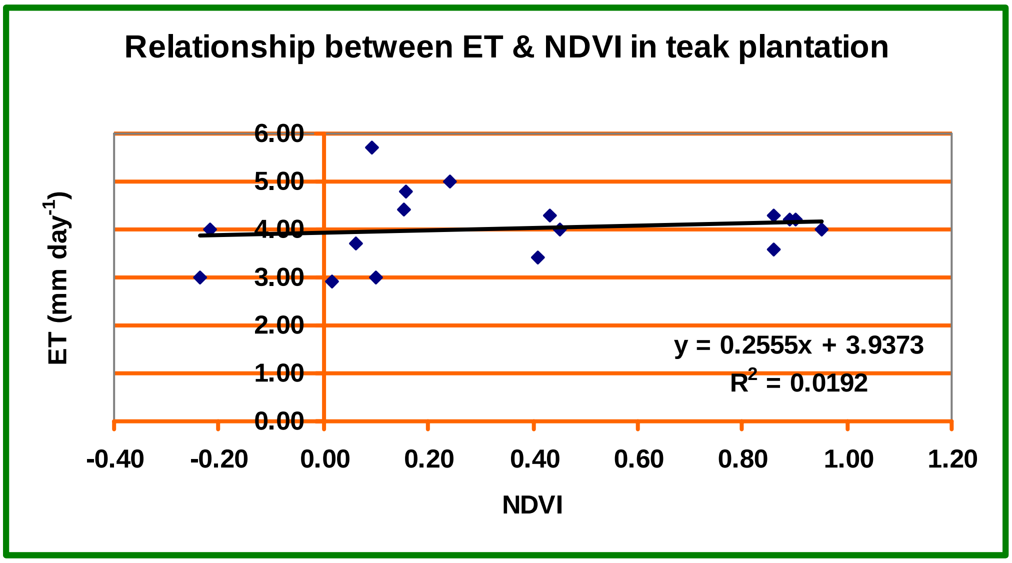
2.2 Land surface temperature

The land surface temperature (LST) had obtained from 17 satellite imageries by using split window technique, derived by Ulivieri *et al*. (1994). Kerenyi (2000) and Vezquez (1997) also reported that the split window technique of Ulivieri shown the lowest varience value and less mistake than others procedure.

The surface temperature in paddy field throughout the whole study period was found that the daily average of surface temperature ranged 22.8^{0}C to 31.9^{0}C with an average of 26.93 ^{0}C while in teak plantation ranged 21.90 ^{0}C to 27.7 ^{0}C with an average of 24.5 ^{0}C. In paddy field the highest surface temperature was presented in April and lowest in February while in teak plantation the highest was found in March and December presented lowest surface temperature.



(a) paddy field



(b) teak plantation

Figure 14 The relationship between ET and NDVI (a) in paddy field, (b) in teak plantation

Table 20 was shown that in rainy season the daily average of surface temperature was 26.5 ^{0}C, while in off planting season the daily average of surface temperature was 27.17 ^{0}C as for in teak plantation in wet season the daily average of surface temperature was 24.48^{0}C while in dry season the daily average of surface temperature was 26.34 ^{0}C, therefore in planting season, water was contained submerge in soil and off planting period there was less soil moisture and no rainfall amount so the higher surface temperature was revealed in this period. The results showed the similar with teak plantation that shown high surface temperature in dry season and low surface temperature in wet season. (Figure 15-17)

2.2.1 The relationship between surface temperature and ET_a

The results shown a moderate relationship between ET and surface temperature in paddy field, the determination of coefficient (r^2) was 0.49 while in teak plantation was 0.45. The results can explain that surface temperature was limiting factor of ET and approximate 50% affected to ET_a. (Figure 18)

The estimated LST of different time derived from the relationship between the LST and actual ground temperature. The value of the estimated LST and actual ground in both station are found in Figure 19

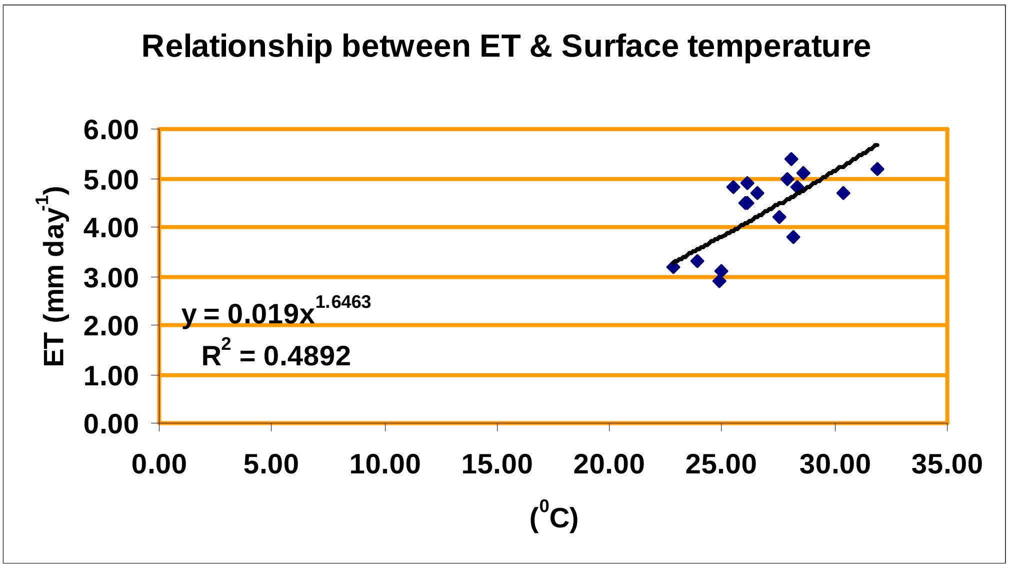
2.3 Surface albedo

The surface albedo of 17 difference images in both sites derived from Valients *et al*. (1995) which used of weighting method of the reflectance from NOAA/AVHRR band 1 and band 2. This method shown the average of reflectance in visible range and NIR.

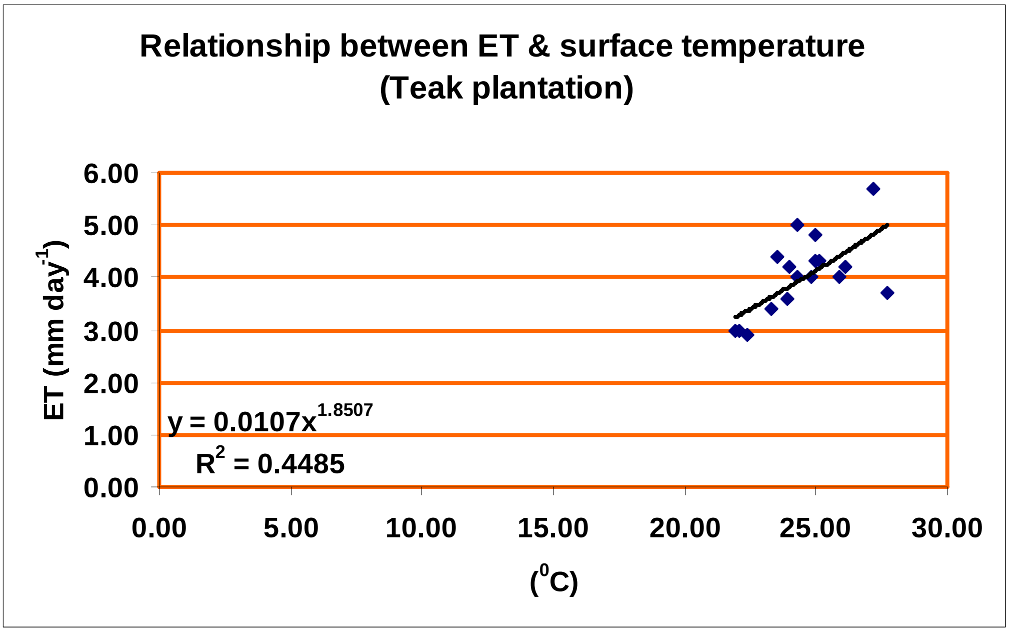
Table 20 The LST of each image in paddy field and teak plantation

Acquired Date	Surface temperature (degree of celsius)	
	Paddy field	Teak plantation
1. 22 August 2002	26.10	24.80
2. 15 September 2002	27.90	26.10
3. 5 October 2002	27.50	24.00
4. 20 November 2002	26.00	23.90
5. 1 December 2002	24.90	21.90
6. 16 January 2003	23.90	22.10
7. 4 February 2003	22.80	25.90
8. 7 March 2003	28.20	27.70
9. 17 April 2003	31.90	27.20
10. 1 May 2003	28.10	25.00
11. 16 June 2003	30.40	24.30
12. 1 July 2003	28.30	23.50
13. 16 August 2003	25.50	25.10
14. 1 November 2003	28.60	25.00
15. 16 October 2003	26.60	24.30
16. 7 November 2003	26.10	23.30
17. 23 December 2003	25.00	22.40
Average	26.93	21.90

In paddy field the estimated surface albedo was ranged from 0.04 to 0.24 %. The highest of surface albedo (0.24%) was presented in May (summer season) with high radiation and temperature. The lowest of surface albedo was 0.04 in December and January which rice growth covered the water surface that effected to low emissivity.

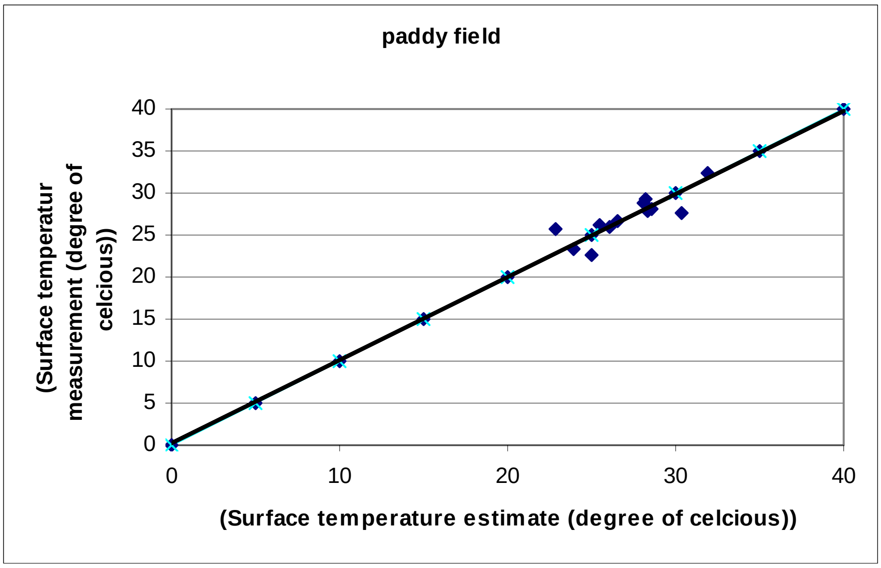


(a) paddy field

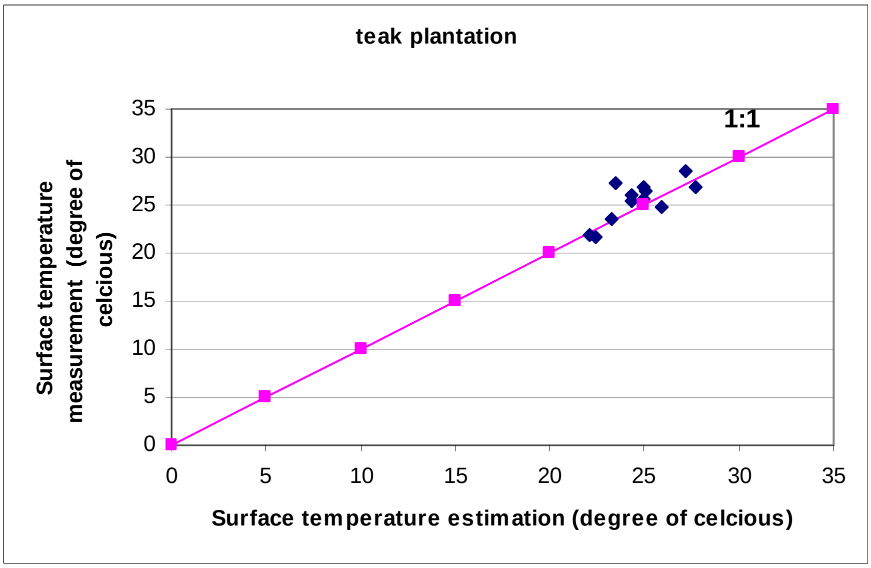


(b) teak plantation

Figure 18 The relationship between ET and surface temperature (a) in paddy field, (b) in teak plantation



(a) paddy field



(b) teak plantation

Figure 19 Comparison between estimation and measurement of surface temperature (a) in paddy field (b) in teak plantation

While in teak plantation surface albedo ranged from 0.12 to 0.25%. The highest of surface albedo (0.25) was shown in March which the falling leave's month and dry. The lowest of surface albedo was found in August (0.12%) which is the rainy season, the teak canopy decrease the reflectance of emission, therefore, less surface albedo (Table 21) and Figure 20-22 as follows :

2.3.1 The relationship between surface albedo and ET

The results shown that the relationship between surface albedo and ET was no significant in both sites (The determination of coefficient, r^2 in paddy field was 0.29 while in teak plantation was 0.13). (Figure 23)

2.4 Statistic Analysis

The statistic analysis between the dependent parameter (ET) and independent parameter (NDVI, LST and surface albedo) which gathering data from satellite imageries by using ET and RS data in same space and time to find out the relationship in form of multiple regression analysis and coefficient of determination (r^2). The ANOVA varience analysis used for significant of equation. The summarized result can be described as follows :

1) Paddy field

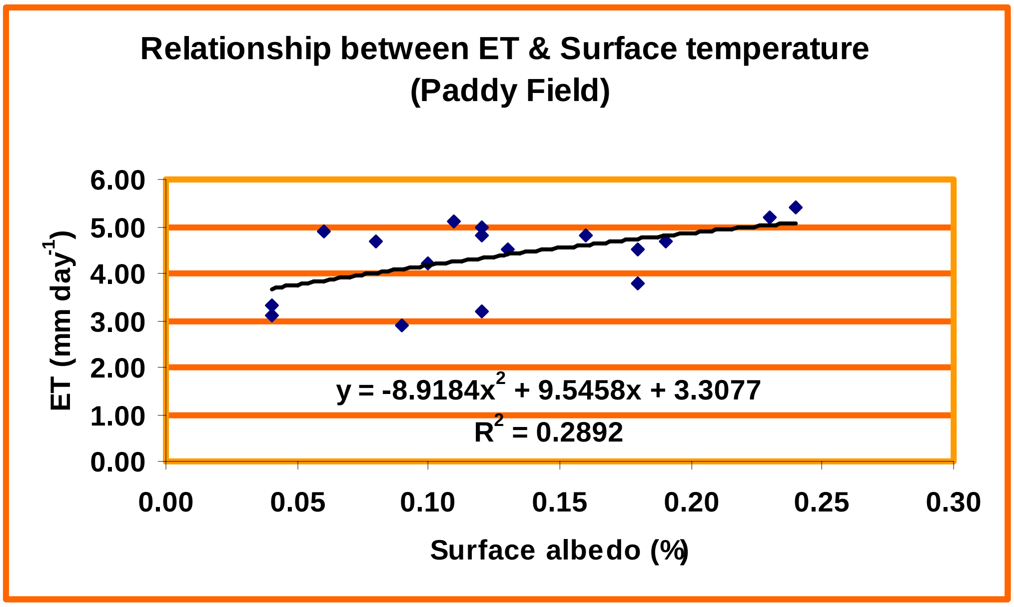
The average relationship data of ET and RS data in January in 2002 and 2003 was found that the r^2 of the relationship between ET and RS parameters was 0.71 ANOVA table and equation was shown in Table 22 and below :

$$ET = -1.21 + 0.73(NDVI) + 0.19(LST) + 4.02(Sur\_alb) \quad : \quad r^2 = 0.71$$

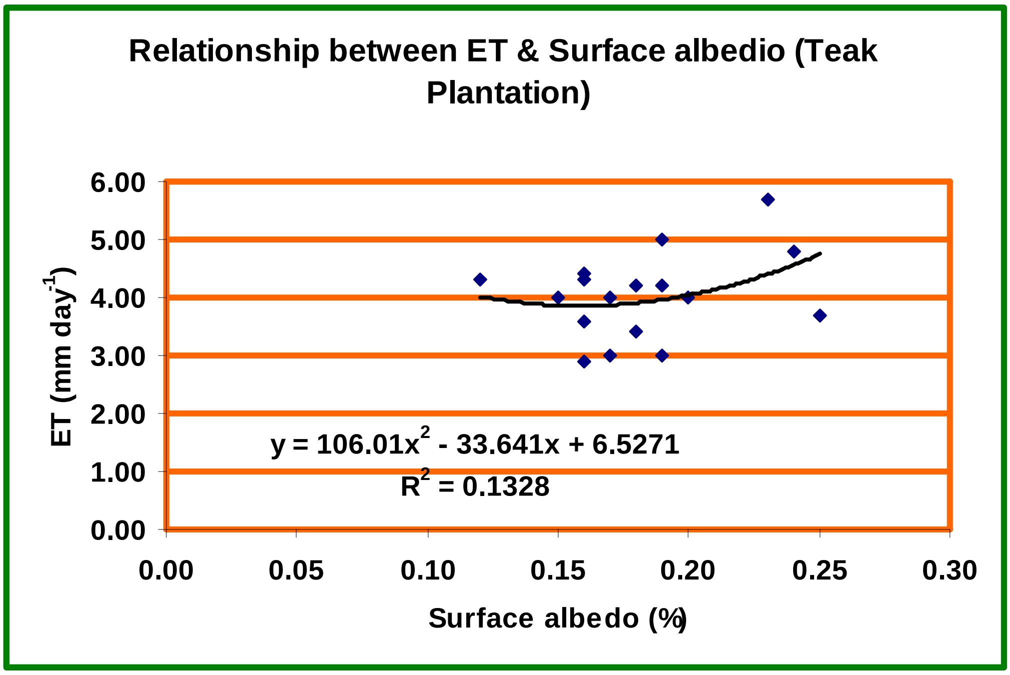
Table 21 The surface albedo of each image in paddy field and teak plantation

Acquired Date	Surface albedo	
	Paddy field	Teak plantation
1. 22 August 2002	0.18	0.15
2. 15 September 2002	0.12	0.19
3. 5 October 2002	0.10	0.18
4. 20 November 2002	0.13	0.16
5. 1 December 2002	0.09	0.17
6. 16 January 2003	0.04	0.19
7. 4 February 2003	0.12	0.20
8. 7 March 2003	0.18	0.25
9. 17 April 2003	0.23	0.23
10. 1 May 2003	0.24	0.24
11. 16 June 2003	0.19	0.19
12. 1 July 2003	0.16	0.16
13. 16 August 2003	0.12	0.12
14. 1 November 2003	0.11	0.16
15. 16 October 2003	0.08	0.17
16. 7 November 2003	0.06	0.18
17. 23 December 2003	0.04	0.16

From the above model, the model derived from all remote sensing (RS) data throughout the year is show the good relationship due to r^2 was 0.71 but it seem not to be reasonable in logic, due to the relationship between NDVI and ET was no significant but effect of NDVI on ET was shown high in equation. These are the limitation of this equation. In case of need to use this equation must be consider to use only positive NDVI.



(a) paddy field



(b) teak plantation

Figure 23 The relationship between ET and surface temperature (a) in paddy field, (b) in teak plantation

Table 22 ANOVA of ET and RS data in paddy field

	dF	SS	MS	F
Regression	3	7.30	2.43	10.84*
Residual	13	2.92	0.22	
Total	16	10.22		

Remarks : $F_{.05}$ (df. 3,13) = 0.00076

* = Significant level 0.05

(1) Rice planting season

The average data of RS data in rice planting season in 2002 and 2003 was found that the r^2 of the relationship between ET and RS parameters was 0.65 ANOVA Table and equation was shown in Table 23 and below :

$$ET = 3.99 + 0.83(NDVI) + 0.01(LST) + 1.61(Sur\_alb) \quad : \quad r^2 = 0.65$$

Table 23 ANOVA of ET and RS data in rice planting season of paddy field

	dF	SS	MS	F
Regression	3	1.92	0.64	3.14*
Residual	5	1.02	0.21	
Total	8	2.94		

Remarks : $F_{.05}$ (df. 3,5) = 0.125

* = Significant level 0.05

The factors which affected to ET are as same as whole year equation. Because of high relationship with NDVI and less relationship with surface temperature. The r^2 of this equation was a little less than whole year equation (r^2 = 0.65)

(2) Off rice planting season

The average data of RS in off planting season in 2002 and 2003 was found that the r^2 of the relationship between ET and RS parameters was 0.85 ANOVA table and equation was shown in Table 24 and below :

$$ET = -1.93 + 1.42(NDVI) + 0.2(LST) + 7.44(Sur\_alb) \quad : \quad r^2 = 0.85$$

Table 24 ANOVA of ET and RS data in off rice planting season of paddy field

	dF	SS	MS	F
Regression	3	5.96	1.90	7.55*
Residual	4	1.04	0.25	
Total	7	6.70		

Remarks : $F_{.05}$ (df. 3,5) = 0.04

* = Significant level 0.05

From the above model, it can be said that the trend of model in off rice planting season was similar with whole period equation (NDVI and surface albedo in this period played a significant role on ET). The surface albedo had most influence on the equation. But it seem not to be reasonable in logic, however if need to use this model must be select only high NDVI condition.

2) Teak plantation

The average data of RS in January in 2002 and 2003 was found that the r^2 of the relationship between ET and RS parameters was 0.41 ANOVA table and The significant prediction model were shown in equation below. (Table 25)

$$ET = -2.87 + 0.18(NDVI) + 0.27(LST) + 0.57(Sur\_alb) \quad : \quad r^2 = 0.41$$

Table 25 ANOVA of ET and RS data in teak plantation

	dF	SS	MS	F
Regression	3	3.55	1.18	2.96*
Residual	13	5.20	0.40	
Total	16	8.76		

Remarks : $F_{.05}$ (df. 3,13) = 0.07

* = Significant level 0.05

The whole RS data recorded throughout the year were use in model derived for prediction daily ET in teal plantation. It could be said tat the surface albedo had high effect on ET following with surface temperature and NDVI respectively.

(1) Rainy season

The average data of NDVI in rainy season 2002 and 2003 was found that the r^2 of the relationship between ET and RS parameters was 0.64 ANOVA table and equation was shown in Table 26 and below :

$$ET = 3.7 - 0.60(NDVI) + 0.07(LST) + 4.57(Sur\_alb) \quad : \quad r^2 = 0.64$$

From the above model, in rainy season showed the highest correlation for predict ET by using RS data (r^2 = 0.64) in this period the highest effect on ET was surface albedo, NDVI and surface temperature respectively.

Table 26 ANOVA of ET and RS data in rainy season of teak plantation

	dF	SS	MS	F
Regression	3	0.59	0.20	3.003*
Residual	5	0.33	0.07	
Total	8	0.92		

Remarks : $F_{.05}$ (df. 3,5) = 0.13

* = Significant level 0.05

(2) Dry season

The average data of NDVI in dry season 2002 and 2003 was found that the r^2 of the relationship between ET and RS parameters was 0.60 ANOVA table and equation was shown in Table 27 and below :

$$ET = -4.23 - 0.0004(NDVI) + 0.37(LST) - 5.8(Sur\_alb) \quad : \quad r^2 = 0.60$$

Table 27 ANOVA of ET and RS data in dry season of teak plantation

	dF	SS	MS	F
Regression	3	3.47	1.16	1.99*
Residual	4	2.33	0.58	
Total	7	5.80		

Remarks : $F_{.05}$ (df. 3,4) = 0.26

* = Significant level 0.05

In dry season, there was less relationship between NDVI and ET when compare with other period model. The main effect on ET was surface albedo and the determination of coefficient (r^2) was approximately 60%

2.5 Evaporative fraction (EF)

The evaporative fraction which implied to soil moisture index ranged from 0 to 1. The highest EF mean wet pixel therefore, wet season, maximum of soil moisture (H = 0) while the lowest mean dry pixel therefore, dry season, minimum of soil moisture (LE = 0)

Hypothesis of EF was the constant value of evapotranspiration index in which coefficient of energy balance parameters. This index can be estimated by below equation and the results were shown in Table 28 and Figure 24-26 as follow :

$$E = \frac{Rn - G - H}{\lambda}$$

In paddy field the variation of the average evaporative fraction (EF) throughout 17 images was shown in Table 28. Te results found that EF ranged 0.2 – 0.98 in December and April with an average of 0.66 while in planting period and off planting season the variation average of EF was 0.75 and 0.57 respectively.

In addition, the variation of the average EF in teak plantation throughout study period ranged 0.1–0.98 in January and April respectively with the average of 0.63. The average of EF in wet season was 0.70 while 0.54 in dry season.

2.6 Estimation evapotranspiration (ETest)

The estimation of evapotranspiration (ETest) was calculated from remotely sensed parameters. This method was modified by SEBAL technique in which surface energy balance algorithm, This procedure were also used energy balance parameters that interpreted from RS data.

Table 28 Evaporative fraction in each satellites image in paddy field and teak plantation.

Acquired Date	Evaporative fraction (EF)	
	Paddy field	Teak plantation
1. 22 August 2002	0.75	0.45
2. 15 September 2002	0.9	0.91
3. 5 October 2002	0.92	0.82
4. 20 November 2002	0.50	0.60
5. 1 December 2002	0.20	0.39
6. 16 January 2003	0.12	0.1
7. 4 February 2003	0.46	0.34
8. 7 March 2003	0.71	0.81
9. 17 April 2003	0.98	0.98
10. 1 May 2003	0.88	0.74
11. 16 June 2003	0.87	0.9
12. 1 July 2003	0.74	0.72
13. 16 August 2003	0.7	0.42
14. 1 November 2003	0.84	0.81
15. 16 October 2003	0.9	0.73
16. 7 November 2003	0.51	0.61
17. 23 December 2003	0.21	0.41

In paddy field, the results shown that the highest value of ETest was found in April (5.096 MJ m^{-2} day^{-1}) and lowest value was found in January (0.396 MJ m^{-2} day^{-1}) while in teak plantation the highest value of ETest was found in April (5.586 MJ m^{-2} day^{-1}) and lowest value was found in January (0.3 MJ m^{-2} day^{-1}). The explanation has shown in Table 29. (Figure 27-29)

Table 29 Estimation evapotranspiration in each satellite imagery in paddy field and teak plantation.

Acquired Date	Estimation evapotranspiration (ETest)	
	Paddy field	Teak plantation
1. 22 August 2002	3.26	1.008
2. 15 September 2002	4.04	4.483
3. 5 October 2002	4.35	3.92
4. 20 November 2002	2.624	2.740
5. 1 December 2002	0.701	1.589
6. 16 January 2003	0.396	0.3
7. 4 February 2003	1.472	1.36
8. 7 March 2003	2.698	2.997
9. 17 April 2003	5.096	5.586
10. 1 May 2003	4.752	3.552
11. 16 June 2003	4.089	4.5
12. 1 July 2003	3.552	3.168
13. 16 August 2003	3.36	1.806
14. 1 November 2003	4.284	3.483
15. 16 October 2003	4.23	2.92
16. 7 November 2003	2.499	2.074
17. 23 December 2003	0.651	1.189

Furthermore, in paddy field the daily average estimated ET throughout study period of was 3.06 while in planting season was 3.58 mm day^{-1} and 2.6 mm day^{-1} in off planting season. On the other hand, in teak plantation the daily average of ETest was 2.75 while in wet season the daily average of ETest was 3.2 and 2.23 respectively.

2.6.1 The relationship between estimated ET (ETest) and measurement ET (ETmea)

The results indicated that the relationship between daily average ETest and daily average ET mea in paddy field was high significant with determination of correlation was 0.80 (r=0.80) as for teak plantation the results shown the same similar with paddy field (r=0.86). (Figure 30)

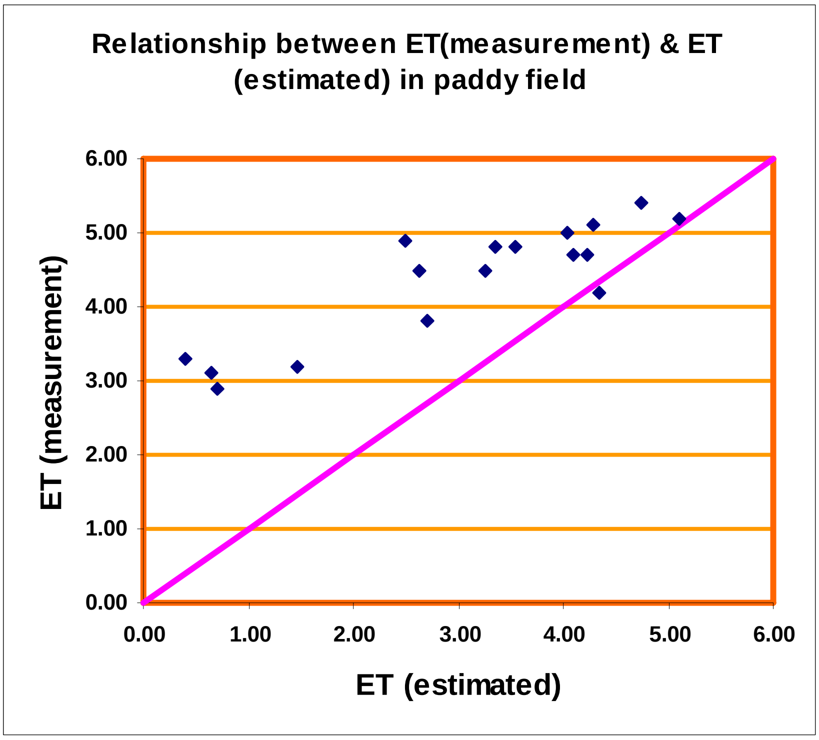
3. The Application of Study Results to Estimate the ET_a for Selected Sub-Watershed

The Mae-Mok sub-watershed was selected for the application of this study results. It was selected because of it is a branch of Yom river, and located near by the study area with a completed climatic data, and also having various land use utilization, as shown in Figure 28 to Figure 29 and Table 30. The result of model application can be described as following :

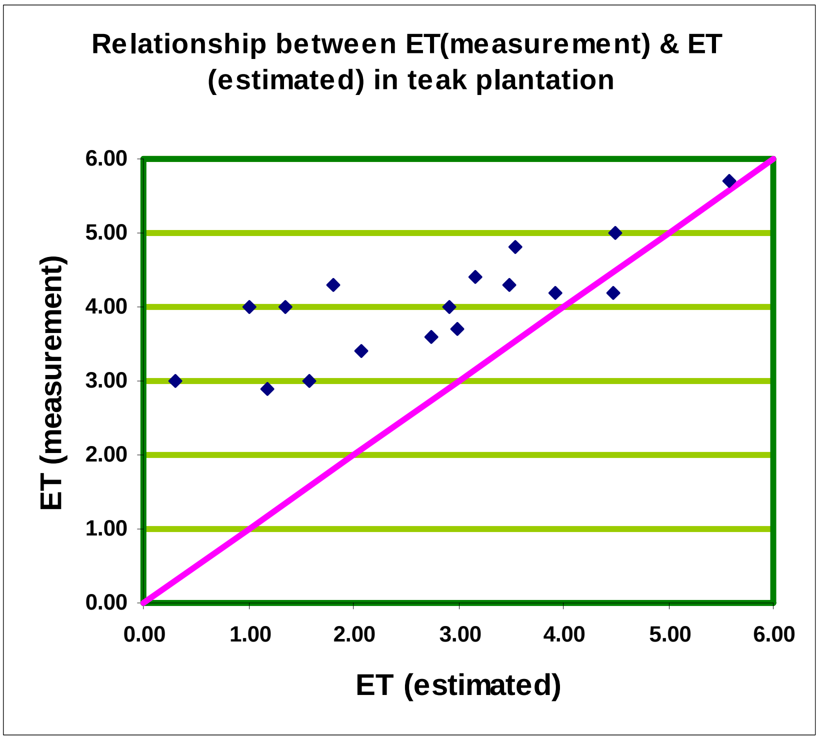
3.1 Location and Land Use Utilization

Mae-Mok sub-watershed located in Amphoe Thuen, Changwat Lampang, with total area 1159.2 $km.^2$ From the geographic map of Royal Thai Survey (scale 1 : 250,000), Mae-Mok sub-watershed was at sheet NE 47-7 series 15015 or in scale 1 : 50,000 at sheet 4946 I and 4946 II, between $18^o39'$ – $18^o54'$ N and $99^o46'$ – $99^o58'$ E, and having outlet of the Royal Irrigation Department (RID) at Ban Pong, Amphoe Ngao, Changwat Lampang (station code Y30 : 01080503). The exact location of the station is on $18^o42'59''$ N and $99^o57'40''$ E.

The land utilization in Mae-Mok sub-watershed is mostly under the deciduous forest, about 586.5 km^2 or 50.6% of total area, followed by the paddy field and mix deciduous forest were about 167.6 and 160.2 km^2 approximately or 14.5 and 13.8% of total area. The rest are dry evergreen forest, agricultural area, teak plantation,



(a) paddy field



(b) teak plantation

Figure 30 Relationship between ET(measurement) & ET(estimated) (a) in paddy field (b) in teak plantation

Table 30 Land use utilization in Mae-Mok sub-watershed, Amphoe Thuen, Changwat Lampang.

Land use type	Area		ET_a (mm day^{-1})
	Km^2	%	Annual
1. Paddy field	167.6	14.5	4.1[1/]
2. Corn field	1.1	0.1	3.9[2/]
3. Shifting area	3.6	0.3	3.2[4/]
4. Mix deciduous forest	160.1	13.8	4.5[2/]
5. Dry evergreen forest	146.5	12.6	2.5[4/]
6. Deciduous forest	586.5	50.6	3.7[3/]
7. Teak plantation	8.1	0.7	3.9[1/]
8.Agricultural area	84.6	7.3	3.5[5/]
9. banana field	1.0	0.1	2.7[1/]
Total	1159.1	100.0	-

Remark : [1/] from this study, [2/] from Piyapong (2001), [3/] from Somnimirt (2001), [4/] from Chankao (1971), [5/] approximated value

Source : modified from Division of Land Use Planning, 1994

corn field and banana field, about 146.5, 84.6, 8.1, 3.6, 1.1 and 0.9 km^2 or 12.6, 7.3, 0.7, 0.3, 0.09 and 0.08% of total areas respectively (Division of Land Use Planning, 1994).

3.2 Hydrological Data

3.2.1 Precipitation

The precipitation data were collected by the hydrological station of RID at Ban Pong from 1969-1998, with the yearly average rainfall amount of 1,113.2 mm. The average rainfall amount per year from 1997–1998 was 1,106.2 mm.

3.2.2 Discharge

The discharge data were also collected by the hydrological station of RID at Ban Pong from 1983-1998, with the yearly average discharge at 120.2 mm. The average discharge per year from 1997–1998 was 54.8 mm.

3.2.3 Pan evaporation

The evaporation data were also collected by RID (2000), with the yearly average pan evaporation of 1,026.9 mm. It seems rather low when compared with the data from Lampang meteorological station and vicinity meteorological station such as Tak, Sukhothai and Lampang. So, the averaged pan evaporation from those station was used in this study which it is 1,543.4 mm.

3.3 The Sub-Watershed ET_a Estimated Using Water Balance Method

To analyze the water balance in Mae-Moklsub-watershed, this study used the water balance equation. The equation was shown as follow :

$$ET = R - Q \pm \Delta S$$

Where ET = water loss from watershed by ET process (mm year^{-1})

R = average rainfall amount in watershed area (mm year^{-1})

Q = run off measured at the outlet point (mm year^{-1})

ΔS = the monthly increasing (+) or decreasing (-) of soil moisture (calculating in all year and long period and given $\Delta S=0$)

3.4 The ET_a Estimation in Mae-Mok Sub-Watershed by Using the Result of This Study

3.4.1 Water balance method

The yearly data observed in the same period of this study (1997-1998), was used to estimate ET_p in Mae-Mok sub-watershed using the water balance method. The average rainfall amount and discharge at Mae-Mok sub-watershed in 1997-1998 were 1,106.5 and 54.8 mm respectively. So, from the equation 117 :

$$ET_p = 1{,}106.5 - 54.8 \pm 0$$
$$= 1{,}051.7 \text{ mm year}^{-1}$$

So, the calculated ET based on water balance method at Mae-Mok sub-watershed was 1,051.7 mm $year^{-1}$

4.4.2 Energy balance and Bowen ratio method

The yearly data of 2002-2004, which was in the same time of this study, was used for estimation of ET_a in Mae-Mok sub-watershed using the energy balance and Bowen ratio method. From data in Table 30, the calculated ET_a was shown in table 31 which could be described as follows :

$$ET_{SP} = \sum_{i=1}^{n} \frac{(ET_1 * A_1) + \ldots + (ET_n * A_n)}{A_1 + \ldots + A_n}$$

And $ET_{ABS} = ET_{SP1} + \ldots + ET_{SPn}$

Where ET_{SP} = total ET_a in the basin for seasonal or periodical

ET_1 = estimated ET_a in land use type 1

ET_n = estimated ET_a in land use type n

A_1 = area of land use type 1

A_n = area of land use type n

ET_{ABS} = total ET_a in the basin for annual

Table 31 Land use utilization in Mae-Mok sub-watershed, Amphoe Thuen, Changwat Lampang.

Land use type	Area		ET_a	ET_a	ET(water balance)
	Km^2	%	(mm day^{-1})	(mm $year^{-1}$)	(mm $year^{-1}$)
1. Paddy field	167.6	14.5	4.1[1/]	-	-
2. Corn field	1.1	0.1	3.9[2/]	-	-
3. Shifting area	3.6	0.3	3.2[4/]	-	-
4. Mix deciduous forest	160.1	13.8	4.5[2/]	-	-
5. Dry evergreen forest	146.5	12.6	2.5[4/]	-	-
6. Deciduous forest	586.5	50.6	3.7[3/]	-	-
7. Teak plantation	8.1	0.7	3.9[1/]	-	-
8.Agricultural area	84.6	7.3	3.5[5/]	-	-
9. banana field	1.0	0.1	2.7[1/]	-	-
Total	1,159.1	100.0	-	1,351	1,051.7

Remark : [1/] from this study, [2/] from Piyapong (2001), [3/] from Somnimirt (2001), [4/] from Chankao (1971), [5/] approximated value

Source : modified from Division of Land Use Planning, 1994

From Table 31, So, the ET_a using the energy balance and Bowen ratio method in daily average evapotranspiration was 1,351 mm while averaged evapotranspiration by water balance method was 1,051.7 mm $year^{-1}$.