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SOIL CHARACTERISTICS UNDER INTENSIFIED SHIFTING CULTIVATION FOR UPLAND RICE CULTIVATION IN UPLAND SABAL, SARAWAK, MALAYSIA

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ABSTRACT

Shifting cultivation practices are regarded as the most important agricultural land-use in the marginal uplands of Sarawak for the livelihood of the rural communities. In response to various socio-economic consequences, previous practices on traditional form of shifting cultivation were altered into much sedentary farming practices. Soil productivity to sustain rice yield under current intensified forms of shifting cultivation should be of prime importance for food security among the local community at the marginal uplands of Sarawak. Therefore, this study was conducted to characterize soil properties influenced by the current intensified shifting cultivation practices at Sabal upland area, Sarawak. Along with the use of agrochemicals, shifting cultivation at Sabal area was conducted through single cultivation practices (10 to 15 years of fallow period and a cycle of rice cultivation) and multiple cultivation practices (5 to 7 years of fallow period and two cycles of rice cultivation). Before burning practices, soil pH was highly acidic (ranged from 4.28 to 4.72) in single cultivation sites; while multiple cultivation sites showed less acidic nature (soil pH ranged from 4.98 to 5.23) with relatively high secondary macronutrient contents, especially soil exchangeable Mg and Ca. No significant observation was found after burning practice in Total C and Total N of the soils at both sites. The level of soil exchangeable bases (K, Mg and Ca) and available P increased after the burning practices in single cultivation farmlands; while multiple cultivation sites showed lower to no increase in exchangeable bases and available P, partly attributed to the limited supply of nutrients from the aboveground biomass. After the harvesting of rice, soils at both sites tended to be more acidic and lower in macronutrient contents (K, Mg and Ca), primarily ascribable to crop uptake during the cultivation period. The average yield of rice in single cultivation sites and multiple cultivation sites were 721 kg/ha and 391 kg/ha, respectively. Our findings suggested that the usage of agrochemicals, particularly fertilizers in multiple cultivation sites are necessary for sustaining rice yield to restore the depleted macronutrients (especially K, Mg and Ca) after successive cultivation.

Keywords: Intensive, macronutrients, shifting cultivation, soil characteristics, upland rice field, upland Sarawak

INTRODUCTION

Shifting cultivation is an old, primitive and predominant land-use system in remote mountainous areas of many regions across the globe. For decades, the Dayak tribe, including the Ibans' and the Bidayuhs' in Sarawak practices shifting cultivation of upland rice as their source of staple food (Kleinman *et al.* 1995). Teng (1993) reported that the annual rate at which land is cleared by the local people in Sarawak ranges from 75,000 to 150,000 ha or 0.6 to 1.2% of the total land areas; while 2.7 x 10^6 ha or 22% of the state land is either underused or had been used at least once for shifting cultivation. Such agricultural system could be regarded as ecologically sound and sustainable under the condition of low population density, poor soil fertility and inaccessibility to market (Fox *et al.* 2000; Mertz 2002; Ickowitz 2006; Nielson *et al.* 2006).

In recent decades, scarcity of arable land resources due to population expansion and urban development resulted in gradual alteration of traditional shifting cultivation practices. It is said that current form of shifting cultivation practice is intensified with the shortening of fallow length, longer cultivation period and incorporation of agrochemicals, especially fertilizers in their

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farming practices (Ichikawa 2004; Kendawang *et al.* 2005; Wasli *et al.* 2009). In reality, some farmers continuously cultivate upland rice at the same land for few cycles. Shortened fallow period caused insufficient recovery of vegetation and soils for the next cultivation, indirectly resulting to the decreasing crop productivity, increasing pest and disease cases and declining of soil fertility. Additionally, applications of agrochemicals especially fertilizers and pesticides are widely practiced by the local farmers partly due to subsidy scheme provided by local government agencies. As the modification in the current intensified shifting cultivation practice remained unapprehended in Sarawak especially in the aspect of soil agroecology, there is a need to obtain fundamental information on the suitability of current state of modified shifting cultivation practices toward sustaining the livelihood and subsistence of the local farmers in the upland agroecosystem of Sarawak.

Few studies were conducted mainly on the effect and impacts of shifting cultivation to soil ecosystems (Cramb 1989; Funakawa *et al.* 1997; Kendawang *et al.* 2004; Tanaka *et al.* 2004; Etsuko *et al.* 2004; Kendawang *et al.* 2005; Bruun *et al.* 2009; Wasli *et al.* 2011). Some researchers reported on the current practices involving shorter fallow period and continuous cultivation for few cycles in Sarawak (Kendawang *et al.* 2004; Bruun e*t al.* 2006; Wasli *et al.* 2009). In addition, Dalle and de Blois (2006) pointed out that reduction of fallow cycles caused a decline in non-crop plant resources especially in pioneer species and an increase in short-lived weedy species. However, none of their studies discussed the outcome of recent intensified shifting cultivation, with special reference to soil physicochemical aspects under different stages of shifting cultivation cycles. Present study is necessary to obtain the baseline information on soil fertility as one of the primary indicator of sustaining upland agriculture productivity, soil resources, self-subsistence and livelihood of the upland communities in Sarawak. Thus, this study was aimed to characterize soil physicochemical properties under current intensified shifting cultivation practices at Sabal upland area, Sarawak. Previously, Kendawang *et al.* (2004) studied soil fertility in this area based on conventional shifting cultivation practices. They concluded that soils at Sabal area were naturally infertile and difficult for the farmers to sustain rice production through traditional form of shifting cultivation practices under such soil condition.

MATERIALS AND METHODS

Study Area

The study was conducted at Sabal upland area (01°04'24.6" N, 110°58'08.6" E), Sarawak, Malaysia as shown in Figure 1.

The study area consisted of mainly undulating hills which extended to steep and mountainous Klingkang range where it meets the border of Kalimantan, Indonesia. Sabal is located about 110 km from south-east of Kuching City and is accessible by Kuching-Sri Aman central road. Local communities resided in the study area are mainly of Iban origin for approximately 100 years. The climate condition of the study area is tropical climate with a mean annual temperature of approximately 32.5 °C and negligible monthly variation throughout the year (Meteorological Department 2014). The average mean precipitation is about 3,585 mm obtained from the nearest weather station located at Sri Aman Airport (Meteorological Department 2014). Soils in the study area were derived from non-calcareous sedimentary rock consisting of fine and whitish sandstone which is further classified into Oxyaquic or Spodic Quartzipsamments based on USDA Classification System (Butt 1983; Soil Survey Staff 1999). Most of the villagers are farmers cultivating subsistence crops such as upland rice, fruits and vegetables as well as other cash crops i.e. rubber, pepper and oil palm.

Site Selection and Agronomic Practices in Relation to Upland Rice Cultivation

Field survey was conducted from August 2013 to March 2014. Prior to soil sampling, community survey via Rapid Rural Appraisal (RRA) approach was conducted to collect baseline information on family background, land-use history and crop management practices. Desirable sites were selected based on the availability of farmlands with shifting cultivation i.e. single cultivation and multiple cultivation practices. Single cultivation practice refers to the long fallow period with short cultivation period. Multiple cultivation practice refers to the short fallow period with long cultivation period. Farmers' perception on site suitability for rice cultivation is based on their traditional knowledge, typically through soil observation and vegetation composition of the desired lands. Accessibility and location of the farmlands were particularly important in farmer's decision for site selection.

Overall, a total of 8 sites for both single cultivation farmlands (n = 4) and multiple cultivation farmlands (n = 4) were selected after interviews. The slope gradients for all study sites ranged from 12 to 20° with elevation ranged from 23 to 88 m above sea level. Land-use history of all study sites was illustrated in Table 1.

Single cultivation sites were fallowed for 11 to 15 years; while multiple cultivation sites had shorter fallow period of 5 to 7 years with continuous cultivation for two cycles, thus intensified. Farmlands size usually depended on the numbers of family members and availability of manpower in managing the farmlands. At Sabal area, the farmland sizes ranged from 0.47 to 3.82 ha with an average of 1.86 ha. Agrochemicals such as fertilizers and pesticides subsidized by government agencies were widely used in the current farming practices, either in single cultivation or in multiple cultivation practices. Fertilizers were applied under single cultivation practices. Unlike research results reported previously in Tanaka *et al.* (2007a) at Mujong River area, previous conventional single cycle of shifting cultivation involved no fertilizers application. Compound N-P-K (17.5-15.5-10.0) and urea (46%) were commonly used in both cultivation practices. The application rate of fertilizers generally varied among the household with an average application rate of 132 kg/ha per cycle for single cultivation sites and 190 kg/ha per cycle for multiple cultivation sites, giving rise to average N-P-K (40-10-7) kg/ha/year and N-P-K (64-13-8) kg/ha/year for single and multiple upland rice cultivation, respectively. In addition, herbicides and pesticides were commonly applied in both cultivation practices during land preparation and rice farming period. Based on the farmers' experience, agrochemicals requirements under multiple cultivation sites were generally higher compared to single cultivation sites due to factors such as weeds and pest infestation. Thus, multiple cultivation sites were regarded as intensified in terms of reduction of fallow age, laborious farm work maintenance and higher rate of agrochemicals application.

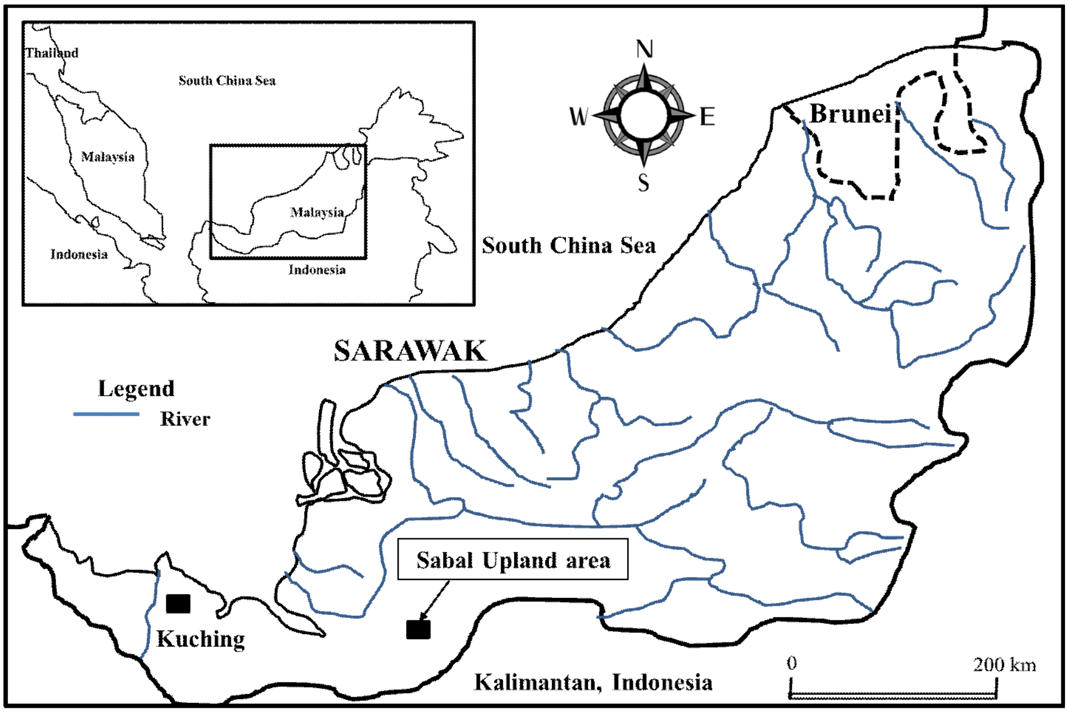


Figure 1 Map of the study area

Table 1 Land-use history of the selected study sites

Sites	Land-use history (year)													
	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000
Single Cultivation (SC)														
SC1	R	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	R
SC2	R	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
SC3	R	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
SC4	R	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	R	▨
Multiple Cultivation (MC)														
MC1	R	R	▨	▨	▨	▨	▨	R	R	▨	▨	▨	▨	R
MC2	R	R	▨	▨	▨	▨	▨	R	▨	▨	▨	▨	▨	R
MC3	R	R	▨	▨	▨	▨	▨	▨	▨	R	R	▨	▨	▨
MC4	R	R	▨	▨	▨	▨	▨	▨	R	▨	▨	▨	▨	R

Note: R = upland rice cultivation; ▨ = fallow period

Soil Sampling and Analysis

Soil samples were collected at 3 different phases of a typical shifting cultivation cycle, notably before burning (BB) of dried vegetation after land clearing (August), after burning (AB) of the dried vegetation (September) and after harvesting (AH) of upland rice (February) in 2013 and 2014, respectively. The yield of upland rice in each farmland at single and multiple sites were recorded as well. Composite soil samples were collected within two weeks' period of each phase at soil depth of 0 – 10 cm and 30 – 40 cm from three random points within the same location at the farmland area. On the other hand, core samples (100 cm^3) were collected from the same depth in triplicates for soil bulk density determination. Composite soil samples collected were air-dried and crushed to pass through sieves with 2 mm mesh for the determination of soil physicochemical properties.

Soil pH (H_2O) was determined in water. Soil pH (KCl) in 1M KCl was determined in a soil to solution ratio of 1:5 using glass electrode method. Electrical conductivity (EC) was measured after the pH (H_2O) measurement using EC meter. Total C is determined by loss on ignition method (Dean 1974). Total N was determined by Kjeldahl acid digestion and measured by colorimeter method. Contents of exchangeable bases and the Cation Exchange Capacity (CEC) were measured respectively, after successive extraction using 1M ammonium acetate adjusted to pH 7.0 and 10% NaCl. Contents of exchangeable bases were determined using Atomic Absorption Spectrophotometry (AAS) for Ca, Mg, K and Na (Coleman *et al.* 1959). Exchangeable Al and H were extracted with 1M KCl from pH (KCl) filtrates. Exchange acidity (Al+H) was determined using titration method with 0.01M NaOH. Content of exchangeable Al was determined with 0.01M HCl. Content of exchangeable H was calculated as the difference between the values of the exchange acidity and exchangeable Al. Available P was quantified using Bray II method (Kuo 1996). In Bray II method, soil samples were extracted with extracting solution consisted of 1M NH_4F and 0.5M HCl. Color developing reagent was then added into the extract. Available phosphorus was determined by absorbance measurement with UV spectrophotometer at wavelength of 710 nm (Bray & Kurtz 1945). Particle size distribution was determined using pipette method with the assistance of soil textural class (Gee & Bauder 1986); while soil hardness was measured by Yamanaka-type push cone penetrometer.

Data Analyses

All statistical analyses were performed using SPSS Version 22 (SPSS Inc.) for comparison of soil physicochemical properties between single and multiple cultivation practices using Student's *t*-Tests. Relationships among yield and fallow period, fertilizers applied as well as soil physicochemical properties were computerized using Pearson's Correlation Coefficients.

RESULTS AND DISCUSSION

Soil Physicochemical Properties under Shifting Cultivation at the Study Area

Table 2 presented the average values of surface and subsurface soil physicochemical properties at different stages of shifting cultivation cycle in relation to single cultivation and multiple cultivation practices at Sabal area.

At all stages, no substantial differences were observed for average surface and subsurface soil properties between single and multiple cultivation sites. It is noteworthy that the discussion of current study was mainly focused on the surface soil layer (0 – 10 cm) rather than on the subsurface soil layer (30 – 40 cm). The effect of burning practice was not distinct at the subsurface layer (Kumada *et al.* 1985; Kyuma *et al.* 1985; Tanaka *et al.* 2001; Kendawang *et al.* 2004; Kendawang *et al.* 2005). However, the properties of the subsoil layer should be obtained to clarify if any significant changes in terms of soil physicochemical properties were observed under current intensified multiple cultivation practices adapted by the local farmers at the study area.

Previous study by Kendawang *et al.* (2004) reported that the soils at Sabal area were characterized by relatively sandy texture and low nutrient contents. Soil Organic Matter (SOM) in the surface soils was visible, mainly composed of coarse fragments of plant debris; while clay mineral composition was dominated by kaolin minerals, and to a lesser extent by quartz (Kendawang *et al.* 2004).

Soil pH (H_2O) under single cultivation sites were acidic (ranging from 4.28 to 4.72) before burning practices; while soil pH (H_2O) value showed an increase to the range from 4.54 to 5.23 after burning practices (Table 2). Later, soil pH (H_2O) decrease slightly to the range of 4.40 to 5.16 after harvesting of the upland rice. In contrast, soil pH (H_2O) under multiple cultivation sites showed gradual decrease with the average of 5.11 at before burning to 4.83 after burning and further decrease to 4.65 after harvesting stages. Before burning practice significantly lower soil pH (H_2O) values in single cultivation sites due to the vigorous uptake of basic cations by the existing vegetation during fallow period (Tanaka *et al.* 1997; Wasli *et al.* 2011). Multiple cultivation sites with lower fallow period were less acidic indicating the remnant ash effects from previous burning practices and fertilizers residues from previous year. After burning practices, soil pH (H_2O) showed an increase from 4.56 to 4.90 at single cultivation sites compared to multiple cultivation sites, mainly caused by direct effect of ash addition into the surface soil. Various studies reported that burning practice significantly increases soil pH due to acid neutralizing capacity of ash (Nye & Greenland 1964; Kyuma *et al.* 1985; Armando *et al.* 1996). In contrast, such effect was not observed in multiple cultivation sites after the burning practice. Shortening of fallow period in multiple cultivation sites has led to poor vegetation regrowth, which in turn limiting the ash input to soils during burning to alleviate soil acidity (Wasli *et al.* 2009). Soil pH (H_2O) was further acidified after the harvesting phase in both cultivations. Soil acidity was mainly caused by the removal of basic cations in the soils from the uptake of the upland rice crops (Tulaphitak *et al.* 1985; Gafur *et al.* 2000; Biswas *et al.* 2012). However, it can be observed that soil acidity was more pronounced in multiple cultivation sites due to the depletion of nutrients after the second cycle of upland rice cropping.

In our study, soil Total C and Total N varied widely among the stages under both types of cultivation practices. In the surface layer, Total C of the soil ranged from 14.2 g/kg to 40.3 g/kg; while Total N of the soil ranged from 0.97 g/kg to 3.00 g/kg. Present studies showed no remarkable changes in Total C and Total N of the soil after burning practice at both single and multiple cultivation sites. In fact, the contents of Total C and Total N in most single and multiple cultivation sites, decreased after burning practices which is in agreement with results of previous findings (Ewel *et al.* 1981; Andriesse & Schelhaas 1987; Hölscher *et al.* 1997; Gafur *et al.* 2000; Tanaka *et al.* 2001). Unlike those reported by various researchers (Nye & Greenland 1964; Kyuma *et al.* 1985; Tulaphitak *et al.* 1985), significant increase in Total C and Total N of the soil were usually found after burning practices. Several sites (both single and multiple) showed a slight increase of Total C and Total N after burning. In their study at Northeast Thailand, Kyuma and Pairintra (1983) investigated that burning resulted in partially carbonized litter added into the soil. However, our study showed that the C/N ratio in all both single and multiple

Table 2 Surface and subsurface soil physicochemical properties under different stages of shifting cultivation cycle in single cultivation and multiple cultivation farmlands

Soil physicochemical properties		Before Burning (BB)		After Burning (AB)		After Harvesting (AH)	
		SC^a	MC^b	SC	MC	SC	MC
Surface Soil (0 - 10 cm)							
pH (H_2O)		4.56 ±0.19*	5.11 ± 0.11*	4.90 ± 0.24	4.83 ± 0.08	4.76 ±0.35	4.65 ±0.16
EC	µS/cm	51±29*	39±6*	55±24	41±2	33±10	29±5
Total C	g/kg	26.0±12.9	26.2±7.1	23.3±9.7	23.8±6.4	24.2±7.6	21.2±3.2
Total N	g/kg	1.9±0.9	1.7±0.2	1.9±0.6	1.7±0.3	1.4±0.3	1.3±0.1
C/N		13.5±1.3	16.0±4.6	12.3±1.1	13.7±2.4	17.4±2.2	16.6±1.9
CEC	cmol$_c$/kg	3.45±1.91	5.15±1.80	3.75±1.46	2.95±0.75	3.35±1.66	2.65±0.50
Exch. K$^+$	cmol$_c$/kg	0.05±0.04	0.07±0.02	0.19±0.10	0.10±0.05	0.12±0.08	0.06±0.01
Exch. Mg^{2+}	cmol$_c$/kg	0.15±0.11	0.27±0.26	0.28±0.08	0.26±0.09	0.29±0.11	0.18±0.02
Exch. Ca^{2+}	cmol$_c$/kg	0.31±0.27	0.50±0.50	1.01±0.54	0.48±0.18	0.68±0.28*	0.34±0.05*
Exch.Al^{3+}	cmol$_c$/kg	0.81±0.52	0.76±0.20	0.83±0.43	0.51±0.32	0.97±0.79	0.61±0.20
ECEC^c	%	1.37±0.72	1.74±0.74	2.34±0.88	1.38±0.48	2.08±1.10	1.22±0.25
Base sat^d	%	16.6±7.6	17.9±11.4	42.2±16.6	31.3±12.9	35.4±13.8	23.4±2.5
Al sat^e	%	59.3±15.0	50.0±21.6	35.5±12.8	34.9±17.6	43.7±15.8	48.9±6.7
Available P	mg/kg	14.8±2.0	37.2±51.1	14.2±7.9	19.4±7.9	5.7±0.4	10.4±5.8
Clay	%	21±15	19±3	20±8	18±8	27±18	18±2
Silt	%	18±4	10±10	16±4	10±6	20±7	16±8
Sand	%	61±18	71±9	64±11	72±12	53±26	66±8
Bulk density	g/mL	1.13±0.28	1.11±0.14	0.97±0.16	1.08±0.17	0.97±0.14	1.12±0.16
Hardness^f	mm	16±2	18±2	17±2	15±3	16±1	15±2
Subsurface Soil (30 - 40 cm)							
pH (H_2O)		4.94±0.19	5.28±0.11	4.86±0.13	5.03±0.34	4.86±0.15	4.86±0.06
EC	µS/cm	19±4	15±2	22±5	20±4	10±1	10±2
Total C	g/kg	10.9±4.6	15.3±4.2	9.9±3.8	8.5±5.4	9.6±4.7	9.8±2.6
Total N	g/kg	0.9±0.4	1.0±0.4	0.8±0.2	0.6±0.2	0.6±0.2	0.4±0.1
C/N		11.7±1.3	17.4±8.7	12.2±4.7	13.5±7.4	16.1±4.1	25.8±11.2
CEC	cmol$_c$/kg	3.20±2.02	2.90±0.60	2.40±0.59	1.85±1.02	3.40±2.49	1.95±0.66
Exch. K$^+$	cmol$_c$/kg	0.02±0.01	0.04±0.02	0.03±0.02	0.03±0.02	0.03±0.02	0.04±0.00
Exch. Mg^{2+}	cmol$_c$/kg	0.08±0.02	0.05±0.01	0.09±0.01	0.08±0.01	0.09±0.02	0.06±0.01
Exch. Ca^{2+}	cmol$_c$/kg	0.29±0.03	0.19±0.05	0.32±0.02	0.29±0.02	0.33±0.04	0.28±0.03
Exch.Al^{3+}	cmol$_c$/kg	0.83±0.43	0.86±0.35	0.82±0.17	0.49±0.36	1.05±0.80	0.70±0.28
ECEC^c	%	1.31±0.44	1.13±0.40	1.35±0.18	0.97±0.35	1.59±0.83	1.14±0.32
Base sat^d	%	20.3±11.3	9.44±2.08	23.2±6.8	34.4±20.2	22.1±13.8	24.4±8.1
Al sat^e	%	60.1±12.8	74.6±6.0	60.3±5.5	44.3±21.8	61.3±13.5	60.0±8.2
Available P	mg/kg	7.9±0.6	4.5±2.4	1.6±0.5	3.0±2.2	2.1±0.3	3.1±1.0
Clay	%	24±15	27±6	25±6	17±9	29±20	20±4
Silt	%	18±6	17±7	16±4	13±7	18±6	17±7
Sand	%	57±21	56±13	60±9	70±14	53±25	63±9
Bulk density	g/mL	1.46±0.20	1.39±0.22	1.45±0.13	1.51±0.15	1.37±0.19	1.42±0.10
Hardness^f	mm	21±1	20±4	21±2	22±1	20±2	20±1

Note: Data in this table are presented as mean ± standard deviation
* = Significant ($p < 0.05$) differences between single and multiple cultivation practices at different stages of shifting cultivation cycle
SC^a = Single Cultivation; MC^b = Multiple Cultivation; ECEC^c = Effective CEC, sum of exchangeable bases and exchangeable Al; Base sat^d = sum of exchangeable bases in percent of CEC; Al sat^e = exchangeable Al in percent of ECEC
Hardness^f was measured using Yamanaka-type push cone penetrometer

cultivation sites tended to either remain unchanged or decrease after burning, indicating that limited or no fresh (partially carbonized) plant materials were added into the soils. As reported by Kendawang *et al.* (2004), in sandy textured soils, fragments of SOM was not absorbed onto or closely associated with soil particles, but occurred as mineral particles which might be washed away during the rainfall after the burning practices. Our study was supported by this observation as the sand contents were negatively correlated with the amount of Total C (r = -0.767, $p < 0.05$) and Total N (r = -0.848, $p < 0.01$) (Fig. 2).

From our field observation, the amount of incompletely burnt, charred branches and stems of young and mature trees left distributed over the field in single cultivation sites were observable (Fig. 3).

Young trees store relatively more nutrients in leaves and branches, whereas mature trees store more nutrients in the stem and large branches (Kyuma *et al.* 1985). The branches and stems from the felling did not burn completely, suggesting that some of the nutrients which stored in the plant materials were not released completely into the soils. Such condition resulted in no remarkable changes in the levels of C and N contents in single cultivation sites, although the fallow period was longer as compared to multiple cultivation sites. Additionally, decreasing Total C and Total N of soil could be ascribed to the lost Total C and N of soil through volatilization to the atmosphere when large quantities of fuel were consumed at the surface layer (Giardina *et al.* 2000). Therefore, soil organic N might be lost to the atmosphere during the thermal oxidation of organic matter in the form of oxidized N gases and N_2, resulting to lower total N levels in the soils even after burning practices (Raison 1979). Andriesse and Schelhaas (1987) also pointed out that C disappears faster than N under high temperature. As the levels of soil Total C and Total N did not show significant increase after burning practices, it can be predicted that the source of N for rice growth mainly supplies through the inorganic form from chemical fertilizers, rather than the biomass from the burnt vegetation. After harvesting of crops, Total C and N generally decreased at the end of the cultivation cycle at both single and multiple cultivation sites. Much of the decline in soil Total C and Total N may be attributed to the decomposition of unhumified materials (Nye & Greenland 1960), though erosion and crop uptake decrease the level of soil Total C and Total N as well as the end of the harvesting cycle.

Content of available P at the surface soil in multiple cultivation sites were generally higher with a wide variation as compared to single cultivation sites. One of the multiple cultivation sites showed an extremely high value of available P which was 113.5 mg P/kg before burning practice. Such condition could be attributed to the unused portion of P added by ashes or the soil samples might have been collected from the points where large amounts of burnt biomass accumulated or chemical fertilizers had been applied (Wasli *et al.* 2009). Similar to soil Total N, soil available P did not show remarkable changes after burning practices at single cultivation sites. On the other hand, multiple cultivation sites showed decrease of soil available P levels after burning practices. Contrary to studies reported by other researchers (Nakano 1978; Tulaphitak *et al.* 1985), available P of soil did not peak after burning phase in both single and multiple cultivation farmlands. As charred plant biomass was left distributed in the field, the P nutrient was not sufficient to release from the burning process. Subsequently, levels of available P of the soil decreased after the harvesting of rice crops at the end of the cycles partly attributed to crop uptake and loss through leaching as well as erosion. In multiple cultivation sites, the contents of available P in surface soil were relatively higher after the second cycles, suggesting that excess and immobile P from the fertilizers might be accumulated in these farmlands under

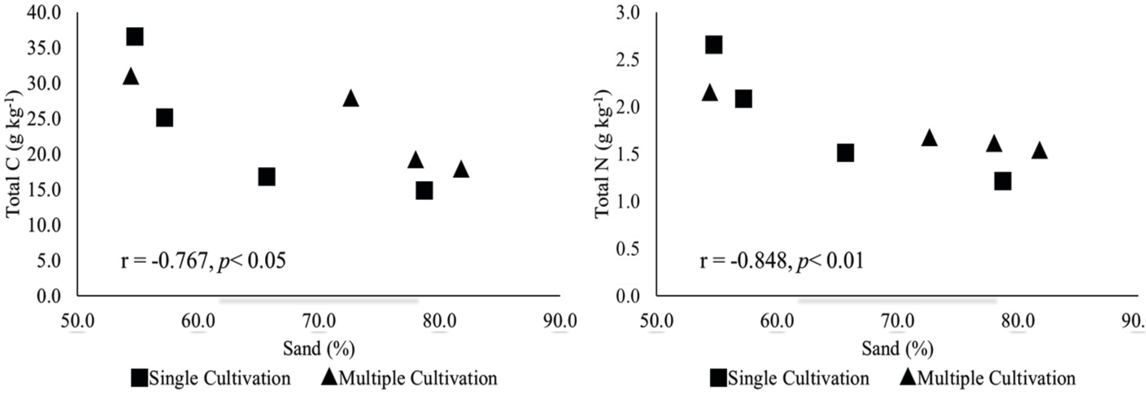


Figure 2 Relationship among sand and Total C (g/kg) and Total N (g/kg) after burning at the surface soils

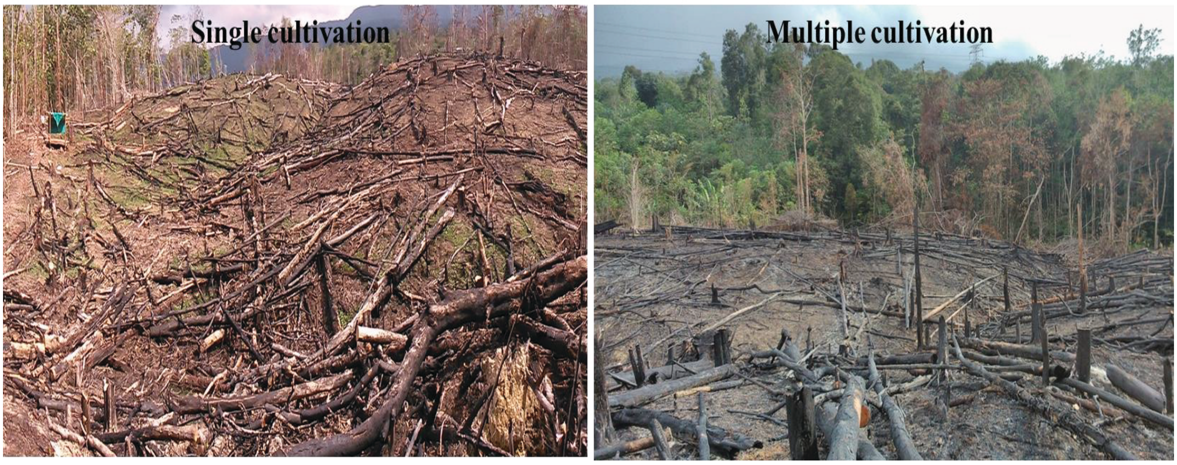


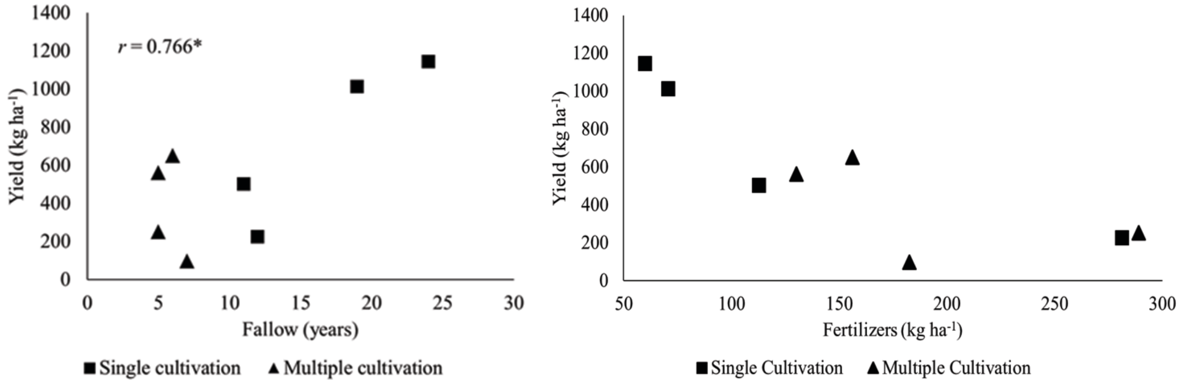
Figure 3 Charred branches of young and old vegetations scattered over the single and multiple cultivations upland rice farms

continuous cultivation practices. As for subsurface layer, the soil available P contents in both single and multiple cultivation sites did not vary from each other after harvesting practices, generally within the range of 1.7 mg P/kg to 4.0 mg P/kg.

Before the burning practice, multiple cultivation sites showed higher levels of exchangeable bases (K, Mg and Ca), generally ranged from 0.05 to 1.25 cmol$_c$/kg, primarily due to remnant ash effects and nutrients from the previous cultivations. After burning practice, the soil exchangeable bases (K, Mg and Ca) were increased to a range of 0.11 to 1.55 cmol$_c$/kg in single cultivation practice from a range of 0.01 - 0.70 cmol$_c$/kg (before burning practice) due to the release of nutrients from dried vegetation biomass during burning. Burning usually leads to accumulation of potash which contributes to the release of macronutrients needed by plants, i.e. potassium, calcium and magnesium (Nye & Greenland 1964; Driessen *et al.* 1976; Kyuma *et al.* 1985). Multiple cultivation sites showed little variations in exchangeable bases (K, Mg and Ca) after burning practices. Levels of exchangeable bases (K, Mg and Ca) slightly increased at several sites compared to single cultivation sites. Herbaceous plant indicating infertile land such as*lalang* (*Imperata cylindrica*) usually predominates after a short fallow period of less than 3 years (Tanaka *et al.* 2007b; Wasli *et al.* 2009), resulting in the restricted supply of nutrients into the soils from the burning of the aboveground biomass. After the harvesting of rice crops, the levels of exchangeable bases decreased rapidly, suggesting that the input of bases through ash effect and subsequent fertilizers application was depleted at both farmlands. Several nutrients might be lost into the environment through volatilization, runoff and leaching throughout the cycle after burning practices, the remaining ones were used by the rice crops during cultivation. At the end of the cycle (AH), single cultivation sites showed higher levels of bases content as compared to the soils at the stage of before burning practice (BB). Although fertilizers input might affect the levels of bases at the end of the cycle, another reason could be ascribable to the existing of remnant ash effects during cultivation period (Nye & Greenland 1964; Juo & Manu 1996; Etsuko *et al.* 2004). Conversely, the levels of surface and subsurface soil exchangeable bases at some multiple cultivation sites were lowered at the end of the cycle (AH) as compared to before burning practices (BB). Such condition indicated that the available nutrients might not be sufficient for next cultivation after two consecutive cycles of cultivation. Thus, the farmer should consider whether to move to another farmland or increase the amount of fertilizers application as the amount of nutrient supply by the aboveground biomass could be limited after two cycles of cultivation.

Rice Productivity under Current Intensified Practice of Shifting Cultivation

In general, the yield of both single and multiple cultivation practices varied widely among the study sites. The yield of single cultivation sites ranged from 225 kg/ha to 1,145 kg/ha with an average of 721 kg/ha. Multiple



(a) (b)

Figure 4 Relationship among upland rice yield and (a) fallow period and (b) fertilizers applied per cycle of cultivation, under single and multiple cultivation sites

cultivation sites ranged from 99 kg/ha to 652 kg/ha with an average of 391 kg/ha. Teng (1993) reported that the yield from traditional shifting cultivation practice of upland rice in Sarawak ranged from 460 kg/ha to 1,184 kg/ha with an average yield of 738 kg/ha. Thus, current study showed lower yield as compared to those reported by Teng (1993). It was noticeable that no major relationship was found between rice yield and soil properties in the study area (data not shown). Figure 4(a) showed the relationship between upland rice yield and the fallow period under current single and multiple cultivation practices. In single cultivation sites, a higher yield of upland rice was observed under longer fallow length from 19 to 25 years. Lower yield of upland rice was observed under the shorter fallow length of 11 to 12 years. Rice yield under multiple cultivation sites with fallowing period of 5 to 7 years was almost similar to single cultivation sites with fallowing period of 10 to 15 years. On the other hand, Figure 4(b) showed the relationship between yield and fertilizers applied per cycle under single and multiple cultivation sites. Although the rate of fertilizers application under multiple cultivation sites were slightly higher than single cultivation sites, the upland rice production under multiple cultivation sites was still lower than that of single cultivation sites. Single cultivation required minimal amount of fertilizers i.e. less than 100 kg/ha to produce the yield of more than 1,000 kg/ha, considering the fallow period of more than 20 years. Such condition leads to suggestions that agrochemicals, especially fertilizers application are crucial to sustain rice production under short fallow period of multiple cultivation practices.

As finding new farmlands with long fallow period is rather difficult, multiple cultivation practices with the appropriate use of agrochemicals could be one of the options to sustain the rice production on the study area. Additionally, SOM plays an important role as nutrient reservoir in determining soil productivity, further investigations should highlight the dynamics of SOM and soil microbial ecological aspects under present intensified multiple cultivation practices, especially after the burning practices. On the other hand, comprehensive nutrient management plan involving both chemical and organic fertilizers with suitable soil conservation practices can be introduced into current intensified shifting cultivation towards sustaining the rice production at the study area.

CONCLUSIONS

Current shifting cultivation has been intensified through multiple cycles cultivation with the shortening of fallow period and use of agrochemicals at upland Sabal area. There were no major significant differences between soil properties among single and multiple cultivation sites at all stages of shifting cultivation cycles within the surface and subsurface layer, except for soil pH (H_2O). Surface soil pH (H_2O) under single cultivation sites increased after the burning practice and decreased after the harvesting of the upland rice. Surface soil pH (H_2O) under multiple cultivation sites were acidified from the beginning until the end of the cycles. Total C and soil Total N of the soil did not significantly different between one another at both single and multiple cultivation sites. The amount of exchangeable macronutrients (K, Mg and Ca) at the surface and subsurface soils at multiple cultivation sites showed decreasing trends of nutrients contents after subsequent cycles of cultivation as compared to single cultivation sites. Continuous cultivation without proper nutrient management plan could result in depletion and exhaustion of soil available macronutrient contents. The function of the fallow period has been substituted by the agrochemicals such as fertilizers and herbicides in sustaining the crop yield. Appropriate usage of agrochemicals could be an option to sustain the rice production for the local people under multiple cultivation practices.

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