Kasetsart J. (Nat. Sci.) 48 : 548 - 559 (2014)

Agroforestry Indices Modeling for Sustainable Land Use Classification in Huai Raeng-Khlong Peed Watershed, Trat Province, Thailand

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ABSTRACT

Land use was modeled based on the sustainability of land uses in terms of biophysical aspects. The main objective of this study was to classify land use sustainability based on three agroforestry indices (organic matter, soil erosion and species diversity) which were determined using a weighting and rating score developed by experts from agroforestry, agriculture and government institutions. The relationship of the indices was established using a weighted linear combination technique to develop the model, and modeling was used to develop an agroforestry index (AFI).

Site observation data were used in the AFI equation to obtain land use types under sustainability (ST) levels. The "highest" ST level was recorded for the home garden which was distributed over only 2 km^2 (1.2% of the area), whist a "moderate" ST level was recorded for most land use types in the study area (124 km^2, 73.4%) consisting of rambutan, mangosteen and para rubber plantations. Oil palm was at the "lowest" ST level. A "low" ST level was not found in the study area. Therefore, the highest ST level should be identified as the best land use; it could be developed from existing land uses or established as a new land use in the study area. This study provided information to help identify priorities with regard to land use types and the sustainable land characteristics that can be useful for managers and planners in local and central governments and in other nongovernmental organizations.

Keyword: agroforestry, landscape agroforestry, sufficiency economy, modeling

INTRODUCTION

Deforestation is one of the largest sources of human-released greenhouse gases into the atmosphere that can be traced to land use/cover changes (Turner *et al.*, 2007). Changes in land use and ecosystems and their implications for global environmental change and sustainability are a major research challenge for the human environmental sciences (Turner *et al.*, 2007). Global deforestation has been severe, especially in tropical forests and the main cause has been conversion to agriculture (Food and Agriculture Organization of the United Nations, 2010). Deforestation has occurred in Thailand with the main cause being agricultural expansion which is widespread and large scale; it has resulted in the loss of multiple functions and a decrease in land productivity due to soil erosion, flooding and drought so that some land has eventually been abandoned (Association for International Cooperation of Agriculture and Forestry, 1999).

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Received date : 13/01/14 Accepted date : 21/07/14

Deforestation can be reduced in several ways. One way is to simply establish new plantation on deforested areas. Agroforestry is a basic land use where woody perennials are deliberately cropped jointly with agricultural crops or animals on the same land management unit; it is a dynamic ecology based on a management system that sustains production for social, economic and environmental outcomes (The International Centre for Research in Agroforestry, 1993). Agroforestry involves enhancing land use by the deliberate planting of woody perennials. This is a solution for dealing with the effects of deforestation. Consequently, agroforestry can be one sustainable land use that contributes to the control of erosion and the maintenance or improvement of soil fertility (Young, 1999).

Thailand still has extensive cropping in rural areas, which often occurs without any appropriate development direction, and although rural land use planning is undertaken by several governmental institutions, the expansion of indirect cropping has continued unabated in rural areas (Delang, 2005). Thus, land use planning in rural areas is a tool that policy makers can use to deal with deforestation in Thailand. One of several ways to conduct land use planning is via land suitability. The assessment of land suitability for a specific type of land use should be based on land use requirements and constraints (Rabia and Terribile, 2013).

Land suitability analysis has been applied in a wide variety of situations, particularly to determine the suitability of land for agricultural activities (Baja *et al*., 2007). An early step in the land suitability process is land evaluation; which is concerned with the assessment of land performance when used for specified purposes (Food and Agricultural Organization of the United Nations, 1976). The most popular evaluation technique is the analytical hierarchy process (AHP) which is contained in multi criteria decision making (MCDM) (Kiker *et al*., 2005). The main process is land suitability underpinning the ability of a given type of land to support a defined use. The pairwise comparison method inherent in the AHP is a technique for the consideration of a variety of criteria. The current research developed a sustainable land suitability model in terms of biophysical aspects. The study aimed: to determine key performance indicators for sustainable agroforestry; to develop the model; and to apply the model to analyze the existing land uses in the study area. The model is a tool which can examine the impact of land use that arises from uncontrolled land use planning and land use change, particularly environmental effects. Therefore, this can be useful for land use planning and for quickly detecting damaging problems that require urgent management.

MATERIALS AND METHODS

Materials

1. Topography map scale 1:50,000 of the Royal Thai Survey Department, sheet numbers 5433 I, 5433 II and 5433 III, 1997.
2. Land use map of the Land Development Department, 2010.
3. Soil type map scale 1:50,000 of the Land Development Department, 2002.
4. Software programs: Arc GIS version 9.3 Geographic Information System (GIS; esri; Redlands, CA, USA) and Microsoft Office 2007 (Microsoft; Redmond, WA, USA).
5. Notebook computer.
6. Sample collection of soil properties: using spatula or knife and small paper bags.

Methods

Site selection

The Huai Raeng-Klong Peed watershed was selected for the study site. This watershed of 445.37 km^2 is a part of Trat province, Eastern Thailand (Figure 1) and has several land uses which are mostly based on woody perennials under

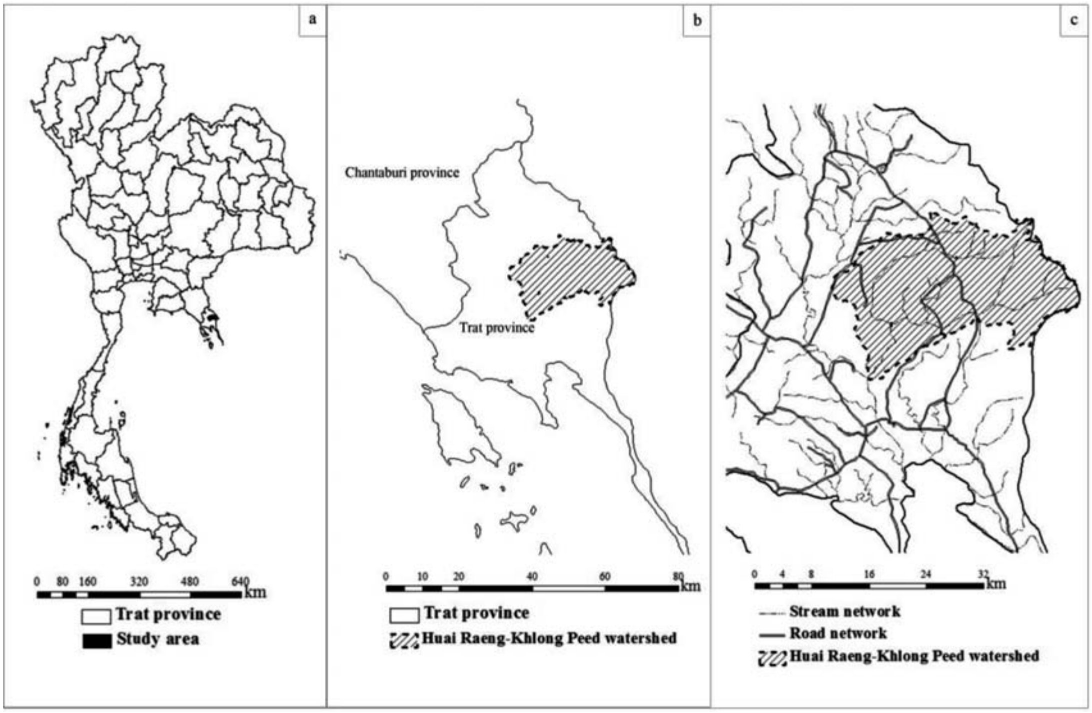

Figure 1 Study area in Huai Raeng-Klong Peed watershed, Eastern Thailand: (a) National scale; (b) Regional scale; (c) Watershed scale.

the general term of agroforestry. The different land uses in 2010 were reclassified into 22 types. Natural forest and forest plantation were the major land uses in the watershed (34.185%). Rubber plantation comprised an important cultivated land area (26.18%), while grass and abandoned land, mixed fruit orchards, and mixed rubber and pineapple represented 9.50, 7.77 and 7.28%, respectively.

Methodology

Land suitability was the main methodology. The goal was defined under sustainable land use in terms of biophysical aspects to detect key indicators. The key indicators were determined using a pairwise comparison method which is a technique of the AHP as the content for MCDM. A combination of the weighted values of key indicators was established using a weighted linear combination technique to develop the model. The model was used to generate the land suitability maps by applying a GIS approach. The methodology framework is shown in Figure 2.

Defining the goal

Defining the criteria and the key indicators were investigated from a review of the literature. Each agroforestry index (AFI) was defined by applying the sustainability concept in terms of the biophysical aspects of land resources and land quality concept as published in the Land Degradation Assessment in Dry Lands (LADA) project (Food and Agricultural Organization of the United Nations, 2011). There were three aspects to the LADA parameters; change in soil properties and soil erosion; change in water resources; and change in vegetation. The current research did not use change in water resources.

Decision and weighting criteria and indicators

Estimation of each key indicator (criteria and indicator) was based on a questionnaire sent to experts. The pairwise comparison method was chosen to determine the weighting of each

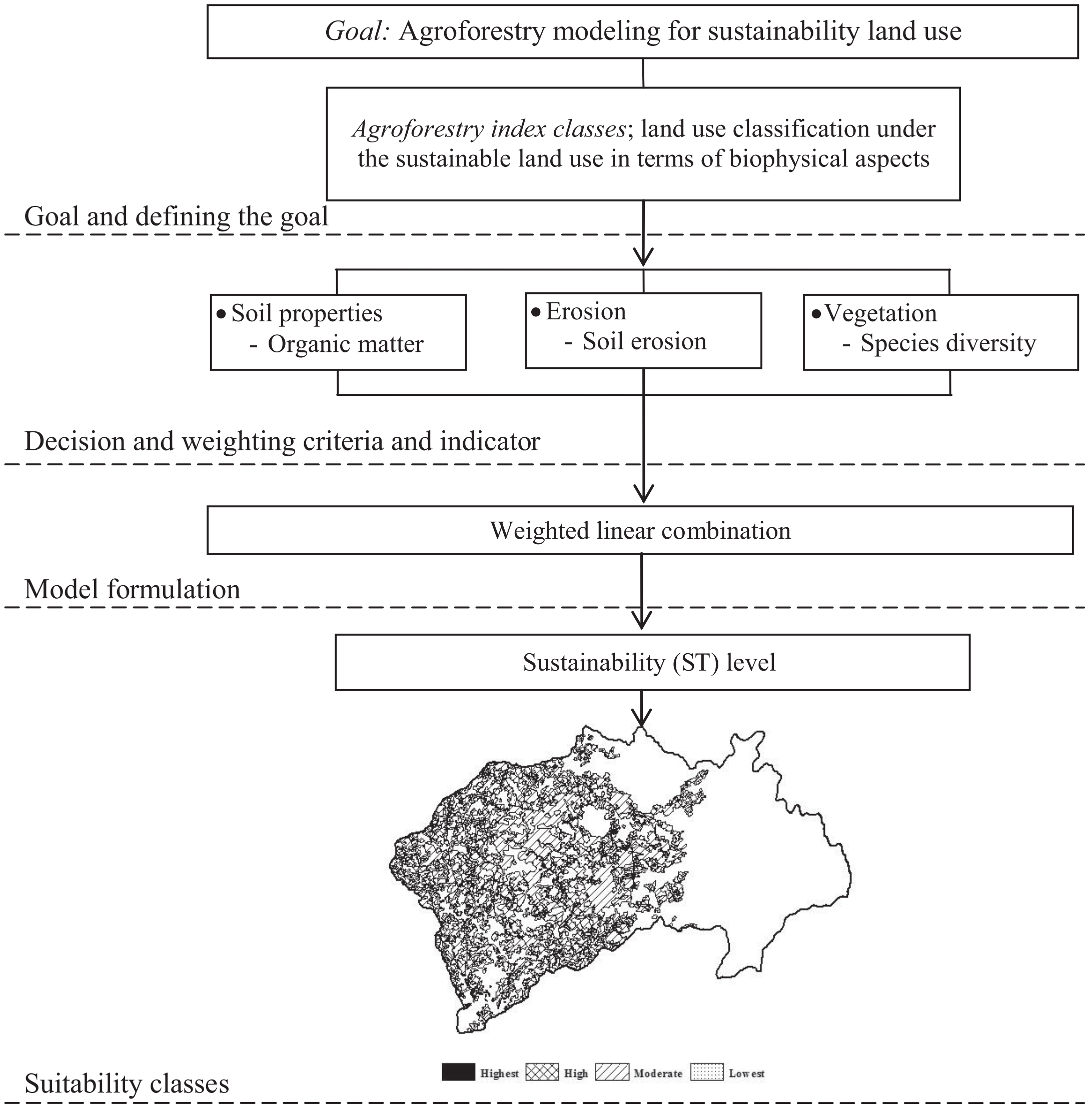

Figure 2 Research methodology framework.

criterion and indicator. Some questionnaires (62) were sent by mail, and 18 were delivered by hand. Three categories of expertise were relevant to this research with the parenthetical figures indicating the number of people surveyed and the percentage of the overall surveys, respectively: agroforestry (22, 27.5%), agriculture (38, 47.5%) and governmental institutions in terms of the land use planning policy aspect (20, 25%). The highest weighted values of the three indicators of soil properties and four indicators of vegetation were chosen with the highest value of each criterion as the indicators of their respective criteria. Weighted values of other criteria were used in the modeling.

Model formulation

The weighted value of each criterion was taken into weighted linear combinations to generate the model called the AFI equation. The model produced sustainability levels called Agroforestry Index Classes (AFICs). Weighted linear combinations are shown by Equation 1:

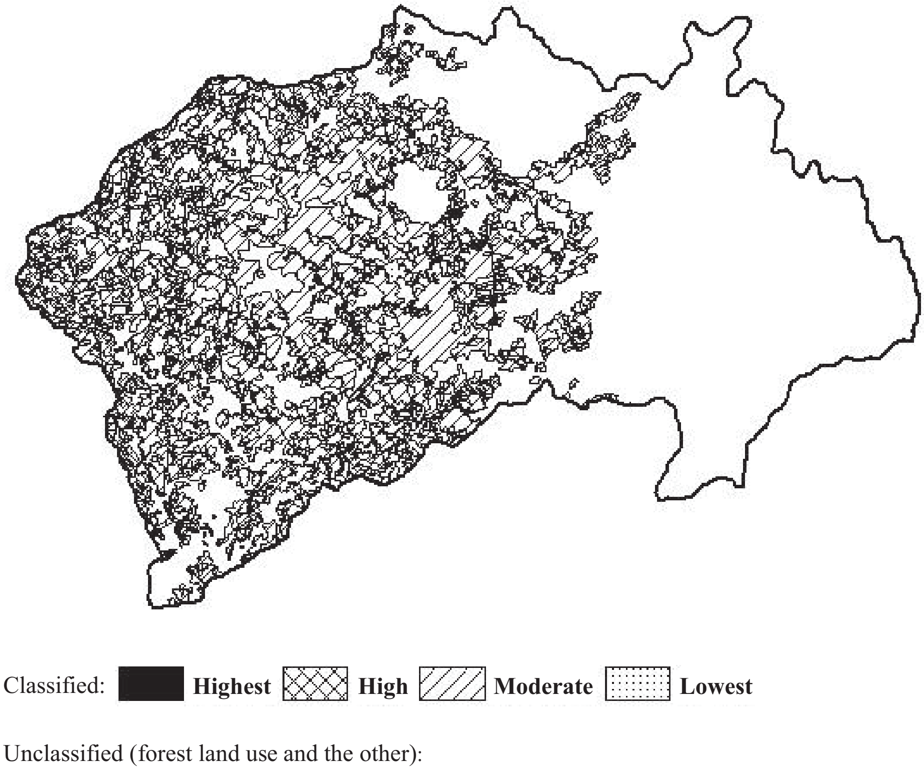

Figure 3 Agroforestry index classes in study area. (Note there was no “Low” class in the study area.)

$$S = \frac{\sum_{i=1}^{n} W_i R_i}{\sum_{i=1}^{n} W_i} \quad (1)$$

where S is the sum of overall cumulative suitability, W_i is the weighted value of each criteria, R_i is the ranking score of each indicator and i is the criteria number from 1 to n.

Suitability classes

Data collection

Each AFIC was determined by spatial matching analysis based on the land use type map in 2010. Land use types were chosen based on the proportion of land use types and land use types based on woody perennial or agroforestry. The land use types chosen are listed in Table 1. Next, the land use types were collected in each AFI by a completely randomized design. Selected land use types were sorted into two slope classes (0–6% and 6–25%) and into soil series. The land use type was considered as the treatment. Two sample plots of each land use type produced 20 sample plots, each sized 40 × 40 m. The methodologies of data collection in each indicator are shown in Table 2.

Data calculation

Each AFIC was generated from the collected data in each indicator, then they were equally ranked using five levels which defined the concept of land suitability of Food and Agriculture Organization of the United Nations (1976), where each level was taken as a representative value from the lowest (1) to the highest (5) as an interval class value. Next, the collected data in each land use type were compared with the interval class value, and these collected data were used as representative values of each level. Subsequently, the representative values were used in the AFI equation. The complete process produced the AFIC land use types under a sustainability concept in terms of biophysical aspects called the sustainability level. To test the different population medians among each indicator of land use type, the Kruskal-Wallis test was chosen to evaluate the population medians on a dependent variable having the same distribution at a significance level of ($P < 0.05$).

Suitability class map

The AFIC of the land use types was indicated by the sustainability level (ST level) which was a representative value in each land use map of the Department of Land Development (2010). Map algebra in ArcGIS 9.3 was used to develop the agroforestry index classes map (AFIC map). The AFIC map illustrated the level of land use type required to achieve the ST level in the study area.

RESULTS

Key performances of agroforestry indices

Of the 80 questionnaires distributed, 58 (72.5%) were returned. The weighted values of the AFI values are shown in Table 3. The highest weighted values of the three soil properties and four vegetation classes were chosen as the indicators of their respective criteria which included organic matter and species diversity. Weighted values of other criteria were used in the modeling; there were three key performance indicators.

Agroforestry index modeling for sustainable land use

The weighed values of the AFI (Table 3) were determined using Equation 1 to develop AFI Equation 2:

$$AFI = \frac{\left[(1R_{om}) + (6.9R_{ERO}) + (2.1R_{SPD})\right]}{10} \quad (2)$$

Table 1 Selected land use types of Huai Raeng-Klong Peed watershed in 2010.

No.	Land use type
1	Oil palm
2	Rubber plantation/fruit orchard
3	Rubber plantation
4	Mixed fruit orchard
5	Eaglewood/para rubber
6	Home garden
7	Rambutan
8	Mangosteen
9	*Acacia mangium* plantation
10	Eaglewood

Table 2 Methodology for each indicator in terms of environmental factors.

Indicator	Methodology
Soil properties	Organic matter (OM); soil samples were randomly collected from 3 points, with 2 samples at each point at soil depth 0–15 cm and 15–30 cm.
Soil erosion	Universal soil loss equation model used to estimate average soil loss.
Vegetation	Species Diversity; the Shannon index (H') was used as an index to measure the species abundance and richness. $H' = \sum_{i=1}^{s} p_i In\ p_i$, where s is the number of species and p_i is the relative cover of the i^{th} species.

where, AFI is the agroforestry index, R_{OM} is the ranking of organic matter, R_{ERO} is the ranking of soil erosion and R_{SPD} is the ranking of species diversity.

The agroforestry indices were divided into five classes using a class interval technique, to produce the AFICs as shown in Table 4. Each AFIC contained ST levels based on the sustainability concept in terms of the biophysical aspect approach.

Agroforestry index classes of the study area

The key indicators which were used in the AFI were collected in the 10 agroforestry land uses. The collected data were ranked and the representative values used as the ranking scores of AFI are shown in Table 5. The AFI values were generated as shown in Table 6. The application of Equation 2 produced the ST levels shown in Table 7.

Although OM was not significant among the agroforestry land uses, this demonstration was able to explain the land use pattern related to OM, as land use change has a negative impact on the soil, especially the soil organic matter (Neufeldt *et al*., 2002; Guimaraes *et al*., 2013), and OM is reduced by reduced physical protection or increased water erosion (Fernandes *et al*., 1997; Parras *et al*., 2013). The soil surface is the vital interface that receives much of the fertilizers and receives the intense

Table 3 Weighted value of agroforestry index class in terms of environmental factors.

Weighted value of criteria		Weighted value of indicator			
		Indicators of vegetation		Indicators of soil properties	
Soil property	1.0	Percentage of crown cover	0.6	Organic matter	6.9
Soil erosion	6.9	Stratification of crown cover	1.5	Bulk density	1.0
Vegetation	2.1	Biomass	2.2	Soil moisture	2.1
		Species diversity	5.7		

Table 4 Agroforestry index classes (AFIC).

AFIC	Agroforestry index	Level of land use type under sustainability
1	4.2–5.0	Highest
2	3.4–4.2	High
3	2.6–3.4	Moderate
4	1.8–2.6	Low
5	1.0–1.8	Lowest

Table 5 Ranking score of agroforestry index in study area.

Ranking score	Interval classes		
	Organic matter (%)	Soil erosion ($t.ha^{-1}.yr^{-1}$)	Species diversity (H’)
5	>4.34	<117.15	>1.232
4	3.70–4.34	117.15–179.10	0.924–1.232
3	3.06–3.70	179.10–241.04	0.616–0.924
2	2.43–3.06	241.04–302.99	0.309–0.616
1	<2.43	>302.99	<0.309

H’ = Shannon index; see Table 2 for definition.

impact of rainfall (Franzluebbers, 2002). Isicheia and Muoghalua (1992) stated that soils under tree canopies were found to have significantly higher levels of organic matter. This conclusion supports the results that the OM was slightly higher beneath the closed tree canopy than under the sparse tree canopy; the OM level was lower than 2% in mangosteen, rambutan, and oil palm. Several researchers have investigated the land use change effect on soil organic matter; OM quantity was analyzed by total organic C and N analysis (Glaser *et al*., 2000) and compared with cultivated fields, with proportions of the soil organic carbon (SOC) of 50% and 30% reported as retained in the shrub cultivated field and tree cultivated field, respectively (Glaser *et al*., 2000; Martens *et al*.,

Table 6 Value ranking scores of the key performance indicators and agroforestry index (AFI) of each land use in the study area.

Land use type No.	Organic matter		Soil erosion		Species diversity		Total value of AFI
	(%)[a]	Ranking score[b]	($t.ha^{-1}.yr^{-1}$)[a]	Ranking score[b]	Shannon index (H')[a]	Ranking score[b]	
1	1.78	1	364.94	1	0	1	1.00
2	2.31	1	121.47	4	0.655	3	3.49
3	2.41	1	119.52	4	0	1	3.07
4	2.74	2	164.82	4	0.693	3	3.59
5	3.32	3	128.97	4	0.691	3	3.69
6	2.05	1	55.21	5	1.505	5	4.60
7	1.97	1	133.70	4	0	1	3.07
8	1.85	1	133.26	4	0	1	3.07
9	4.98	5	105.87	5	0	1	4.16
10	2.81	2	113.80	5	0	1	3.86
Significance	0.42[NS]		0.16[NS]		0.02*		

[a] = Collected data, [b] = Ranking score. Values within a column followed by the same letter are not significantly different ($P < 0.05$, Kruskal Wallis test).* = Significant at 0.05 level of probability, [NS] = Not significant at 0.05 level of probability.

Table 7 Sustainability level (ST) of each land use type.

Land use type	Agroforestry index	Agroforestry index class	ST level	Area	
				km^2	%
Oil palm	1.00	5	Lowest	5.0	2.9
Rubber plantation	3.07	3	Moderate	124.0	73.4
Rambutan	3.07	3	Moderate		
Mangosteen	3.07	3	Moderate		
Rubber plantation/fruit orchard	3.49	2	High	38.0	22.5
Mixed fruit orchard	3.59	2	High		
Eaglewood/para rubber	3.69	2	High		
Acacia mangium plantation	4.16	2	High		
Eaglewood	3.86	2	High		
Home garden	4.60	1	Highest	2.0	1.2

2004). Murty *et al*. (2002) reviewed the literature to assess changes in soil C upon conversion of forests to agriculture and found that conversion led to an average loss of approximately 30% of soil C. Furthermore, the level of OM in different soil levels was investigated; on land converted into cultivated land, OM was significantly reduced in the surface soils (0–20 cm) by over 50% (Solomon *et al*., 2002; Celik, 2005), whereas SOC stocks in the mineral soil (down to a depth of 60 cm) were lower in forest soil than in agricultural soils (John *et al*., 2005). Consequently, the land conversion to cultivated land not only influenced the total SOC and N stocks in the soils and the SOM fractions, but also changed the chemistry of the SOM in the soil density fractions (John *et al*., 2005; Helfricha *et al*., 2006).

Soil erosion had no significant effect in the current study. Clearly, soil erosion is a complex process that depends on soil properties, ground slope, vegetation and the rainfall amount and intensity (Selby, 1993). A change in land use is widely recognized as being capable of greatly accelerating soil erosion (Ursic *et al*., 1965). Studies involving different environments agreed that the runoff and sediment yield decrease with an increase in soil cover by vegetation (Francis and Thornes, 1990; Duran *et al*., 2006). These conclusions support the results that oil palm produced the highest soil erosion because it had the lowest crown cover. These results also confirmed the previous finding of Quinton *et al*. (2007) that the canopy cover showed a significant relationship with soil loss and runoff with the greatest reduction in soil loss taking place at canopy cover levels greater than 30%. Not only did the topographical effect dominate the overall regional erosion response but so also did land use conversion of forest to cultivated land. The conversion of forest to cultivated land with a soil loss >100 $Mg.ha^{-1}.yr^{-1}$ was significant (José *et al*., 2000). Often, this may be amplified by the conversion of arable land to forest on steeper slopes (Bakker *et al*., 2008). However, soil erosion is likely to be more affected than runoff by changes in rainfall, though both are likely to be significantly impacted; the percentage of erosion and runoff will likely change more for each percent of change in rainfall intensity; changes in ground cover have a much greater impact on both runoff and erosion than changes in canopy cover alone (Nearinga *et al*., 2005).

Only species diversity (0.02, $P < 0.05$) was significant. Clearly, the results showed that home gardens contained the highest species diversity. These results confirmed a previous study (Niedrist *et al*., 2009) that found the number of plant communities along with the number of species decreased constantly and significantly with increasing land use intensity and on abandoned land. Likewise, intensive commercial monocropping is likely to result in low species diversity (Tolera *et at*., 2008) and reduced biodiversity (Thrupp, 1998; Brookfield, 2001; Rajendra *et al*, 2010). Furthermore, species diversity influences soil microbial communities, as Mercirisa *et al*. (2006) and Gastinea *et al*. (2003) stated that the culturable soil microbial activity, substrates used and diversity declined with declining plant diversity and composition in grassland ecosystems.

The home garden produced the lowest level of soil erosion but contained the highest species diversity. Furthermore, the oil palm produced the highest soil erosion but had the lowest level of soil organic matter and contained the lowest species diversity. Consequently, home garden had the highest ST level while oil palm had the lowest ST level. Most of the tree-based cultivation systems produced high ST levels—namely, *Acacia mangium* plantation, eaglewood, eaglewood/para rubber, mixed fruit orchard and rubber plantation/fruit orchard. Land uses determined as being at the low ST level were not identified in the study area.

A total of 73.4% (124 km^2) was graded at the moderate ST level followed by the high ST level (22.5%, 38 km^2), the lowest ST level (2.9%, 5 km^2) and the highest ST level (1.2%, 2 km^2). Most of the land use types were distributed on the gentle slopes in the middle and on the western side of the watershed as most characteristics of the study area were associated with a gentle slope and they did not relate to critical land for cultivation.

CONCLUSION AND RECOMMENDATION

The key performance indicators were defined from a review of the literature in terms of land quality and sustainability. Each agroforestry index (AFI) consisted of three criteria: soil properties (organic matter), soil erosion and vegetation (species diversity). The weighted values among criteria were clear. The highest weighted value was soil erosion, which indicated that these criteria were efficient in the modeling. The analysis of ST levels in the study area found only home garden had the highest ST level. The high ST level consisted of *Acacia mangium* plantation followed by eaglewood, eaglewood/para rubber, mixed fruit orchard and rubber plantation/fruit orchard, respectively. The moderate ST level consisted of rambutan, mangosteen and para rubber plantation. Oil palm was reported at the lowest ST level. The low ST level was not found in the study area. Therefore, the highest ST level should be identified as the best land use; it might be developed from the existing land use or established as a new land use in the study area.

This study provided information to help identify priorities with regard to land use types and the land characteristics under sustainability. Thus, it is a tool for sustainable resource management. The application developed in this paper can be useful for managers and planners in local and central governments and in other nongovernmental organizations.

ACKNOWLEDGEMENTS

The authors sincerely thank the National Science and Technology Development Agency, Thailand for providing a financial scholarship, and the Faculty of Forestry, Kasetsart University and the Trat Agroforestry Research and Training Station for providing the research laboratory and the study area, respectively.

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