Vegetation conditions and soil fertility of fallow lands under intensified shifting cultivation systems in Sarawak, Malaysia

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ABSTRACT **This study was conducted in order to evaluate the vegetation conditions and soil fertility status of fallow lands under intensive shifting cultivation systems in the Engkari river area in Sarawak, Malaysia. The shifting cultivation by the several Iban communities selected at Engkari area for upland rice farming were currently being conducted with 2 to 7 years of continuous cropping followed by 1 to 6 years of fallow with application of chemical fertilizers and agrochemicals. Since agricultural management methods and land productivity under the current shifting cultivation systems conducted by the Iban farmer were our concerns, we carried out vegetation and soil surveys on fallow lands of which suitability for rice cropping using shifting cultivation had been classified by Iban landowners from their knowledge of vegetation conditions; 20 suitable and 20 unsuitable sites were analyzed. The results of our vegetation survey showed no substantial differences between suitable and unsuitable sites in the species composition and the sizes of tree species, as measured by the stem diameter at breast height (DBH). The plant density of grass and fern groups tended to be higher in most of the sites even after extensive fallow duration. As compared to our previous studies, the DBH of the trees in most of the Engkari area study sites was small even after extensive fallow duration. The soil properties in the study sites could be characterized by a strongly acidic nature with low levels of exchangeable bases. No substantial differences were found in the soil properties in terms of site suitability and fallow duration. Our results suggest that the rationality of farmers' traditional knowledge related to vegetation-based site selection is no longer applicable under intensive shifting cultivation practices in the Engkari area. Considering the high acidity and poor nutrient contents of the soils, as well as poor aboveground biomass added to soil as ash during burning, certain measures will be necessary for the farmers in the Engkari area to continue rice cropping through the intensive shifting cultivation system. These include effective types of fertilizer and appropriate application methods as well as countermeasures to soil erosion in order to prevent the loss of fertilizer nutrients from soil ecosystems.**

Key words: shifting cultivation, short fallow, vegetation conditions, soil fertility, Iban, Sarawak

INTRODUCTION

Shifting cultivation has been practiced for many decades as one of the most important traditional farming systems in Southeast Asia. Traditional shifting cultivation by indigenous farmers integrates a relatively short cropping phase and a relatively long forest fallow phase as a rotational system in space and time (Klienman at et. 1995). In the interior upland areas of Borneo, various tribes have practiced shifting cultivation as a major source of livelihood. The Iban, the largest ethnic group in Sarawak, traditionally lives in longhouse communities located along the main rivers and small streams of the forest interior and conducts subsistence shifting cultivation, with upland rice as their main crop (Freeman, 1955, 1970; Padoch, 1982). Recently, the shifting cultivation practices of the Iban have tended more towards intensive land use systems consisting of a longer cropping period and a shorter fallow period, with the application of chemical fertilizers and agrochemicals in response to alternation of socio-economic conditions (Kendawang et al. 2005a; Ichikawa, 2004, 2007). In view of the current situation, conventional cash crop farming has become indispensable to meet their necessities for cash income, while rice farming is still important to produce rice for self-consumption (Cramb, 1993; Mertz et al. 1999).

There have been many anthropologic and socioeconomic studies regarding the Iban's shifting cultivation practices (Freeman, 1955, 1970; Padoch, 1982) and the transitional nature of the shifting cultivation practice (Cramb, 1993; Hansen & Mertz, 2006). In an effort to elucidate the influences of shifting cultivation on forest and soil ecosystems in Sarawak, various studies have been conducted to clarify the effects of burning and rice cropping on soil ecosystems (Andriesse & Koopmans, 1984; Tanaka et al. 2004, 2005) as well as changes in soil properties along with fallow duration (Bruun et al. 2006; Tanaka et al. 2007a,b, 2009). Many studies have also investigated the changes in vegetation conditions, such as species composition after shifting cultivation (Okimori & Matius, 2000; Kiyono & Hastaniah, 2005; Kendawang et al. 2007) and forest fire in natural or old secondary forests (Halenda, 1989; Hashimoto et al. 2000). However, most of these ecological studies were concerned with the influences of traditional types of shifting cultivation with a short cropping and a long fallow period, on ecosystems. Moreover, limited scientific information was available on the influence of intensive shifting cultivation systems on the ecosystem especially on the vegetation recovery and soil fertility status of the fallow lands. Ishizuka et al. (2000) investigated soil fertility status in lands degraded by shifting cultivation, while Tanaka et al. (2009) described the soil fertility of fallow lands under the intensive type of shifting cultivation conducted by the Iban, as compared to cash crop farming. In addition, few studies have reported on the effect of intensive agricultural practices on the vegetation succession of abandoned agricultural lands (Ohtsuka, 1999).

Living closely with the surrounding forests, the Iban have accumulated profound knowledge about cropping and forest management. In her ethnographical study, Padoch (1982) reported that the Iban examined vegetation conditions such as species composition and the extent of secondary forest regrowth when selecting sites for rice cropping by shifting cultivation. Such knowledge for site selection also seemed to be common among many other tribes in Borneo: the Benuaq by Sardjono & Sansoedin (2001) and Gönner (2002); the Kantu' by Dove (1981); and the Kenyah by Chin (1985), Inoue (1990), and Sindju (2003).

At the Mujong River in Sarawak, where shifting cultivation was conducted with a single cropping of rice followed by a fallow duration of around 10 years with a low rate of fertilizer application rate, we investigated the Iban's knowledge of site selection in relation to ecological conditions, including vegetation and soil fertility (Tanaka et al. 2007a, b). Our findings revealed that farmers' traditional knowledge for site selection was reasonable in supplying nutrients to rice plants in traditional shifting cultivation practices without fertilizer application.

The objective of the present study was to evaluate the influence of the current form of shifting cultivation systems at the Engkari river area in Sarawak, Malaysia on the vegetation condition and soil fertility status of fallow lands. Since agricultural management methods and land productivity under the present form of shifting cultivation conducted by the Iban farmers were our concerns, we applied the Iban site selection method based on their observation of vegetation conditions into our study approach to pre-classify study sites before the field survey. Due to the similar topography and geological conditions in the present study and our previous study (Mujong River), the basic assumption in this study is that the soil fertility and vegetation conditions are different in terms of site suitability.

MATERIALS AND METHODS

Study area

The field survey was conducted in the Engkari area from July 2005 to March 2006 (Fig. 1). The Engkari River is a tributary of the Ai' River in the Sri Aman district. Reports on the history of migration and settlement of the Iban at Engkari revealed that they had settled in the area since the 16th century (Padoch, 1984). With the completion of the Batang Ai' hydroelectric dam at the Ai' River watershed (Windle, 2002), the reservoir rendered the town center (Lubok Antu) accessible to members traveling by boat from Iban settlements located along the upper reaches of the reservoir.

Most of the landscape in Engkari is hilly with a slope gradient ranging from 20° to 30°. Primary forests, especially located along riversides, are completely lacking. The mean annual precipitation during 1996 to 2005 was 3276 mm (Department of Irrigation and Drainage, 2006). The mean annual temperature from 1996 to 2005 was 26.5°C (Meteorological Department, 2006). Soils originated from non-calcareous sedimentary

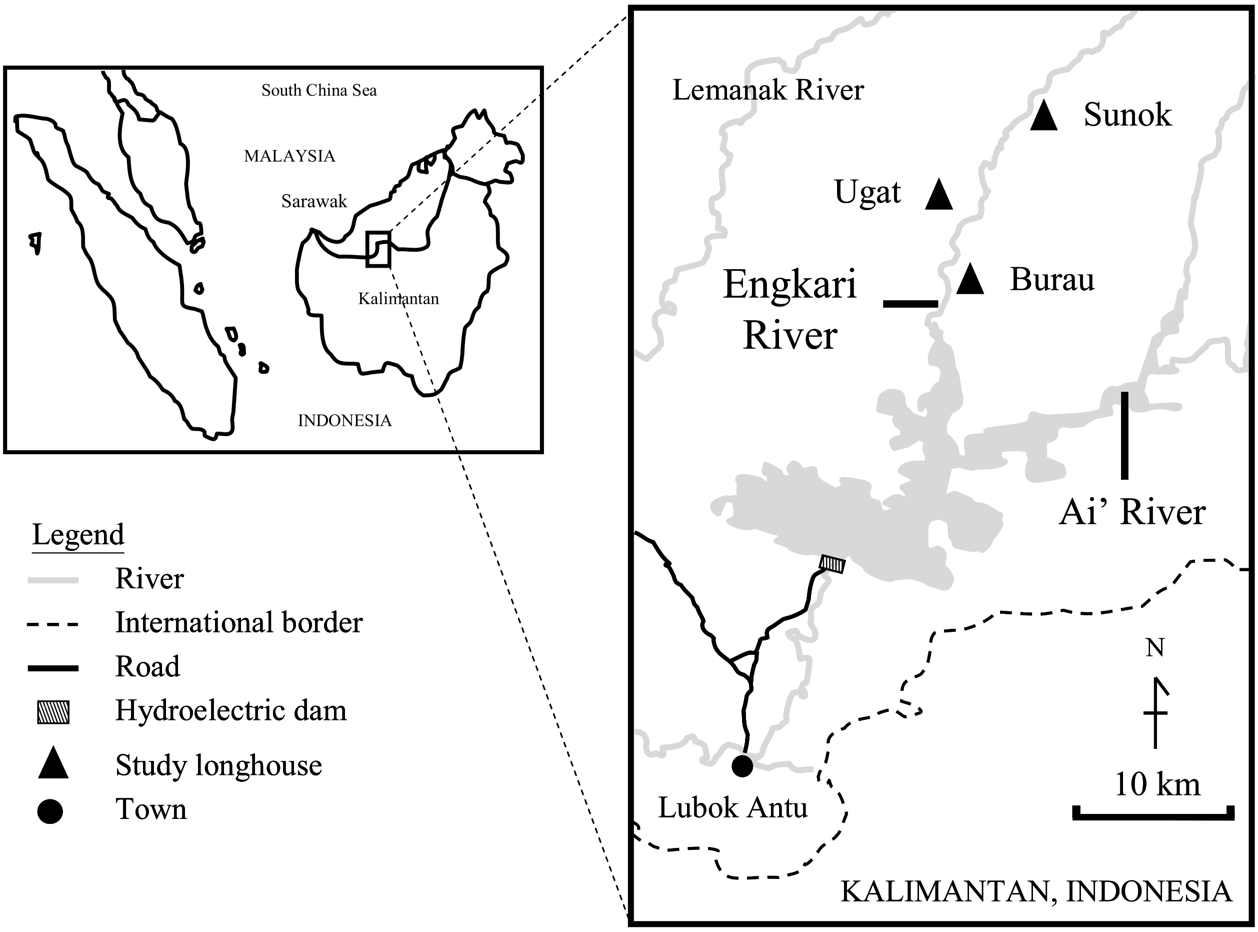

Fig. 1 Map of the study area.

rocks, predominantly shale, and were classified into the Merit family of the Red Yellow Podzolic Soil group based on the Sarawak soil classification system (Scott, 1963), which corresponds to Paleudults or Dystropepts under the Soil Taxonomy of the USDA system (Soil Survey Staff, 2006).

For this study, three Iban longhouse communities in Engkari were selected: Burau (01°15'12"N, 111°56'33"E), Sunok (01°18'68"N, 111°56'66"E), and Ugat (01°17'46"N, 111°56'28"E). The longhouses were located along the riverbanks of the Engkari River and have existed for more than 300 years. At the time of the survey, the longhouses were composed of 37 to 52 households with populations of about 230 to 380 persons. All families performed upland rice farming by shifting cultivation on slope lands. In contrast to the case of the Mujong (Tanaka et al. 2007), upland rice in Engkari was cultivated for 2 to 7 years continuously on the same land. After the extensive cropping period, the land would be fallowed for 1 to 6 years prior to the next clearing and burning. According to farmers' estimations, the size of the area for upland rice farming was about 2 hectares; about 1000 kg (20 bags of 50 kg) of brown rice could be produced in a normal farming year. Although the application rate of chemical fertilizers for rice cropping varied among each household, depending on their economic condition, urea was a common fertilizer and used at the rate of about 100 kg ha^{-1} (2 bags of 50 kg commercially available fertilizer) on average. Some farmers also applied NPK compound fertilizers, less frequently and at reduced amounts. Agrochemicals such as herbicides were commonly applied for land preparation as well as for upland rice farming. In addition to upland rice farming for self-subsistence, the farmers also cultivated pepper and rubber as main sources of cash income. According to our field observations, most of the fields for upland rice farming tended to be located in close proximity to the fields for cash crop farming. These farmlands tended to be located close to longhouses or riverbanks so that the accessibility to these fields could be made easy by using boat as well as on foot, and time and labor required could be saved.

Data collection and analysis

From May to July, 2005, all of the study sites surveyed were established on the fallow lands developed after rice cropping cycles in a shifting cultivation scheme. These sites belonged to 17 Iban landowners who were selected randomly among the longhouse communities. Before the field survey, we interviewed the landowners to obtain fundamental information about agricultural practices, including farming histories of their fallow lands. Then, the landowners brought us to some of the lands to be surveyed. We asked them to classify the lands as suitable or unsuitable for upland rice farming by using their traditional knowledge about the vegetation conditions for site selection. The ages of fallow lands were determined based on the owners' recalling. Finally, we obtained 20 suitable and 20 unsuitable lands as our study sites.

Vegetation and soil surveys were carried out in a quadrat of 10×10 m^2 or 20×20 m^2 in each study site. For the vegetation survey, the local name, density and stem diameter at breast height (DBH) of all woody plants were recorded based on the Iban's nomenclature system. The names and density of other smaller plants (grasses, ferns, tree seedlings, etc.) were recorded at three sub-quadrats (2×2 m^2) established within the main quadrat. Plant specimens were collected and identified with their scientific names at the Forest Research Centre, Sarawak Forestry Corporation. According to the Iban plant classification system, the Iban classify plants principally based on morphology, cultivation status and uses (Tun Jugah Foundation, 2001). Although this system shows a high degree of coincidence with the scientific classification system at a genus or family level, the relationship is not necessarily a one-to-one correspondence, especially at the species level. Considering this fact and the responses of the landowners, the plants observed during the survey were categorized into 11 plant groups: bamboos, ferns, gingers, grasses (including herbs except for ginger), vines (including woody and non-woody vines), palms, rattans, shrubs, trees, wild bananas, and unknowns. The unknown group consisted of the plants that were not identified by the farmers.

At each depth of 0–10 cm and 30–40 cm from three points located randomly within the quadrat, about 500 g of soil samples were collected from each point. The soil samples obtained were mixed well to yield one composite sample. The samples were air-dried and passed through a 2 mm mesh sieve for physicochemical analyses. Core samples (100 mL) were collected from the same depths in triplicate for determination of bulk density.

The analytical methods for soil analysis are as follows; soil pH was determined in water or 1 M KCl in a soil to solution ratio of 1:5 using glass electrodes. Total C and N contents (T–C and T–N) were analyzed using an NC analyzer (Sumigraph NC-80; Sumika Chemical Analysis Co., Osaka, Japan). The contents of exchangeable bases (Ca, Mg, K, and Na) and the cation exchange capacity (CEC) were measured after successive extraction using 1 M ammonium acetate adjusted to pH 7.0 and 10% NaCl, respectively. The amount of NH_4 replaced by Na was determined for CEC using the steam distillation and titration method. The contents of exchangeable bases were determined by atomic absorption spectrophotometry for Ca, Mg, and K, and by flame photometry for Na (AA-6800; Shimadzu Corp., Kyoto, Japan). Exchangeable Al, H, and NH_4 were extracted with 1 M KCl. Exchange acidity (Al + H) was determined by titration with 0.01 M NaOH, and the content of exchangeable Al was determined with 0.01 M HCl. The content of exchangeable H was calculated as the difference between the values of the exchange acidity and exchangeable Al. The content of exchangeable NH_4 was measured using the indophenole blue method (Mulvaney, 1996). Available phosphorus was quantified by the Bray II method (Kuo, 1996). Particle size distribution was determined using the pipette method. Clay mineral composition was identified by X-ray diffraction analysis using CuKα radiation (Shimadzu, XD-D1w). Soil hardness was examined at depths of 0–10 and 30–40 cm using a Yamanaka-type push cone penetrometer.

RESULTS AND DISCUSSION

Vegetation condition of fallow lands

At the 40 study sites, 215 plant species were recorded, including 174 and 146 species at suitable and unsuitable sites, respectively (Table 1). Tree species accounted for 50% of the 215 species observed. Climax species such as Dipterocarpaceae (such as *Shorea macrphylla*, *Shorea scabrida*, *Shorea smithiana*) were rarely recorded. Plants of the vine, grass and fern groups were also commonly recorded in the study sites. Although the total species number of the tree group in suitable sites was higher than that at the unsuitable sites, most of the species of the tree group were rarely recorded. For the vine, fern and grass groups, no substantial differences in the total number of species were found between the suitable and unsuitable sites. In terms of the fallow duration (0 - 20 years) of the study sites, no clear tendency was observed with regard to species number for tree, vine, fern or grass

Table 1. Number of plant species observed during field survey.

Plant group	Number of plant species		
	Whole survey (*n* = 40)	Suitable sites (*n* = 20)	Unsuitable sites (*n* = 20)
Bamboos	2	1	2
Ferns	13	13	10
Gingers	9	8	4
Grasses	21	18	19
Vines	43	31	28
Palms	4	4	2
Rattans	5	4	3
Shrubs	6	6	4
Trees	105	82	68
Wild Bananas	1	1	1
Unknowns	6	5	4
SUM	215	174	146

Vine group includes woody and non-woody vines.

groups (data not shown).

Several plant species were observed with higher frequencies. Table 2 presents the list of plant species recorded at more than 8 sites out of the 40 sites surveyed (i.e., 20% of the study sites). According to the generic names of the plant species listed in Table 2, some of the species were pioneer and high-light demanding species that commonly existed in the abandoned fields after shifting cultivation, i.e. *Artocarpus*, *Vitex, Dillenia*, *Macaranga, Coelorachis* and *Melastoma* (Ipor & Tawan, 2004; Kiyono & Hastaniah, 2000; Davies & Semui, 2006). In addition, several plant species (*Bedega' (Pteridium caudatum)*, *Kemiding (Stenochlaena palustris)*, *Lalang (Imperata cylindrica)*, *Kemunting (Melastoma polyanthum)*) were perceived by the Iban as plant indicators of infertile soils (Wasli et al. 2006; Tanaka et al. 2007a). In case of the present study in Engkari, some landowners mentioned that *Lalang* (*Imperata cylindrica*), *Resam* (*Dicranopteris linearis*) and *Kemunting* (*Melastoma malabathricum*) were the indicators for infertile lands. Several studies have reported on the characteristics of

Table 2. List of the common plant species observed during field survey.

Plant group	Local name	Family	Scientific name	Plants occurring at more than 8 sites out of 40 sites (i.e., 20% of the study sites)		
				Total	Suitable sites	Unsuitable sites
Fern	*Bedega'*	Pteridaceae	*Pteridium caudatum*	15	6	9
Fern	*Kelindang*	Blechnaceae	*Blechnum orientale*	19	10	9
Fern	*Kemiding*	Blechnaceae	*Stenochlaena palustris*	27	13	14
Fern	*Paku helang*	Hymenophyllaceae	*Selenodesmium obscurcum*	9	4	5
Fern	*Paku kubok*	Aspidiaceae	*Cyclopettis presliana*	17	10	7
Fern	*Resam*	Gleicheniaceae	*Dicranopteris linearis*	10	6	4
Ginger	*Pukpulok*	Zingiberaceae	*Costus speciosus*	8	6	2
Ginger	*Senggang*	Zingiberaceae	*Hornstedtia reticulata*	8	3	5
Grass	*Encherkup*	Gramineae	*Coelorachis* sp.	11	7	4
Grass	*Kejuru*	Cyperaceae	*Soleria pupurescens*	25	15	10
Grass	*Lalang*	Gramineae	*Imperata cylindrica*	8	5	3
Shrub	*Kemunting*	Melastomataceae	*Melastoma malabathricum*	20	9	11
Shrub	*Lemba*	Hypoxidaceae	*Curculigo latifolia*	18	6	12
Shrub	*Mambong*	Compositae	*Blumea balsamifera*	9	4	5
Tree	*Buan*	Dilleniaceae	*Dillenia suffruticosa*	8	5	3
Tree	*Entali*	Euphorbiaceae	*Macaranga costulata*	8	5	3
Tree	*Kepapa*	Verbenaceae	*Vitex longipes*	13	7	6
Tree	*Lengkan*	Moraceae	*Ficus grossulariodes*	8	4	4
Tree	*Pulo*	Melastomataceae	*Pternandra* sp.	15	8	7
Tree	*Tekalong*	Moraceae	*Artocarpus elasticus*	8	6	2
Vine	*Merejemu*	Scrophulariaceae	*Brookea dasyantha*	12	4	8

Vine group includes woody and non-woody vines.

these species in conjunction with degraded lands: *I. cylindrica* commonly inhabits open-canopy sites on low-fertility soil, dominates land after shifting cultivation and forest fires, and prevents the regrowth of the woody vegetation because of its fibrous root systems (Menz et al. 1998). *D. linearis* is a sun-demanding fern and can be a pioneer species in primary succession of lands affected by landslides, road-cuts, farming activities, tree plantation and forest degradation (Cohen et al. 1995). *M. malabathricum* grows on acidic soils with very low nutrients and does not dominate at the early succession stage of lands with fertile soils (Davies & Semui, 2006).

Tanaka et al. (2007a) reported that in the sites classified by the Iban farmers as suitable lands for farming, the plant density of the grass group and, to a lesser extent, the fern group was lower at the early stage of the fallow period. At the later stages, the average density of the tree group tended to be higher. In the present study, the plant densities of the tree, grass and fern groups showed no clear tendencies in terms of fallow duration or site suitability (Fig. 2). However, the plant densities of *I. cylindrica*, *D. linearis* and *M. malabathricum* tended to be high among whole vegetation in both the suitable and unsuitable sites, especially at the early stages of fallow duration (data not shown). Plants in the fern and grass groups tended to dominate among vegetation even after 5 years of fallow. According to Kiyono & Hastaniah (2005), the repetition of the slash and burn agriculture would cause less existence of tree species and decrease the abundance of vulnerable species in fallow lands.

In terms of DBH, Tanaka et al. (2007a) reported that average DBH of the trees in the suitable sites was significantly larger than that of trees in the unsuitable sites. The average DBH values of trees in the suitable sites were around 8 cm and more than 10 cm after 5 and 10 years of fallow duration, respectively. In the unsuitable sites, the average DBH values of trees were less than 5 cm even after 10 years. However, in the present study, the DBH values of the trees at both the suitable and unsuitable sites, except for some of the suitable sites, were similar to each other in terms of fallow duration (Fig. 3). These values were almost equivalent to those measured in unsuitable sites by Tanaka et al. (2007a). Remarkably, the DBH for trees in some of the suitable sites reached the levels reported in their study.

Soil fertility status of fallow lands

The average values of soil physicochemical properties are given in Table 3. No substantial differences between the suitable and unsuitable sites were found for average soil properties. The soils could be characterized by a strongly acidic nature with pH(H_2O) values around 4.5 at both surface and subsurface layers and a relatively clayey texture. The clay mineral composition was dominated by kaolin minerals, followed by quartz, chlorite, illite and gibbsite and, to a lesser extent, goethite and hydroxyl-interlayered vermiculite. The contents of exchangeable bases were low compared with that of exchangeable Al, resulting in a very high level of Al saturation. The contents of available P in the surface soil varied widely from 2 to 113 mg kg^{-1}, but most of the sites showed low levels of available P. Only two unsuitable sites possessed extremely high levels of available P (86 and 113 mg kg^{-1}), probably because some portion of P added as ash or fertilizer was unused by plants and remained. Other possible reason could be that these soil samples may have been collected from the spot where large amounts of biomass had been burnt or chemical fertilizer had been applied.

As compared with previous studies on secondary

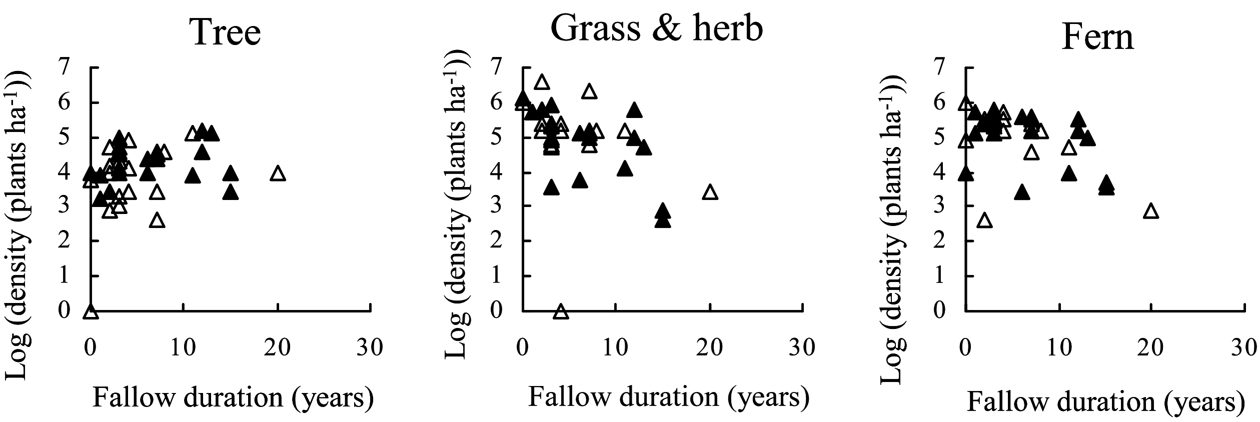

Fig. 2. Relationship between plant density and fallow duration of the study sites: closed triangles, suitable sites; open triangles, unsuitable sites. Density is transformed to log (density (plants ha^{-1})).

forests under shifting cultivation systems (Andriesse & Koopmans, 1984; Tanaka et al. 2007b) and selectively logged secondary forests (Tanaka et al. 2004, 2005) in Sarawak, the soil fertility in the present study was low with higher soil acidity and lower contents of exchangeable bases despite similar levels of soil organic matter and soil texture. Tanaka et al. (2009) investigated soil fertility of fallow lands in the Lubok Antu area close to the Engkari where Iban farmers conducted shifting cultivation with 1 to 3 years of continuous cropping and around 5 years of fallow period. The soils in their study were also strongly acidic (pH of around 4.1) and low in nutrient content.

Figure 4 shows the levels of pH (H_2O), exchangeable Ca and K, and Al saturation along with fallow duration. During the early stages of fallow periods, irrespective of soil suitability, some of the study sites revealed relatively less acidity and higher contents of exchangeable bases, compared with the other sites. This could be ascribed to the remaining effects of ash and fertilizer application at cropping time and nutrient uptake by vegetation regrowth during fallow. Tanaka et al. (2007b) also described soils with less acidity and higher contents of exchangeable bases during the early stages of the fallow period. In comparison, soil acidity in the present study was clearly higher during the early fallow stages. The Al saturation ranged from 20 to 80 % in their study and from 70 to almost 100 % in our study. Some studies on the shifting cultivation in Sarawak have reported that no tendency was observed in the levels of soil T-C and T-N with increasing fallow period (Tanaka et al. 2007b; Bruun et al. 2006). Our results also showed similar trends in the soil T-C and T-N contents along with fallow duration (data not shown).

Higher soil acidity and less content of exchangeable bases observed in fallow lands under the current shifting cultivation practices in Engkari might be ascribed to nutrient depletion from soil ecosystems as well as the concomitant soil acidification due to a long history of agricultural activities and settlement. In addition, shortened fallow periods in the current shifting cultivation systems in this area lead to poor vegetation recovery, resulting in less ash input to soils at burning time to alleviate soil acidity and supply nutrients to growing plants. Although chemical fertilizers were applied during upland rice farming, it is likely that fertilizer application could not compensate sufficiently for the loss of soil nutrients since urea was the fertilizer used most frequently by the farmers.

In traditional shifting cultivation, the N availability of soils is an important factor to sustain crop production since most N contained in aboveground biomass would be lost into the atmosphere at the time of burning (Giardina et al. 2000; Kendawang et al. 2005b). Tanaka et al. (2007b) evaluated N availability based on C/N ratio and exchangeable NH_4 in surface soils from fallow lands.

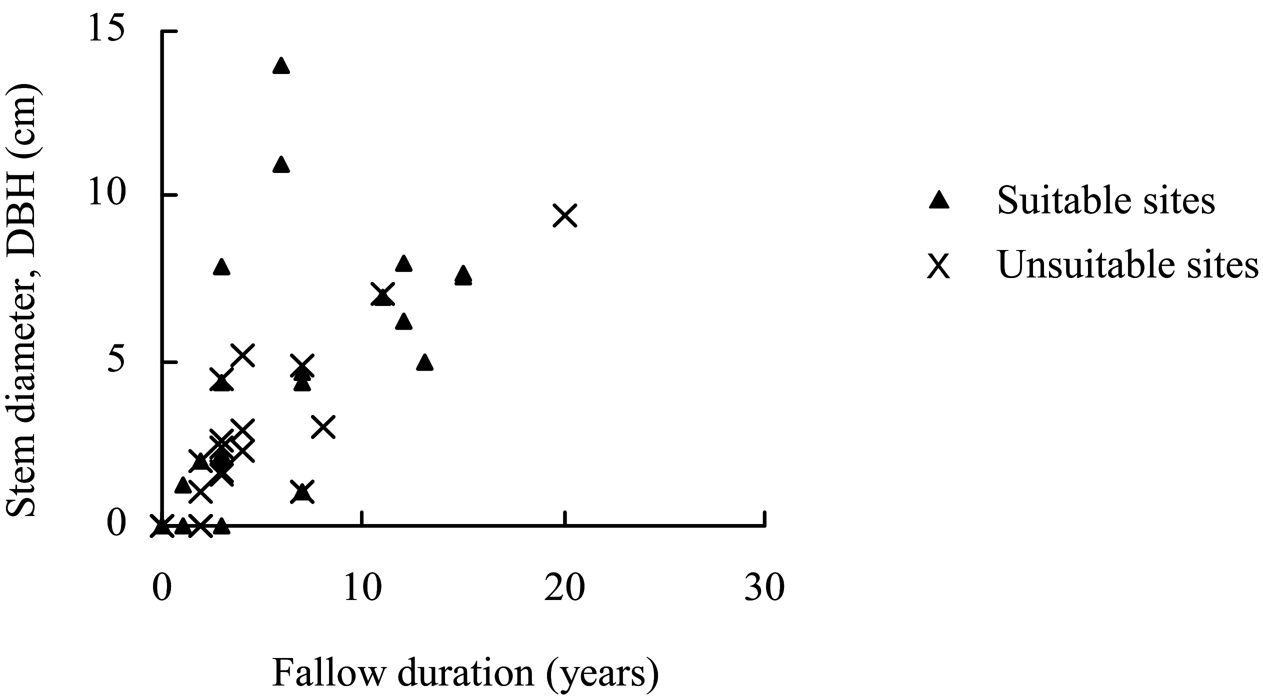

Fig. 3. Relationship between average DBH of trees and fallow duration of the study sites.

Table 3. Soil physicochemical properties of the studied sites.

		All sites (n = 40)			Suitable sites (n = 20)			Unsuitable sites (n = 20)		
Surface soil, 0 - 10 cm depth										
pH(H_2O)		4.41	±	0.22	4.40	±	0.19	4.42	±	0.24
pH(KCl)		3.42	±	0.14	3.40	±	0.14	3.44	±	0.14
T-C	(g kg^{-1})	33.3	±	13.4	31.5	±	13.5	35.1	±	13.4
T-N	(g kg^{-1})	2.11	±	0.67	2.02	±	0.71	2.20	±	0.64
C/N ratio		15.5	±	2.5	15.2	±	2.8	15.8	±	2.2
CEC	($cmol_c$ kg^{-1})	17.5	±	3.7	17.0	±	3.3	17.9	±	4.0
Exchangeable Ca	($cmol_c$ kg^{-1})	0.19	±	0.36	0.15	±	0.25	0.23	±	0.45
Exchangeable Mg *	($cmol_c$ kg^{-1})	0.19	±	0.20	0.12	±	0.08	0.26	±	0.26
Exchangeable K	($cmol_c$ kg^{-1})	0.22	±	0.12	0.24	±	0.14	0.21	±	0.10
Exchangeable Al	($cmol_c$ kg^{-1})	7.54	±	2.92	8.13	±	2.84	6.94	±	2.96
Exchangeable NH_4	($cmol_c$ kg^{-1})	0.08	±	0.03	0.07	±	0.02	0.08	±	0.04
ECEC	($cmol_c$ kg^{-1})	8.18	±	2.80	8.68	±	2.81	7.67	±	2.76
Al saturation	(%)	90.7	±	9.2	92.6	±	6.1	88.8	±	11.4
Available P	(mg kg^{-1})	18	±	23	15	±	15	20	±	29
Clay	(%)	39.9	±	7.5	38.2	±	7.6	41.6	±	7.1
Silt	(%)	21.7	±	6.7	23.0	±	5.4	20.4	±	7.6
Sand	(%)	38.4	±	9.7	38.8	±	10.4	38.0	±	9.1
Bulk density	(g mL^{-1})	0.89	±	0.13	0.89	±	0.15	0.89	±	0.11
Soil hardness	(mm)	9	±	3	8	±	3	10	±	3
Subsurface soil, 30 - 40 cm depth										
pH(H_2O)		4.54	±	0.13	4.52	±	0.13	4.56	±	0.13
pH(KCl)		3.42	±	0.20	3.38	±	0.22	3.46	±	0.18
T-C*	(g kg^{-1})	8.4	±	3.5	7.1	±	3.0	9.6	±	3.6
T-N*	(g kg^{-1})	0.96	±	0.29	0.87	±	0.26	1.06	±	0.29
C/N ratio		8.5	±	2.0	8.0	±	2.0	8.9	±	1.9
CEC	($cmol_c$ kg^{-1})	10.9	±	2.4	10.6	±	2.3	11.2	±	2.5
Exchangeable Ca	($cmol_c$ kg^{-1})	0.02	±	0.02	0.01	±	0.02	0.02	±	0.03
Exchangeable Mg	($cmol_c$ kg^{-1})	0.04	±	0.04	0.04	±	0.03	0.05	±	0.05
Exchangeable K	($cmol_c$ kg^{-1})	0.11	±	0.07	0.10	±	0.04	0.12	±	0.09
Exchangeable Al	($cmol_c$ kg^{-1})	4.86	±	1.74	5.28	±	1.91	4.44	±	1.48
Exchangeable NH_4	($cmol_c$ kg^{-1})	0.05	±	0.02	0.05	±	0.01	0.05	±	0.02
ECEC	($cmol_c$ kg^{-1})	5.05	±	1.72	5.45	±	1.90	4.65	±	1.47
Al saturation	(%)	95.7	±	3.1	96.4	±	2.1	95.0	±	3.7
Available P	(mg kg^{-1})	4	±	4	3	±	2	5	±	5
Clay	(%)	40.2	±	8.1	38.7	±	8.7	41.7	±	7.3
Silt	(%)	23.9	±	8.5	22.1	±	7.4	25.6	±	9.3
Sand	(%)	36.0	±	11.2	39.2	±	11.1	32.7	±	10.7
Bulk density	(g mL^{-1})	1.01	±	0.14	1.03	±	0.14	0.99	±	0.13
Soil hardness	(mm)	15	±	4	14	±	4	16	±	3

Means ± standard deviation. ECEC, effective CEC, sum of exch. bases and exch. Al. Al saturation, ratio of exch. Al to ECEC. Hardness was measured using a Yamanaka-type penetrometer. * Significant differences between suitable and unsuitable sites at 5% levels using Student's *t*-test.

These measurements revealed that the N availability was relatively high in the soils under well growing vegetation with a C/N ratio of about 12 and exchangeable NH_4 of about 0.4 $cmol_c\ kg^{-1}$. Compared with these values, in the present study, the C/N ratio was higher around 15 to 16 and the content of exchangeable NH_4 was low (around 0.1 $cmol_c\ kg^{-1}$), irrespective of site suitability (Table 3) and fallow duration (data not shown). The lower N availability could be ascribed to the loss of N from soil ecosystems and the insufficient recovery of soil N pools under poor vegetation regrowth due to intensive land use in this area. Notably, less leguminous plants were found in the study sites.

Alterations in shifting cultivation practices in terms of vegetation conditions and soil fertility

Poor regrowth of fallow lands in the present study at the Engkari area could be ascribed to repeated burning for an extensive cropping period with a shorter fallow duration. Before the field survey, the farmers were asked to classify their fallow lands into suitable and unsuitable sites for upland rice farming by using their knowledge for site selection based on vegetation conditions. However, as shown in the results from our vegetation survey, farmer classification of suitable sites seemed not to reflect the vegetation conditions. Only a few farmers evaluated their lands as suitable with criteria appropriately based on vegetation conditions. Rather, farmers may have relied upon other criteria or preferences in making their classifications. These may have included accessibility, the length of the fallow period itself, or farmers' memories of high rice yields in previous farming. For most of the study sites in the present study and for the unsuitable sites described by Tanaka et al. (2007a), no substantial differences were found between study sites (irrespective of site suitability) with regard to vegetation conditions such as species composition or tree growth. Thus, our results imply that the practical importance of farmers' traditional knowledge related to vegetation-based site selection was no longer applicable under intensified shifting cultivation practices in the Engkari area, despite the persistence of this knowledge throughout the generations.

Padoch (1982) surveyed the Iban communities along

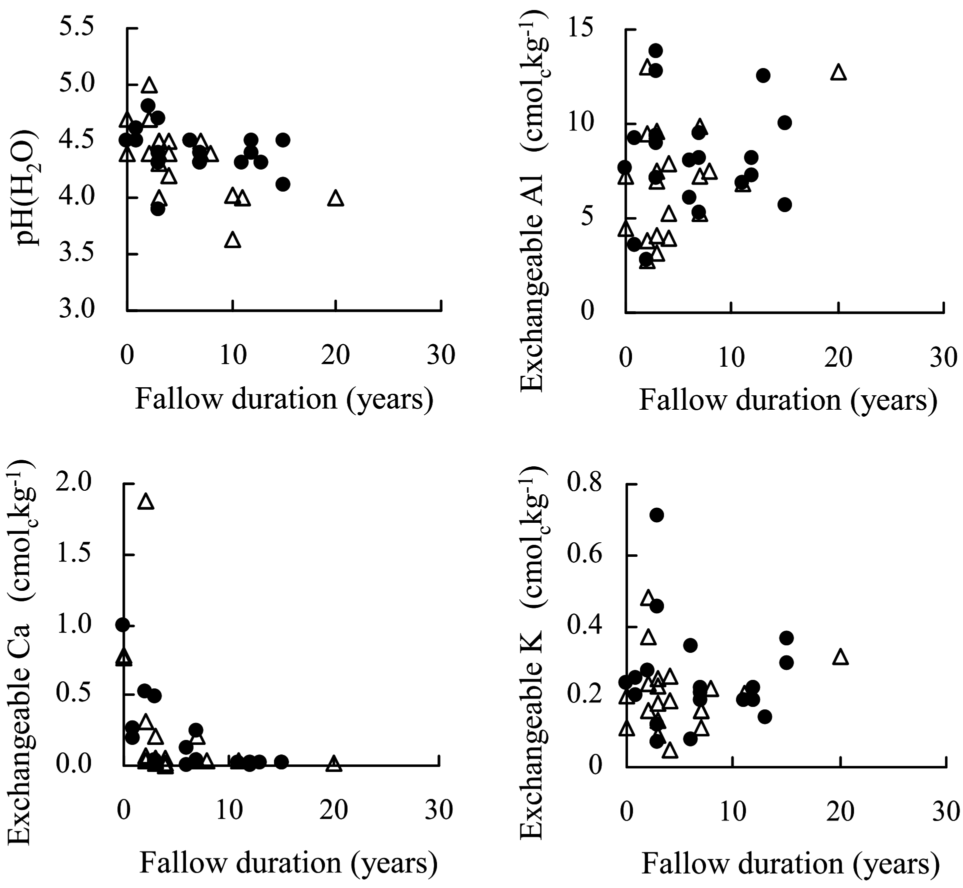

Fig. 4. pH, exchangeable bases (K and Ca) and Al of the surface soils: closed circles, suitable sites; open triangles, unsuitable sites.

the Engkari river and found that the shifting cultivation practice systems there at that time comprised of one time cropping and 4 to 15 years of fallow (about 10 years on average). Such fallow regrowth conditions were probably similar to those reported in Tanaka et al. (2007a) and could provide enough ash input to soils to alleviate soil acidity and improve nutrient conditions, as well as ensure appropriate weed control (Kendawang et al. 2004, 2005; Tanaka et al. 2004, 2005, 2007b). However, these indispensable functions of the fallow period, characterized by sufficient accumulation of aboveground biomass were replaced by the application of chemical fertilizers and herbicides in the current intensive systems of shifting cultivation, resulting in reduced amounts of aboveground biomass. According to the landowners surveyed, herbicide application, in particular, seemed to reduce the labor and time necessary for effective weeding activities. Farmers also applied fertilizer, usually urea, since it was often subsidized by the Department of Agriculture in Sarawak as part of an agricultural development scheme. Considering the high acidity and poor nutrient content of soils as well as the poor aboveground vegetation biomass added to soils as ash at burning time, serious consideration is necessary if the farmers would continue rice cropping for subsistence through the current form of shifting cultivation practices. One possible suggestion could be to introduce the usage of liming materials and appropriate types of fertilizer such as NPK compounds as a substitute for urea, although more expensive, could supply sufficient nutrients and alleviate soil acidity. In this case, effective application methods and countermeasures to soil erosion will be indispensable to save cost and to prevent excessive loss of fertilizer nutrients from soil ecosystems.

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