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Relating plant diversity to biomass and soil erosion in a cultivated landscape of the eastern seaboard region of Thailand

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ABSTRACT

Plant diversity can affect ecological processes through effects on biomass and soil condition. A study was carried out in an agricultural watershed of Thailand to document plant species richness of different agricultural land uses and to assess its relationship with biomass and soil erosion. A nested sampling design of 20 × 20 m, 10 × 10 m, 5 × 5 m and 1 × 1 m quadrats was employed to study species richness of three categories of plants: herbaceous plants, shrubs and trees. Interviews were conducted with farmers who owned the cultivated fields where sampling plots were located. Plant diversity was assessed by computing Shannon index, Simpson index, and Species richness. Species utility index, which is the percentage of species identified as useful, was also estimated for each land use. Biomass was estimated using methodology recommended by FAO and soil erosion was estimated using the universal soil loss equation (USLE). From among the different land use types, mixed orchard ranked first in terms of plant diversity while paddy ranked last. Land uses with monocropping of shrubs, such as cassava, pineapple and sugarcane had lower plant diversity than land uses with monocropping of trees, such as coconut and para rubber. Monocropping of eucalyptus was an exception. Rotations of monocrops, namely pineapple–cassava and sugarcane–cassava, or intercropping, namely coconut–cassava, also had a higher plant diversity as compared to monocropping of shrubs. The highest species utility index of 61 was found in orchards, the lowest of 9 was found in Eucalyptus plantations. Plant diversity was found to have a significant positive correlation with biomass and a negative, though non-significant, correlation with soil erosion.

Introduction

Agrobiodiversity has been recognized as an important factor in maintaining or enhancing agricultural sustainability (Brookfield, Padoch, Parsons, & Stocking, 2002). Agricultural biodiversity or ‘agrobiodiversity’ are now established terms in their own right and are defined as ‘the variety and variability of animals, plants and microorganisms that are used directly or indirectly for food and agriculture, including crops, livestock, forestry and fisheries (FAO, 1999). Agricultural biodiversity includes all components of biological diversity that are relevant for agricultural production (Thrupp, 1998). Agricultural biodiversity has multiple functions, such as contributing to food and livelihood security as well as to environmental sustainability (FAO, 1997). Agricultural biodiversity can also assist in controlling land degradation (Stocking, 2002) and in increasing nutrient use efficiency. Evidence from experimental intercropping systems has demonstrated that higher species

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richness can be associated with increased crop yield (Tilman, 1996), possibly due to differences in nutrient cycling characteristics that regulate soil fertility (Ewel, Mazzarino, & Berish, 1991; Hooper & Vitousek, 1998; Vandermeer, 1988, 1990).

Agrobiodiversity, however, is being depleted in many agroecosystems, causing economic losses, which lead to a broad range of social costs (Thrupp, 1998). Biodiversity conservation in agricultural land uses is one of the greatest challenges, especially in the tropics where rapid population growth, intensification of land use, and unplanned settlement and fragmentation destroy fragile habitats and lead to a particularly rapid rate of biodiversity loss (NEMA, 2001). Thailand, where new opportunities have arisen through national and international market demand for industrial crops and commercial vegetable crops, has been undergoing rapid changes in land use. Commercialized land uses focus mostly on a few or on only one species and commonly result in the disappearance of local varieties from farmers' fields (Rerkasem & Rerkasem, 2000). Data for assessing agrobiodiversity are generally scarce (Dumanski & Pieri, 2000). However, declining agrobiodiversity can be deduced from preliminary indicators, for example from loss or fragmentation of natural habitat (Smith, 1996).

Plant diversity and biomass

Hypotheses on the link between diversity and energy in ecosystems suggest a positive relation between biomass and biodiversity. Plants in more diverse communities may increase total resource capture and thus have a higher net primary production (Hooper, 1998). Such an increase in net primary production with increasing plant diversity is mainly attributed to increased nutrient and water uptake due to different depths of root systems (Berendse, 1979), increased leaf area index and light capture due to differences in shoot architecture (Naeem, Thompson, Lawler, Lawton, & Woodfin, 1994; Tilman, 1996), and increased efficiency of resource capture over time due to differences in phenology (Gulmon, Chiariello, Mooney, & Chu, 1983; Steiner, 1982).

Plant diversity and soil erosion

Almost one third of Thailand's cultivated area is subject to severe land degradation, especially to water-induced soil erosion in sloping terrain and in upland areas. Soil erosion causes loss of soil productivity, degradation of water quality, and loss of organic carbon (Brown & Wolf, 1984; Lal, Kimble, Follet, & Cole, 1998; Walling, 1987). Vegetation cover plays an important role in mitigating soil erosion. The protective capacity of vegetation cover is related to biomass and species diversity. Biomass converted to soil organic matter can protect against soil erosion by stabilizing aggregates (Oades, 1993) and enhancing soil structure (Waters & Oades, 1991). Cardinale, Wright, Cadotte, Carroll, Hector, Srivastava, Loreau, & Weis (2007) reported that species mixtures can produce on average 1.7 times more biomass than species monocultures. Soil stability depends also on the above- and below-ground structure of plant communities. Heterogeneity in the shoot and root architecture of plant communities is capable of reducing both rainfall erosivity and soil erodibility. The greater the diversity of root growth forms, the less likely it is that extreme events will lead to soil erosion (Beierkuhnlein & Jentsch, 2005). Hence, loss of plant diversity in terms of both species diversity and structural complexity, and prevalence of monocultures can enhance susceptibility to soil erosion (Power & Follett, 1987), especially in high mountains (Korner, 1999).

In Thailand, plant diversity in cultivated landscapes has been affected by the rapid commercialization of agriculture which goes hand in hand with increasing monocropping of food crops, commercial value crops (para rubber, eucalyptus), and, lately, biofuels. Commercial agricultural land use can also have an effect on soil erosion. The objective of this study was to assess plant diversity of various agricultural land uses of a cultivated watershed, and to explore how plant diversity relates with plant biomass and soil erosion. Plant diversity is in this study represented by plant species richness. A study like this can help to identify land use types which promote plant diversity, and to maintain ecological integrity by better land use allocation within a watershed.

The study area

The study area, *Khlong Yai* watershed, is located between 12° 65′–13° 14′ N latitude and 101° 03′–101° 44′ E longitude in the eastern seaboard region of Thailand, and covers 170,175 ha (Fig. 1). The area is under the influence of a tropical monsoonal climate with a rainy season extending from May to October. The average annual rainfall is 1383 mm in 120 average annual rainy days. The average annual temperature is 28.3 °C. More than 75% of the sub-watershed has flat or gently undulating topography suitable for upland cultivation. Slope complex (steep land) covers 10% of the total area of the watershed. The dominant soil types in the area are Typic Paleudults and Oxic Paleustults.

Almost the entire area (80%) of the watershed is under agricultural cultivation. The range of agricultural land uses in the study area is rather broad; the main categories are: shrub monocrops, mixed orchards, tree monocrops, and tree–shrub intercrops. Mixed orchards and monocrops of para rubber (*Hevea brasiliensis*), pineapple (*Ananas comosus*) and cassava (*Manihot esculenta*) are the dominant land uses covering an area of 19.4, 16.3 12.9 and 12.1% of the total watershed, respectively. Paddy (*Oryza sativa*) covers about 4% of the total agricultural area. Other agricultural land uses in the area are monocrops of coconut (*Cocos nucifera*), eucalyptus (*Eucalyptus camaldulensis*), and sugarcane (*Saccharum officinarum*), intercrops of coconut–cassava, and rotations of sugarcane–cassava and pineapple–cassava. The agricultural cultivation is mostly intensive and commercially-oriented.

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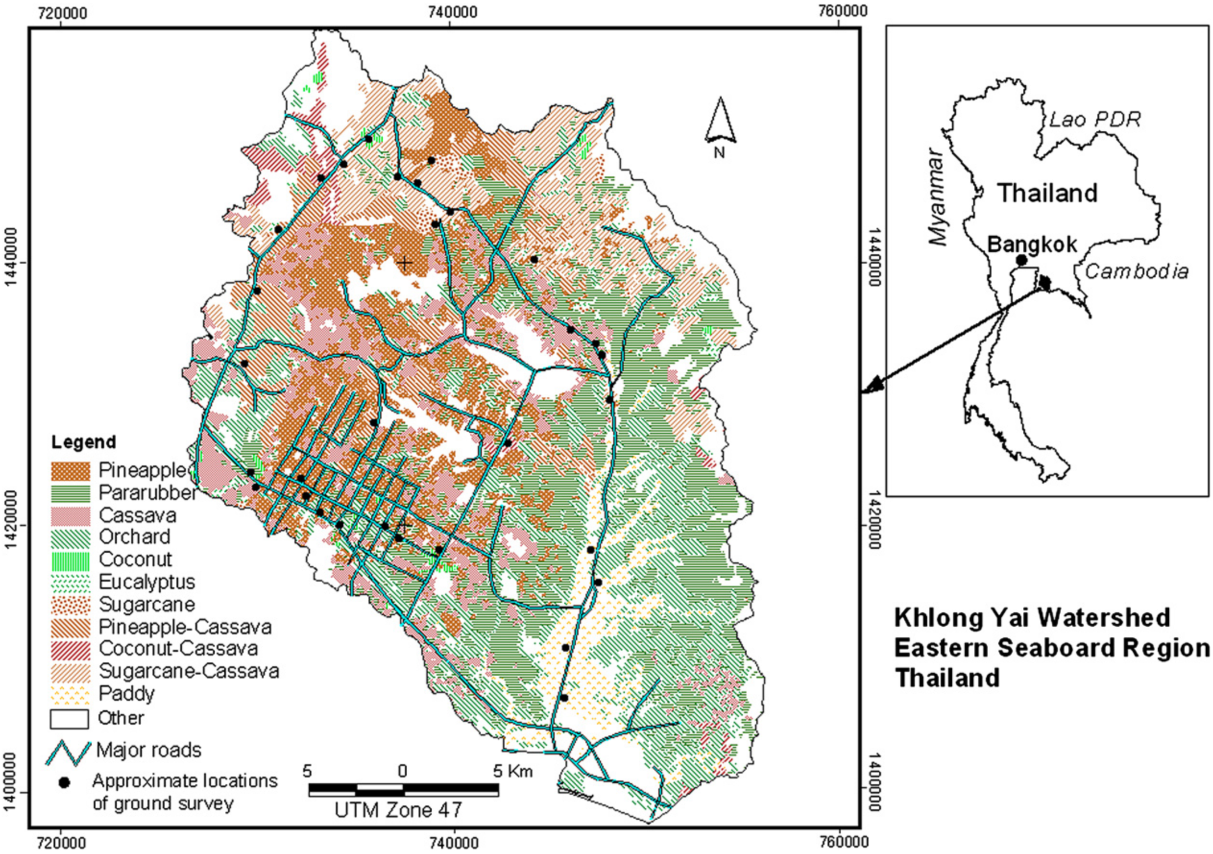

Fig. 1. Location of the study area.

Materials and methods

Sampling design

The study was conducted according to the methodology and terminology suggested by Zarin, Huijun, and Enu-kwesi (2002). With respect to terminology, land use type refers to the dominant annual or perennial crop(s) and their temporal or spatial association in any given field. In this study, land use types were identified using the available land use map. For the purpose of biomass estimation, land use types were identified as or subdivided into three layers: tree layer, shrub layer, and herb layer. However, results were presented at the level of land use types. Land use under mixed orchard, para rubber, eucalyptus and coconut were considered as tree layer land use as these crops grow to a height of more than 2 m. Land uses with pineapple, cassava and sugarcane are referred to as shrub layer as their height ranges between 0.5 and 2 m. Paddy rice is considered a herb layer, because rice is an annual plant, which does not produce woody tissue.

We used the nested plot/sub plot sampling design suggested by Avery and Burkhart (1983) with 20 × 20 m, 10 × 10 m, 5 × 5 m and 1 × 1 m quadrats, nested within each other, as sampling units for plant diversity and biomass estimation. The 20 × 20 m quadrats were used for morphometric measurements of the tree layer to estimate biomass, for tree species identification, and for counting the number of individuals of each species, especially in land use types with large canopy trees and many species, e.g. mixed orchard. 10 × 10 m quadrats were used for land uses identified as tree layer with a greater uniformity of species, excluding mixed orchards. 5 × 5 m quadrats were used for measurements in the shrub layer and 1 × 1 m quadrats were used for the herb layer. A stratified sampling design using land use type as strata with the number of sampling sites proportional to the size of the area covered by each land use class was employed as a sampling framework. The total number of sampling quadrats was 75 with 4–12 quadrats in each land use category. When positioning sample quadrats, soil type was considered in order to ensure representational coverage of the dominant soils of the study area. Field work was conducted during September–November of 2006, i.e. at a time when annual crops have matured. Quadrats were sampled only once. Farm households, who cultivated the fields where sample quadrats were located, were interviewed to collect relevant information, such as utility value of species and yield data.

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Plant diversity assessment

For the assessment of biodiversity or, more narrowly, plant diversity, various methods and indices are available. In this study, species richness, Shannon index, Simpson index, and Species utility index (Zarin et al., 2002) were used to estimate plant diversity for each land use type. The indices were calculated separately for herb layer, shrub layer and tree layer. The standardized methodology of linear scaling was adopted in order to combine different indices so that a single index could be derived to rank different land use types in terms of plant diversity.

In this paper, we focus on plant species richness as a measure for plant species diversity, including both crops and spontaneous vegetation. Species richness is a simple numerical count of the number of species found in a given sampling unit (Magurran, 1998), in our case the quadrat. The Shannon's diversity index (H), ranging in theory from 0 to infinity, accounts for both abundance and evenness of the species present. H increases as the number of species increases and individuals are evenly distributed. It is zero when only one species is present irrespective of its individuals. In the following equation, Shannon's diversity index (H) calculates the proportion of species i relative to the total number of species (p_i), and then multiplies by the natural logarithm of this proportion ($\ln p_i$). The resulting product is summed up across species, and multiplied by -1 (Magurran, 1998).

$$H = -\sum_{i=1}^{N} p_i \ln p_i$$

Simpson's index (Simpson, 1949) gives the probability of two randomly chosen individuals drawn from a population belonging to the same species. Simpson's index was calculated by adding the sum of squares of proportional abundance of each species identified in the sampling quadrats. The higher the probability that individuals belong to the same species, the lower the diversity. The index was converted to (1-D) for easy interpretation, because a higher value of (1-D) also indicates a higher diversity.

$$D = \sum pi^2$$

The species utility index was calculated by dividing the number of species identified as useful by the farmers by the total number of identified species. The utility index was calculated by combining the species in all three layers. In addition, the number of layers was also taken as one index in order to incorporate the vertical aspect of diversity and to avoid bias due to richness in only one layer.

Plant diversity ranking

The land use types in the study area were heterogeneous in terms of crops grown, of management practices, and of number of layers. Plant diversity should meaningfully be considered in both the horizontal and the vertical dimension. Given that the study area is a cultivated landscape, it is important that diversity be represented not only by the higher number of plant species and their relative abundance but also by the utility value of the species to the farmers. It is therefore essential to combine all indices into one index in order to compare the plant diversity of the different land uses. Linear scaling of the different indices in different layers is thus suggested in order to obtain a single index for ranking plant diversity of the different agricultural land uses. A min-max normalization technique as shown in the following equation was used to combine all indices into a single index for each land use type. This simple and commonly used normalization technique linearly arranges observed data into a specified range.

$$R = [(Yi - Y_{\min})/(Y_{\max} - Y_{\min})] \times 10$$

where, R is rescaled diversity index. Yi is ith diversity index to rescale, $Y_{\max}$ is maximum value of ith diversity index among land uses of the watershed, and $Y_{\min}$ is minimum value of ith diversity index among land uses. All the calculated indices were linear scaled at a range of 10 and averaged to get a single plant diversity index. Land use types were then ranked according to the calculated single plant diversity index.

Biomass estimation

We followed the methodology for biomass estimation suggested by FAO (1997) as described in Gnanavelrajah, Shrestha, Schmidt-Vogt, and Samarakoon (2008). The biomass of tree, shrub and herb layers of each land use type was estimated separately, using the data collected from nested-quadrat sampling in order to finally compute the total biomass per unit area.

Biomass was measured by summing up the biomass of all plants in a quadrat and eventually converting it to biomass per hectare. The biomass of the tree layer was estimated according to the method for estimating the biomass of palms described by FAO (1997). The biomass of the shrub layer in the perennial tree crop land uses was estimated by measuring the stem volume and multiplying this with the respective wood density values of each species. Since the contribution of foliage to shrub volume is considered negligible (Ponce-Hernandez, Koohafkan, & Antoin, 2004), foliage was not considered in the

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overall estimation of total biomass. The biomass of shrub crops was estimated using the average yield data for each crop obtained from the household survey as well as the harvest index values of respective crops obtained from secondary sources (Bhattacharyya & Bhattacharyya, 1992; Howeler, 1985; Kawashima, Sumamal, Pholsen, Chaithiang, & Boonpakdee, 2001). Herb biomass was estimated in all land use types by harvesting the aboveground biomass and measuring its oven dry weight. The belowground biomass of each quadrat was considered equivalent to 30% of the aboveground biomass as suggested for broad leaf vegetation by Ponce-Hernandez et al. (2004).

The total biomass was calculated by summing up the aboveground and belowground biomass for herb, shrub and tree layers. Land use-wise biomass was calculated by averaging the biomass of all quadrats surveyed in a particular land use type. Statistical tests such, as Analysis of Variance (ANOVA) and Duncan's Multiple Range Test (DMRT) were carried out using SPSS ver 10 software for land use type-specific biomass components and total biomass to examine the differences in biomass among different land use types. The relation between plant diversity and biomass was examined by using simple correlation analysis.

Soil erosion estimation

The universal soil loss equation (USLE) given by Wischmeier and Smith (1978) was used to model soil erosion. The equation estimates the mean annual soil erosion in tons/ha/yr by multiplying six factors of soil erosion, namely rainfall erosivity (R), soil erodibility (K), slope length (L), slope steepness (S), crop management (C) and erosion control practice (P). Due to the complexity of tropical farming systems, there is high uncertainty in USLE parameters particularly with respect to the C and P factors which can vary considerably between different cropping systems thus impacting the computed results on soil erosion. In Thailand, the Land Development Department has recommended modification of USLE parameters including C and P values for the various cropping systems of Thailand. Accordingly, each parameter was computed using the method appropriate for local conditions encoded in GIS thematic layers of rainfall, soil, slope, and land use for computing the average annual soil erosion as described in Gnanavelrajah (2007). Soil erosion was thus computed at the level of each mapping unit, which is a unique cartographic unit resulting from the overlaying of the aforementioned thematic layers.

Results and discussion

Plant diversity in herb, shrub and tree layer of different land uses

The plant species collected as described in the sampling design section were identified with the help of a specialist from the Office of Plant Herbarium, Department of Natural Resources, Thailand. Altogether 44 species in herbaceous layer, 22 species in shrub layer and 20 species in tree layer were identified in all land use types of the study area (Appendix 1).

The most common vegetation layer was the herbaceous layer which was found in almost all land use types. Table 1 presents the Shannon index, Simpson index, and Species richness of the three layers in the 11 land use types. The highest species richness of 22 was recorded in the herbaceous layer of the para rubber land use type followed by 21 in orchards. Eucalyptus and paddy had the lowest species count of 9 each. The computed index shows that orchard land use had the highest Shannon index of 2.76, and paddy had 1.69, the lowest. The computed Simpson index was found highest (0.91) in the sugarcane–cassava land use type followed by orchard (0.91) whereas land use under paddy scored the lowest (0.66). This suggests that the orchard land use type, which is mostly a mixed species orchard, has comparatively greater diversity in the herbaceous layer than other land use types.

Eucalyptus and paddy did not have any species in the shrub layer, whereas pineapple and sugarcane, being shrub-based monocultures, had only one species each. Hence, Shannon or Simpson indices were not calculated. The orchard shrub layer

Table 1
Shannon, Simpson and Species richness indices in different land use.

Land use	Herbaceous layer			Shrub layer			Tree layer			Plant diversity index[a]	Rank
	Shannon index	Simpson index	Species richness (No.)	Shannon index	Simpson index	Species richness (No.)	Shannon index	Simpson index	Species richness (No.)		
Pineapple	2.50	0.85	16	–	–	1	–	–	0	2.48	8
Para rubber	2.52	0.78	22	1.02	0.69	4	–	–	1	4.79	3
Cassava	2.48	0.89	15	0.03	0.01	2	–	–	0	2.65	7
Orchard	2.76	0.89	21	2.46	0.85	17	2.37	0.087	17	9.92	1
Coconut	2.48	0.78	15	1.31	0.69	7	0.07	0.02	3	4.97	2
Eucalyptus	2.00	0.77	9	–	–	0	–	–	1	1.37	10
Sugarcane	2.44	0.88	12	–	–	1	–	–	0	2.60	9
Pine–Cass	2.51	0.87	16	0.65	0.62	2	–	–	0	3.55	5
Coco–Cass	2.39	0.85	17	0.04	0.48	2	–	–	1	3.00	6
Suga–Cass	2.60	0.91	15	0.62	–	1	–	–	0	3.76	4
Paddy	1.69	0.65	9	–	–	0	–	–	0	0.04	11

Note: indices are linear scale; Pine–Cass = Pineapple–Cassava, Coco–Cass = Coconut–Cassava, Suga–Cass = Sugarcane–Cassava.
[a] linear scale range of 0–10.

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scored the highest diversity with corresponding computed indices of 2.34, 0.85 and 17 for Shannon index, Simpson index, and species richness, respectively (Table 1). Plant diversity in the shrub layer of coconut with indices of 1.31, 0.69, and in the shrub layer of para rubber with indices of 1.02, 0.69, 4.0 scored second and third rank. In addition to spontaneous species, orchard and coconut had also useful and cultivated species in this layer. Very young para rubber fields had cultivated species, such as pineapple, in their shrub layer.

The majority of land use types, namely pineapple, cassava, sugarcane, sugarcane–cassava, pineapple–cassava and paddy did not have any tree species in the fields. Land use types coconut–cassava, eucalyptus and para rubber had only one tree species, coconut had three tree species, and orchard land use had a variety of tree species as shown by the higher species richness of 18, Shannon index of 2.37, and Simpson index of 0.87.

Species utility index

The species utility index was computed on the basis of farmers' opinion, however, no in-depth study was made on how these species are used. The species identified as useful by the farmers are presented in Appendix 1. Three out of 45 plant species, occurring in the herbaceous layer, were identified by farmers as useful species. In the shrub layer, on the other hand, 20 species were identified as useful out of a total of 22, and in the tree layer all 20 species were considered useful.

In Table 2, the highest utility index (61%) was computed for orchard land use and the lowest (9%) for eucalyptus. The land use types, coconut, coconut–cassava and sugarcane–cassava had utility indices of 29%, 24% and 23%, respectively. Coconut plots, in addition to coconut as the main crop, also contained other species, both cultivated and spontaneously growing. Land uses under coconut–cassava and sugarcane–cassava had more useful spontaneous species contributing to a higher utility index than other land uses.

Plant diversity in different land uses

Plant diversity in terms of number of different plant species was recorded for each land use and expressed as Shannon index, Simpson index, and Species richness. The comparison between land use types shows that orchard land use had the highest and paddy land use the lowest plant diversity (Table 1). The cropping pattern of orchard was mixed cropping with a variety of crops in all three layers, whereas the pattern of paddy land use was monocropping with intensive weed management, which accounted for its lower plant diversity. Weeds in paddy fields are controlled by herbicides and other chemicals; herbicides are not applied in orchards, only some insecticides. Aquatic plants, which may occur in paddy fields and which would increase plant diversity, were not considered in the study.

With respect to plant diversity, coconut and para rubber land uses ranked second and third place. Even though these are monocropping land uses, due to the fact that they are based on perennial crops, farmers do not manage against weeds as intensively as they do in land uses based on annual crops. This results in a higher number of spontaneous plant species. Mixed land uses, such as sugarcane–cassava and pineapple–cassava ranked fourth and fifth, respectively. These two land uses are monocrop rotations, and therefore have a higher diversity than monocrop land uses without rotations, such as cassava, pineapple or sugarcane. Coconut–cassava as an intercrop land use ranked sixth. In comparison to coconut monocrop, coconut–cassava intercrop was found to have less diversity because cassava as an annual crop requires complete tilling of the field which suppresses the growth of spontaneous vegetation.

Ranks seven, eight, and nine were occupied by land uses with monocropping of shrubs. The plant diversity of eucalyptus, even though it is a tree-based land use with low management intensity, was even lower than the plant diversity of these shrub monocrops. Similar findings of low plant species diversity in eucalyptus plantations when compared to plantations with native species have been reported by Sangha and Jalota (2005). This is probably due to allelopathic effects, i.e. the toxic influence of certain biochemicals of eucalyptus (Verma & Totey, 1999), and to reduction of soil moisture by transpiration of eucalyptus.

Table 2
Species utility index of land use under different crops.

Land use	Cropping system	Species utility index (%)
Pineapple	Annual monocrop	18
Para rubber	Perennial monocrop	21
Cassava	Annual monocrop	11
Orchard	Mixed crop	61
Coconut	Perennial monocrop	24
Eucalyptus	Perennial monocrop	9
Sugarcane	Monocrop	15
Pineapple–cassava	Monocrop–rotational	17
Coconut–cassava	Intercrop	31
Sugarcane–cassava	Monocrop–rotational	22
Paddy	Monocrop	11

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Biomass of land uses

Average total biomass (Table 3) was highest under para rubber land use (247.89 tons/ha) and lowest under paddy (12.87 tons/ha). The total biomass of mixed orchard was slightly lower (189.43 tons/ha) than that of para rubber. Significantly lower total biomass was recorded for land use types without a tree layer, such as pineapple, cassava, pineapple–cassava rotation, sugarcane, and sugarcane–cassava rotation. Among the land uses with tree crops, coconut, coconut–cassava and eucalyptus had less total biomass than mixed orchard and para rubber, mainly due to greater plant spacing and less intense management in coconut and eucalyptus plantations. Mixed orchard was highly variable depending on plant species, age, and management.

Shrub biomass was highest in sugarcane (28.59 tons/ha). All perennial land uses except coconut–cassava intercrop scored low in the shrub biomass group. Shrub-based land uses had a lower biomass than tree-based land uses. Among the shrub-based land uses, sugarcane and pineapple had a lower herb biomass than others because of intense weed management, close spacing, and close canopy of these plants. Land use under cassava, pineapple–cassava rotation, and coconut–cassava intercrop had higher herb biomass compared to other shrub land uses because of less intense management of cassava leading to high weed growth.

Land use under trees had higher herb biomass than land use under shrubs due to less competition and less intense weed management. Land uses under eucalyptus, coconut and coconut–cassava had less tree biomass than mixed orchard and para rubber due to lower biomass per individual plant, but also due to greater plant spacing. The biomass of sugarcane (37.79 tons/ha) in the study area is comparable to the value of 39.71 tons/ha reported by Rahman, Pal, and Alam (1992), but much lower than the biomass values 46.32–63.25 tons/ha reported for sugarcane by De Silva and De Costa (2004).

The rate of carbon sequestration varies according to tree species, soil type, regional climate, topography, land use change, and management practice (US EPA, 2006). No-till farming, for instance, sequesters more carbon than conventional tillage practice (West & Post, 2002). While there is a need for location-specific information on the rate of carbon sequestration by plant species and land use practices, it is reported that trees and other perennials in agroforestry systems are capable of retaining greater biomass, thus enhancing carbon sequestration (Scherr & Sthapit, 2009). The finding of this study that all tree-based land uses, including coconut–cassava intercrop, had higher biomass/ha than the shrub-based land uses indicates the importance of tree-based land uses for ecological functions, such as carbon sequestration.

Relationship between plant diversity and biomass

Considering all land uses and the biomass from all layers, this study found a significant positive correlation (Pearson correlation, $r = 0.646$, $r^2 = 0.418$) between average plant diversity and biomass in the observed land uses (Fig. 2). This is in line with the findings of Tilman, Knops, Wedin, Reich, Ritchie, and Siemann (1997) who reported that biomass increases with increasing plant diversity. However, this does not mean that the highest plant diversity is necessarily correlated with the highest biomass or vice versa as reported in studies by Hooper (1998), and Hooper and Vitousek (1998). In the category of shrub crop land uses, biomass increases with increasing plant diversity in the case of pineapple, cassava, pineapple–cassava and sugarcane–cassava. Sugarcane, on the other hand, which had the highest biomass of all shrub crop land uses, has a rather low plant diversity. Relations like this can be due to the fact that individual species differ from each other with respect to their relative efficiencies in converting resources into biomass depending on the degree of complementary and competitive interaction among species (Hooper, 1998).

Therefore, using species richness as a measure of biological diversity does not provide enough explanatory power, as ecosystem processes are affected by the functional characteristics of organisms involved rather than by their taxonomic identity. Moreover, the observation that increasing species diversity leads to increasing functional group diversity (Schmid, Joshi, & Schlapfer, 2001) in most natural ecosystems does not necessarily apply to agricultural systems. This may serve as an

Table 3
Biomass of land use under different crops.

Land use	Above ground			Below-ground biomass	Total biomass
	Tree biomass	Shrub biomass	Herb biomass		
	Tons/ha				
Pineapple	0	18.50b	0.85a	5.8a	25.17a
Para rubber	187.53c	1.39a	1.75c	57.20d	247.89d
Cassava	0	20.36b	1.86c	6.66a	28.89a
Orchard	141.76bc	1.31a	2.63d	43.71cd	189.43cd
Coconut	100.70ab	4.81a	1.51bc	32.10bc	139.17bc
Eucalyptus	60.14a	0	1.80c	18.58b	80.52bc
Sugarcane	0	28.59c	0.47a	8.72a	37.79a
Pineapple–cassava	0	22.71b	1.25b	7.19a	31.15a
Coconut–cassava	100.72ab	20.43b	1.20b	36.71bc	159.07bc
Sugarcane–cassava	0	21.36b	1.47bc	6.85a	29.69a
Paddy	0	9.13a	0.77a	2.97a	12.87a

Means with similar letters along the columns are not statistically different according to Duncan Multiple Range Test.

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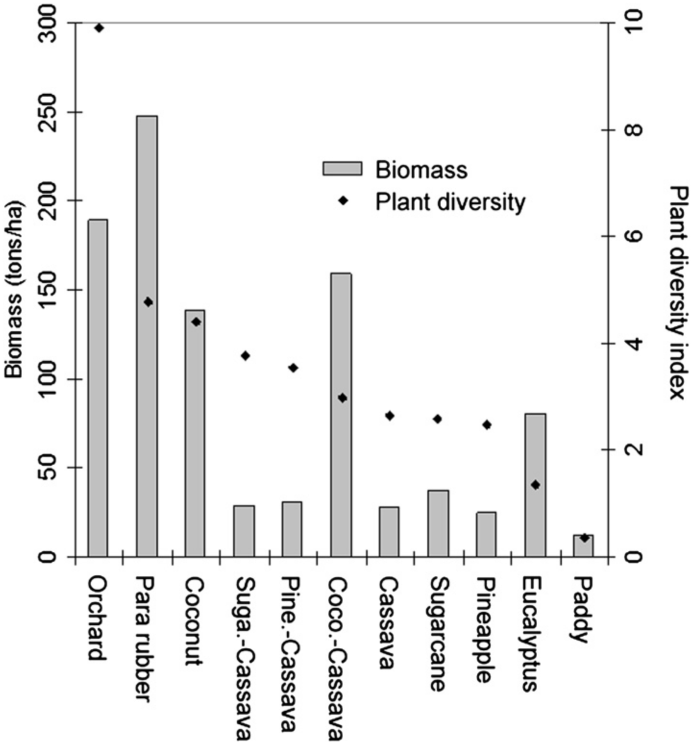

Fig. 2. Land use-wise plant diversity and biomass.

explanation for cases mentioned in this study, when land uses with low plant diversity yield more biomass than land uses with higher plant diversity, such as in the case of sugarcane, which has a higher biomass than all other shrub crop land uses, but which is characterized by low plant diversity that is higher only than that of paddy. High biomass, in the case of sugarcane, is probably due to the fact that it is a C_4 plant, which uses a more efficient method of carbon dioxide uptake, by which a 4-carbon molecule instead of the two 3-carbon molecules as in C_3 plants is formed. High plant diversity of other shrub crop land uses does not imply an increase in number of C_4 plants, and thus does not necessarily lead to an increase in biomass. Similarly, while coconut had higher plant diversity than coconut–cassava, coconut–cassava had a higher biomass than coconut, because the biomass production of cassava is higher than that of the spontaneous shrub species under coconut.

When it comes to the choice of commercial upland crops like cassava, sugarcane and pineapple, agricultural policy can play a more important role than demand and supply. Another important factor is land tenure (Gnanavelrajah, 2007). Paddy is economically less attractive compared to other crops in the study area and in Thailand, and is grown in areas where cultivation of upland crops is constrained by high soil moisture.

Soil erosion in different land uses

Potential soil erosion was assessed for each of the different land uses. 84% of the study area has a potential erosion rate of 2 tons/ha/yr or below. A potential soil erosion rate of 2–4 and 4–12 tons/ha/yr was found in 6 and 7% of the total area, respectively. The flat to undulating terrain of the study area is not conducive to soil erosion, and the annual crop fields are under good agricultural management practices in the study area. Only 3% of the study area was found to have an erosion rate exceeding the maximum permissible limit of 12 tons/ha/yr. In Thailand, soil erosion of less than 12 tons/ha/yr is generally not considered a very serious problem. Soil erosion higher than the permissible limit was observed in land uses with upland crops (sugarcane, cassava), and plantation crops (eucalyptus, young para rubber) where ground cover during the early vegetation period is sparse.

Relationship between plant diversity and soil erosion

Soil erosion, though computed at the mapping unit of spatial scale, was aggregated at the land use level to examine the relationship between plant diversity and soil erosion. In general, the correlation between average soil erosion of land uses and their respective plant diversity was found to be negative as well as non-significant (Fig. 3). As soil erosion is a function of rainfall, soil, topography, vegetation type and land management practices, it was difficult to get a clear and unambiguous correlation in this study. However, a comparison of individual land uses yielded some interesting information.

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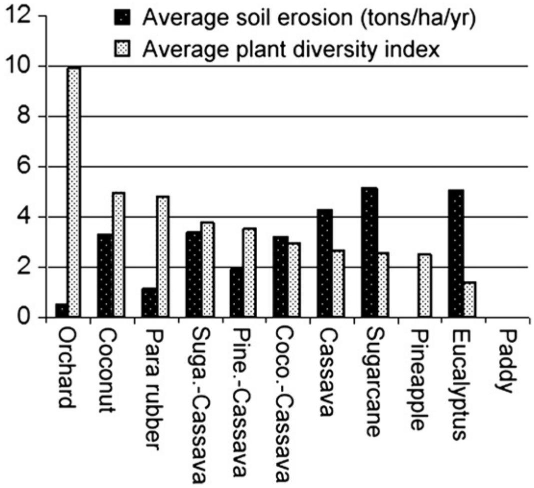

Fig. 3. Land use-wise plant diversity and soil erosion.

Higher average potential soil erosion was observed under sugarcane and eucalyptus, which are land uses characterized by low plant diversity. Low soil erosion was observed in some land uses with higher plant diversity, for example mixed orchard, but not in others, as for instance, coconut, which has a relatively high plant diversity but also high soil erosion. This may be due to the coconut canopy not providing sufficient protection against soil erosion. The lower average erosion under para rubber and pineapple can be attributed to the dense canopy structure, which more effectively reduces rainfall erosivity. In the case of paddy, the lowest level of plant diversity was associated with the lowest average soil erosion rate. This can be explained by the fact that paddy cultivation in the study area is practiced on flat terrain, which naturally is less prone to soil erosion.

Ground cover, canopy and mulch influence soil erosion substantially. It would have been interesting to examine the relation between soil erosion and vegetation biomass, but the present study did unfortunately not provide the scope for such an examination.

Conclusions

This study in a landscape largely devoted to agriculture was carried out in an attempt to record plant diversity of different agricultural land use types, and to understand its relationship with biomass and erosion, both of which connect to broader issues of carbon sequestration and land conservation. In a cultivated landscape characterized by diversity of land uses as is the case in the study area, different land use practices influence plant species diversity differently. The study found that land use under orchard had the highest, and land use under paddy had the lowest plant diversity. Monocropping of shrubs, such as cassava, pineapple and sugarcane had lower plant diversities than monocropping of trees with the exception of eucalyptus. Rotational monocropping, such as pineapple–cassava and sugarcane–cassava, or intercropping, such as coconut–cassava, had a higher plant diversity than monocropping shrubs. These findings are in agreement with other observations on monocropping of shrubs reducing biodiversity (Brookfield, 2001; Thrupp, 1998). Tree monocrops, on the other hand, had a higher plant diversity than shrub crop rotations or tree–shrub intercrops. In terms of the relationship of plant diversity with biomass and soil erosion, a significant positive correlation was observed between biomass and plant diversity of the respective land uses. However, when comparing land uses individually, higher biomass of land uses was not always found to correspond directly with higher plant diversity and vice versa. Other factors, such as the metabolism of dominant plant species, and the ecological relations between plant species may in some cases have a stronger effect on biomass than the plant species richness of land uses. This highlights the limitations of species richness as a measure of plant diversity and the need for supplementary methodology in studies devoted to exploring the linkages between plant diversity and other characteristics of a plant cover. Soil erosion was found to be negatively correlated with plant diversity. The evidence for this, however, was not strong due to the correlation being non-significant. In-depth studies with field measurements would help to better examine the relation between plant diversity and erosion.

It can be concluded from the findings of this study that the trend towards monocropping of shrubs, which can be expected to accelerate in Thailand due to the prioritization of export crops and, more recently, biofuels, will lead to a further reduction in plant diversity on a landscape level. The effects of this trend on carbon sequestration and soil erosion are either uncertain or must be viewed in a differentiated manner as in the case of sugarcane. Land uses with a tree layer were found superior to other land uses in terms of both plant diversity and biomass. This is true even for monospecific tree plantations and includes the much-maligned rubber plantations. From our findings, we therefore argue for conservation or promotion of land uses based on or including the management of a tree layer. A further argument for land use based on perennials is the satisfaction

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of farmers expressed by the utility index. Choice of land use should be determined by the capacity of land uses to fulfill more than only one function over a long time perspective. Multifunctionality on a landscape scale is, however, best maintained by retaining or enhancing the diversity of land uses which is so characteristic of *Khlong Yai* watershed.

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Appendix 1. Species in herbaceous, shrub and tree layer identified in different land uses.

Species name	Pineapple	Cassava	Para rubber	Orchard	Coconut	Eucalyptus	Sugarcane	Pine.–cassava	Suga.–cassava	Coco.–cassava	Paddy
Herbaceous layer											
Acalypha indica									x	x	
Achyranthes aspera				x					x		
Ageratum conyzoides	x	x	x	x	**x**	x	x	x		x	
Abutilon indicum			x		x					x	
Alternanthera sessilis		x	x								
Amaranthus viridis	x	x		x	x		x	x		x	
Aeschynomene aspera						x				x	
Azadirachta indica				x							
Brachiaria reptans				x							
Catharanthus roseus	x										
Coccinia grandis	x								x	x	
Chloris barbata		x	x	x	x	x	x		x	x	x
Cleome viscosa		x									
Crotalaria striata							x		x		
Cynodon dactylon	x		x	x	x	x		x		x	
Cyperus difformis			x								
Cyperus pulcherrimus			x								
Dactyloctenium aegyptium										x	
Digitaria ascendens	x		x					x	x		
Echinochloa colonum									x		
Echinochloa crus-galli			x	x							x
Eleusine indica				x		x		x			
Eupatorium odoratum	x	x	x	x	x	x	x	x	x	x	
Eupatorium sp.			x					x			
Euphorbia hirta	x	x	x				x				
Euphorbia geniculatum		x									
Gomphrena celosioides	x	x	x	x	x		x	x	x	x	
Hymenachne pseudointerrupta											x
Ipomoea aquatica											x
Ipomoea gracilis	x										
Leptochloa chinensis							x	x			x
Mimosa pudica		x	x	x	x		x	x		x	x
Oryza sativa											x
Panicum repens			x			x					
Physalis angulata	x	x					x	x			
Phaseolus lathyroides	x		x	x	x		x			x	
Phyllanthus niruri	x	x	x	x	x				x	x	x
Pueraria phaseoloides	x	x		x				x	x		x
Rhynchelytrum repens				x	x			x			
Ruellia tuberosa			x	x	x				x		
Setaria geniculata	x	x	x	x	x	x	x	x	x	x	
Tridax procumbens	x		x	x	x	x		x		x	
Trianthema protulacastrum				x					x		
Veronica cinerea		x	x		x			x	x	x	
Shrub layer											
Ananas comosus	x							x			
Azadirachta indica			x								
Callotropis sp.				x	x						
Calamus sp					x						
Capsicum annuum				x							
Catharanthus roseus					x						

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Citrus aurantifolia			x	x					
Citrullus lanatus			x						
Lantana camera	x		x	x					
Leucaena leucocephala		x	x	x					x
Luffa cylindrica			x						
Lycopersicon esculentum			x						
Manihot esculenta	x		x				x	x	x
Musa paradisiaca			x						
Psophocarpus tetragonolobus			x						
Saccharum officinarum			x			x		x	
Solanum melongena			x						
Solanum nigrum									
Tectona grandis		x							
Vigna sinensis			x						
Zingiber officinale			x	x					
Ziziphus jujuba		x							
Tree layer									
Arecanut sp			x						
Averrhoa carambola			x						
Azadirachta indica			x	x					
Artocarpus heterophyllus			x						
Bouea macrophylla			x						
Carica Papaya			x						
Cocos nucifera			x	x					x
Dimocarpus longana			x						
Durio zibethinus			x						
Eucalyptus camaldulensis					x				
Eugenia jambosa			x						
Hevea brasiliensis		x							
Garcinia mangostana			x						
Mangifera indica			x						
Manilkara zapota			x						
Moringa oleifera			x						
Nephelium lappaceum			x						
Psidium guajava									
Tamarindus indica			x						
Tectona grandis			x						

Note: Species name in bold letters are those identified as useful by farmers, x = presence; Pine. = Pineapple, Suga. = Sugarcane, Coco. = Coconut.

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