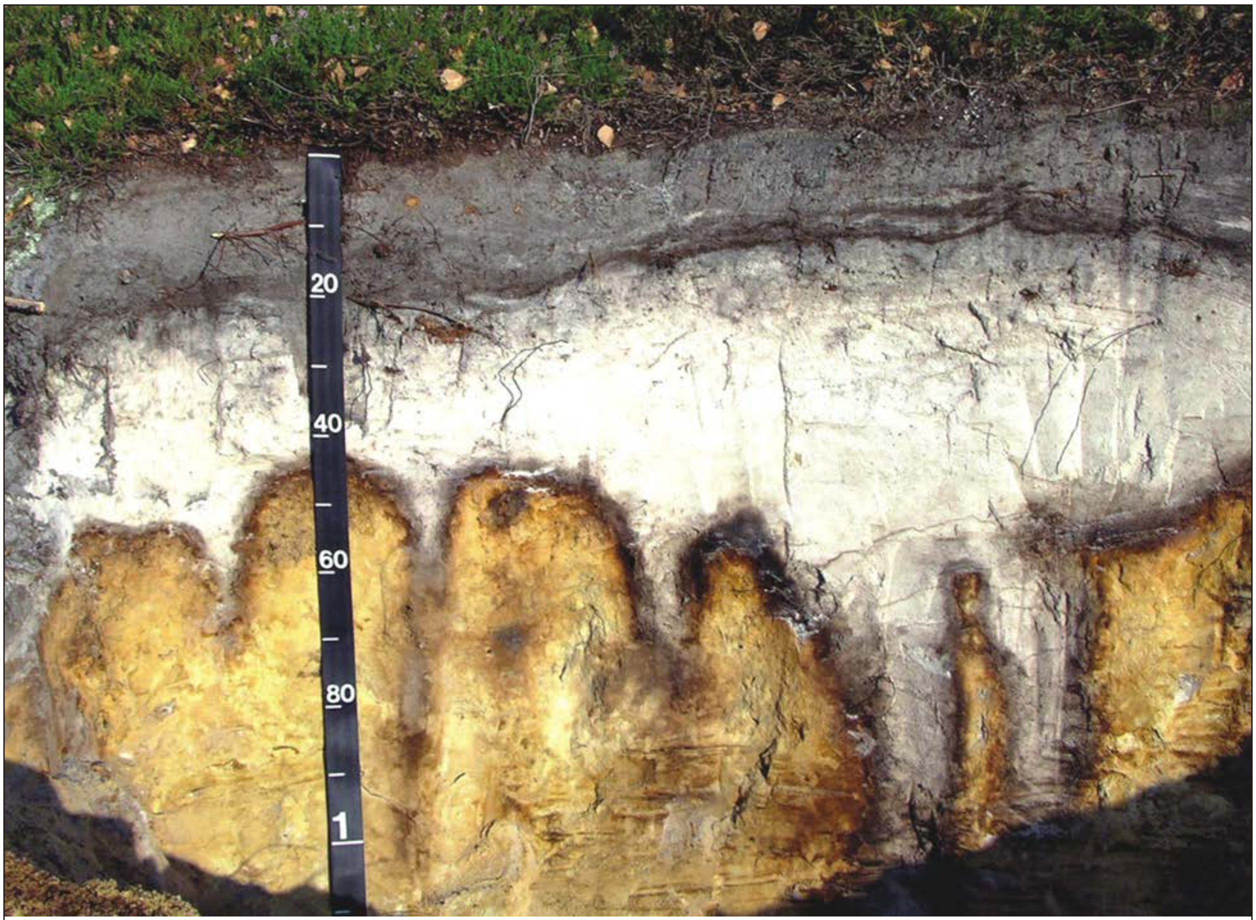

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Soil Changes Associated with *Imperata cylindrica* Grassland Conversion in Indonesia

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ABSTRACT

Imperata grassland is recognized as environmental threats causing low land productivity. This has increased the need to assess the effect of grassland conversion to agricultural fields on soil. Undisturbed and disturbed soil samples were collected from Bengkulu Province, Sumatra, Indonesia. We used five different land management practices such as *Imperata cylindrica* dominated grassland as a reference, cassava field, banana field, legume field and agroforestry. Result shows that 6-year of cassava cultivation decreased 35% of soil water content at field capacity, 23% of water holding capacity, 11% of porosity, 13% of organic C and microbial biomass C, 32% of inorganic N and 10% of mineralizable C. Conversion to banana field only lowered C organic about 6% and soil microbial biomass C up to 8%. Conversion to legume fields and agroforestry significantly increased all the soil properties tested. Agroforestry system has maintained higher soil C and N levels than the other fields. On average, degradation index in cassava field was 11%. The aggradation index has increased from banana field (14%), agroforestry system (37%) and legume field (38%). In conclusion, conversion of *Imperata* grassland to conservative agricultural land is considered one way to improve soil ecosystem.

Key words: Aggradation index, degradation index, *Imperata cylindrica*, organic matter

INTRODUCTION

Imperata cylindrica (L.) Beauv. commonly cover large areas throughout moist tropical regions, particularly in Southeast Asia. The grass is categorized as one of the invasive plant species and considered as a serious weed problem in 18 countries (Holm *et al.*, 1979). In Asia, the major variety of *Imperata cylindrica* primarily affects the ecology, economy, fertility and productivity of the farm (Garrity *et al.*, 1997). In general, *Imperata* grassland may exist in large contiguous areas, small patches in vegetation mosaics and also mixed with shrubs in agricultural fields.

Imperata grasslands have primarily existed following deforestation activities such as after repeated logging and the subsequent treatments by fire during shifting cultivations (Suryatna and McIntosh, 1976). In this case, annual fires prevent the natural succession to be a secondary forest (Wibowo *et al.*, 1997). The existing of *Imperata cylindrica* has occasionally been associated to land with poor soil physical properties, low nutrient content and retention capacity and high exchangeable aluminum level (Kauffman *et al.*, 1998; Lal, 1997). Most of the time, these grasslands are referred as fallow fields or resting land. Previous research indicates that *Imperata* grasslands are found widely distributed over the wide range of soil orders (Garrity *et al.*, 1997).

In Indonesia, the total area of *Imperata* grasslands has been estimated at approximately 8.6 million ha (Garrity *et al.*, 1997). A continues decline in the amount of agricultural area per family has led to shortened the fallow period and more *Imperata* grassland has been cultivated (Riswan and Hartanti, 1995). Therefore, recent information on the effect of *Imperata* grasslands conversion on soil properties needs to be collected.

Soil management practices following cultivation of grassland may rapidly improve or decline soil properties. Previous studies show that soil quality degradation can significantly reduce crop productivity (Hameeda *et al.*, 2006; Handayani and Prawito, 2008; LeBlanc and Handayani, 2011; Malgwi and Abu, 2011; Uzoije and Onunkwo, 2011; Zaidey *et al.*, 2010). Conservative agricultural practices such as no till, organic farming and agroforestry may improve soil organic matter and physical properties (Ayodele and Omotoso, 2008; Fallahzade and Hajabbasi, 2011; Mbah *et al.*, 2007; Opara *et al.*, 2007; Ratnayake *et al.*, 2011). Therefore, evaluation of early soil changes upon land conversion for varying agricultural purposes is crucial. The objectives of this research were: (1) to determine and compare the changes in physical, chemical and biological soil properties in response to different land management system and (2) to calculate the aggradation and degradation indexes of each agro-ecosystem as compared to *Imperata* grasslands.

MATERIALS AND METHODS

Study site: The study site was located in Bengkulu Province (03°48'S and 102°16'E), Sumatra Island, Indonesia. Before grassland, the area was originally covered with typical tropical forest, such as *Aporosa aurita*, *Areca* sp., *Arthocarpus champede*, *Cinnamomum porectum*, *Durio zibethinus*, *Parkia spesiosa*, *Pithecellobium latum*, *Rhodomnia cinerea* and *Spondias pinnata*. The forest has been cleared through cutting the wood to meet the need for farm land.

The climate of the area is tropical monsoon with the rainy season occuring from October to March and dry season from April to September. The mean annual temperature is 26°C, while the mean rainfall is 200 mm/month. The relative humidity ranges between 75-90%. The soils are classified as very fine, mixed, isohyperthermic, Typic Palehumult according to US Soil Taxonomy. These soils are poorly to moderately drained and occur on undulating to flat uplands. The elevation is below 75 m above sea level.

Soil sampling: Surface soil samples at the depth interval of 0 to 20 cm were collected from four sites of each of five adjacent land management types: (1) legume field for 6 years. The field had a mix of green bean (*Phaseolus vulgaris*), soybean (*Glycine max*), mung bean (*Vigna radiata*) and snake bean (*Vigna unguiculata*); (2) banana (*Musa acuminata*) field for 6 years; (3) cassava (*Manihot esculenta*) field for 6 years; (4) 6-year of agroforestry system. It mostly consisted of durian (*Duriozibethinus*), macang (*Mangifera* spp.,), mango (*Mangifera indica*), candle nut (*Aleurites moluccana*), pinang (*Areca catecu)* and hairy fruit (*Nephelium lappaceum*) and (5) the naturally growth of *Imperata cylindrica* for about 8 years ('grassland'). The latest field was used as a reference. For each site, 10 soil cores (1.9 cm diameter each) were randomly sampled and mixed to obtain a composite sample that was sealed in a plastic bag. Field-moist soil samples were gently sieved through a 2 mm mesh to remove stones, roots and large organic residues and sealed in plastic bags to store at 4°C. Soil biological analyses were carried out within 10 days of sampling after an overnight acclimatization period at room temperature.

Soil physical, chemical and biological analyses: The constant-head method was used to measure saturated hydraulic conductivity (Ksat) (Klute and Dierksen, 1986). Soil bulk density

(BD) was measured by the core method and total porosity was calculated using a particle density of 2.65 g cm^{-3}. Gravimetric water field capacity and water holding capacity were determined by pressure plate apparatus method (Scott *et al*., 1994). The hydrometer method was used to analyze soil texture.

Soil acidity was determined in 1:2.5 soil-water slurry, using glass electrode. Total C (TC) and nitrogen (TN) contents were analyzed on finely ground air-dried soils by wet combustion according to the method of Kandeler (1995). The fumigation-incubation method was selected to account soil microbial C (SMBC) (Jenkinson and Powlson, 1976). Moist soil (30 g dry-weight equivalent) was placed in 50 mL beakers, fumigated, brought to a water potential of approximately -30 J kg^{-1} with deionized water (0.3 kg kg^{-1}) and incubated in 1 L air-tight canning jars in the presence of 10 mL of 0.5 M KOH at 26°C for 10 d. The quantity of CO_2-C absorbed in the alkali was determined by titration (Anderson, 1982). Soil microbial biomass C was calculated from the following equation:

$$\text{SMBC} = [\text{mg } CO_2\text{-C kg}^{-1} \text{ soil } (10 \text{ d})^{-1}]_{\text{fumigated}}/\text{kc}$$

Where, kc = 0.41 (Voroney and Paul, 1984).

Mineralizable C and inorganic N were estimated from the quantity of CO_2-C and net NH_4-N+NO_3-N, respectively, released from an unfumigated sample during 10-d incubation at 26°C and a soil water potential of -30 J kg^{-1} (Campbell *et al*., 1991). Specific respiratory activity of soil microbial biomass C was calculated by dividing the net potential microbial activity (i.e., mineralizable C) by the size of the SMBC (Campbell *et al*., 1991).

Particulate organic matter (POM-C) was determined according to the method of Cambardella and Elliott (1992). POM-C was isolated by dispersing 30 g of soil in 5% of sodium hexametaphosphate and passing the dispersed sample through a 53 µm sieve which retains the POM fraction+sand and allows the passage of mineral associated soil organic matter.

Water Soluble Organic C (WSOC) was analyzed by the method of Mazzarino *et al*. (1993). Soil suspensions (1:2.5 soil:distilled water) were shaken for 30 min at 150 rev/min then centrifuged for 5 min at 2500 rev min^{-1} and filtered through Whatman no 42 filter paper. Carbon in the extract was determined following the method of Nelson and Sommers (1982).

Statistical analysis: An analysis of variance was performed to test differences in soil physical, chemical and biological properties across land management systems. For statistically different parameters ($p<0.05$), means were separated using the Least Significant Difference (LSD) comparison test.

RESULTS AND DISCUSSION

Soils under cassava field had the highest bulk density than other land-use types (Table 1). Consequently, it had low in porosity and saturated hydraulic conductivity. The cassava and banana fields contained slightly lower in silt and clay than adjacent soils under *Imperata* grassland. This is most likely as a result of preferential removal of silt by accelerated erosion during the rainy season (Handayani, 2001). The lowest saturated hydraulic conductivity was found in grassland soils and the highest was observed in legume field and agroforestry. Greater organic matter content resulted in higher rate of saturated conductivity in both soils as compared to cassava field and grassland. Low plant residues and organic inputs were probably the cause for high bulk density (Table 1).

Table 1: Selected soil physical properties under five different land-covers of similar soils in Bengkulu Province, Sumatra

Land cover type	Soil Texture	FC (%)	WHC (%)	BD (g cm^{-3})	Porosity (%)	Ksat (cm min^{-1})	Clay (%)	Silt (%)
Grassland	Silt loam	24.1^c	26.5^c	1.25^b	52.83^b	0.429^b	28.27	32.14
Cassava field	Silt loam	15.8^d	20.3^d	1.41^a	46.79^a	0.512^b	23.42	29.75
Banana field	Silt loam	26.1^b	32.1^b	1.15^c	56.60^c	0.788^a	22.89	30.81
Legumes field	Silt loam	28.2^a	34.5^a	1.00^d	62.26^d	0.892^a	29.10	38.20
Agroforestry	Silt loam	29.5^a	35.2^a	1.00^d	62.26^d	0.851^a	28.89	37.71

Means of duplicate analysis of three sites for each land-use type. Similar letter at the same column indicates no significant different using α 5%. FC: Gravimetric soil water content at field capacity, WHC: Water holding capacity, BD: Bulk density and Ksat: Saturated hydraulic conductivity

Table 2: Selected soil chemical properties under five different land-covers of similar soils in Bengkulu Province, Sumatra

Land cover type	C org (g kg^{-1})	N total (g kg^{-1})	pH (1:2.5)	C/N ratio	Inorganic N (mg kg^{-1})
Grassland	29.95^b	2.09^d	4.1	14.33	15.26^b
Cassava field	26.20^b	2.10^d	4.3	13.10	10.32^c
Banana field	28.15^b	2.35^c	4.5	11.97	17.32^b
Legume field	35.61^a	2.95^a	4.5	12.07	31.78^a
Agroforestry	37.23^a	2.85^a	4.2	13.06	27.52^a

Means of duplicate analysis of three sites for each land-cover type. Similar letter at the same column indicates no significant different using α 5%

Increased soil water holding capacity, water content at field capacity and saturated hydraulic conductivity in agroforest and legume fields is consistent with greater input of labile C. This was due to more contribution from high quality of litter-fall or plant residues and root exudates as indicated by higher WSOC and SMBC (Table 3). In addition, extracellular polysaccharides produced during C turnover processes and root extension have improved soil aggregation (Cambardella and Elliott, 1992; Opara *et al.*, 2007). This mechanism contributed to greater soil water content and saturated hydraulic conductivity. However, soil organic matter in cassava field has less physically protected than that of agroforest and grassland soils. In cassava field, tillage practices periodically breaks up macroaggregates exposing protected organic matter (Gupta and Germida, 1988; Mbah *et al.*, 2007). Therefore, compaction easily developed in cassava field.

Total nitrogen under cassava field and grassland was lower compared to banana field, agroforestry and legume fields. Legume field had the highest total N (Table 2). As expected, N content is high in soil dominated by legumes or N fixing crops such as bean. The organic C levels were significantly higher in agroforestry than those of other fields. The C/N ratios were wider under undisturbed ecosystems such as grassland, indicating higher C accumulation or slower decomposition resulted in C stabilization inside soil aggregates (Feller and Beare, 1997; Handayani *et al.*, 1995). Cassava field had lower inorganic N content than that of agroforestry and grassland. This indicated that less available-N were released through mineralization under cassava field; because this ecosystem had low N stock from labile N pools, such as in soil microbial biomass N and particulate organic matter N (POM-N).

Limited amount of total C and N in cassava field may be resulted from a combination of low biomass C returned and greater C losses due to aggregate disruption. Aggregate destruction increased following tillage, cultivation, plant residue burning and soil erosion during rainy season (Handayani, 2000). Low organic C and N content in the disturbed areas is mostly caused by the breakdown of macroaggregates (Blair *et al.*, 1995; Gupta and Germida, 1988) and greater organic matter oxidation following tillage and or cultivation (Handayani *et al.*, 2001).

Table 3: Selected soil biological properties under five different land-covers of similar soils in Bengkulu Province, Sumatra

Land cover type	Mineralizable C (mg/kg/day)	SMBC (mg kg^{-1})	WSOC (g kg^{-1})	POM-C (g kg^{-1})
Grassland	66.69	287^b	1.25^c	3.87^b
Cassava field	60.25	250^b	1.12^d	4.46^b
Banana field	70.15	265^b	1.49^b	4.85^b
Legume field	97.10	590^a	1.85^a	8.89^a
Agroforestry	90.23	527^a	1.46^b	9.69^a

Means of duplicate analysis of three sites for each land-cover type. Similar letter at the same column indicates no significant different using α 5%. SMBC: Soil microbial biomass C, WSOC: Water soluble organic C and POM-C: Particulate organic matter

The differences in soil organic C content in grassland and farm land were about 12 to 20%, with the lowest content found in cassava field (Table 2). The variation of organic C content in this study is lower compared to the study by Arya (1990). However, the range of the organic C values from this research is greater than the study by Shiddieq (1993). Arya (1990) reported a value of soil C of 68 g kg^{-1} for a secondary forest/rubber agroforest and a value of 24 and 12 g kg^{-1} after the soil was cultivated for 4 and 12 years, respectively. In this site, the agricultural systems were under extensive tillage and high lime application above the average. Shiddieq (1993) observed that soil C content was reduced about 15 g kg^{-1}, after the soils were converted to coffee or rubber plantations for 25 years. In West Sumatra, Nakano and Syahbuddin (1989) reported that soil C content reached their lowest value 3-4 years after the beginning of a fallow and gradually increased thereafter.

Soil acidity in agroforest, legume field, banana field, cassava field and grassland soils varied from 4.0 to 4.5 (Table 2). Agroforest and grassland soils were slightly more acidic than those of other farm fields. The amphoteric nature of Al, pre-weathered parent materials in these tropical soils and the intense leaching of basic cations during the rainy season are the contributors to the naturally very acid pH levels in these soils (Handayani, 2000).

The values of the measured biological properties were significantly higher in legume fields and agroforestry than banana field, cassava field and grassland soils, except for mineralizable C (Table 3). Mineralizable C rates did not vary significantly among fields but tended to be relatively higher in the soils under legume and agroforestry. High rate of mineralizable C was resulted from either large pool of labile C substrates or rapid oxidation of a smaller pool. Increased mineralizable C may indicate a high level of ecosystem productivity and soil bioactivity (Mazzarino *et al*., 1993).

A better indicator of soil quality in term of the rate of mineralization is the rate of mineralizable C per unit SMBC. This is called specific respiratory activity of soil microbial biomass C or SRAC. High level of SRAC has been associated with ecosystem stresses (Handayani and Coyne, 1999; Killham, 1985).

The highest SRAC was found in banana field (26.47%) and the lowest was in legume fields (16.46%) (Table 4). Increased microbial activities in soils under legume and agroforest are associated with greater levels of substrates C resulting in greater labile fraction of organic C. As a result, soil microbial communities under both soils have less biologically active. Higher rates of SRAC for the banana field, cassava field and grassland suggest that intense competition for available C may favor those microorganisms which use more C energy for cell integrity and maintenance than for their growth. Consequently, more intensive farming system (legume, cassava and banana fields) favor bacteria-based food webs which have low C assimilation efficiencies and faster turnover rates (Hendrix *et al*., 1986). In this study, additional N from legume also increased SRAC indicating more biologically active microorganisms. A lower SRAC implies a more stable and

Table 4: Effect of land-cover type on the properties related fractions of soil organic matter at adjacent areas of similar soils in Bengkulu Province, Sumatra

Land cover type	Min-C/SMBC (%)	SMBC/C org (%)	WSOC/C org (%)	POM-C/C org (%)
Grassland	23.24	0.958	4.174	12.922
Cassava field	24.10	0.954	4.275	17.023
Banana field	26.47	0.941	5.293	17.229
Legume field	16.46	1.656	5.195	24.965
Agroforestry	17.12	1.416	3.922	26.027

Min-C: Mineralizable C, SMBC: Soil microbial biomass C, WSOC: Water soluble organic C and POM-C: Particulate organic matter

mature system (Insam and Haselwandter, 1989; Turco *et al.*, 1994). The highest SMBC was found in legume field and agroforestry (558 mg kg^{-1}) and the lowest occurred in cassava field (250 mg kg^{-1}). Cassava field has the lowest WSOC compared to other fields.

Data in Table 3 show the amount of labile C pools under different land management systems. The availability of labile C pools in soil under different vegetation-cover appears in Table 4. Microbial biomass C is often limited in size by the availability of C-labile substrates. It is sensitive to variations in vegetation and management practices (Insam and Haselwandter, 1989). A lower proportion of SMBC is indication of biologically active soil C degradation. Tillage practices tend to decrease root production in grassland, cassava and banana fields (Gupta and Germida, 1988). Lower root biomass and removal of clipping resulted in lower substrate availability and thus lower SMBC.

WSOC is considered an intermediate organic substrate for soil microorganisms (McGill *et al.*, 1986). Turnover of SMBC requires repleshnisment of WSOC supplies. Repleshnisment mechanisms include desorption from soil colloids, dissolution from litter, exudation sloughing and exfoliation from plant roots, or hydrolysis of insoluble soil organic polymers (McGill *et al.*, 1986). Changes in soil environment, soil management and cropping practices would affect the above mechanisms, thus altering WSOC supply and both amount and activity of SMBC. The lower proportion of WSOC in total organic C under agroforestry indicates more soil organic matter was in protected condition, so they are not readily soluble or not readily available to microorganisms.

POM-C is classified as the active soil organic matter pool and has been successfully used as an indicator of nutrient availability (Dalal and Mayer, 1987). Loss of POM-C is an important aspect in soil organic matter degradation. POM-C increased after grassland conversion to farm land. Present study shows that POM-C characteristics may also serve as early indicators of soil organic matter aggradation. Values of ratio POM-C/organic C indicate similar trend with values of POM-C which show the highest under agroforest soils and the lowest in grassland soils. This implies that availability of POM-C continuously increased when more plant biomass involved (Table 4).

The aggradation and degradation indexes were calculated by scaling technique (Scott *et al.*, 1994). These indexes reflect the percent changes in soil properties from their values under standard values under grassland soils. Scaling of soil properties was used to relate the characteristics of one land-use to the same characteristics of another land-use by dividing the mean values of each soil property from the grassland. Therefore, the values from the grassland would have a scale of 1.0 and other land-use would have a scale value less than 1.0, indicating the decline of soil quality. All scale values were averaged at each land-use, subtracted by 1.0 and convert to percentage as indicated by degradation level. The aggradation level was observed if the value more than 1.0. In this study, soil properties scale was made on saturated hydraulic conductivity, gravimetric soil water content at field capacity, water holding capacity, porosity, C organic, N total, inorganic N, mineralizable C, soil microbial biomass C and particulate organic matter (Table 5).

Table 5: Soil aggradation and degradation indexes following *Imperata* grassland conversion to agricultural fields

	Scaling factor													
Land-cover	FC	WHC	Porosity	Ksat	Organic C	Total N	Inorganic N	Min C	SMBC	POM-C	Total	Means	Aggradation index (%)	Degradation index (%)
Cassava field	0.65	0.77	0.89	1.193	0.87	1.00	0.68	0.90	0.87	1.15	8.973	0.897	--	11
Banana field	1.08	1.21	1.07	1.837	0.94	1.12	1.13	1.05	0.92	1.25	11.607	1.161	14	--
Legume field	1.17	1.30	1.18	2.079	1.19	1.41	2.08	1.46	2.06	2.30	16.227	1.623	38	--
Agroforestry	1.23	1.37	1.18	1.983	1.24	1.36	1.80	1.35	1.84	2.50	15.851	1.585	37	--
Total	4.13	4.65	4.32	7.09	4.24	4.89	5.69	4.76	5.69	7.20	--	--	--	--
Means	1.03	1.16	1.08	1.77	1.06	1.22	1.42	1.19	1.42	1.8	--	--	--	--

FC: Gravimetric soil water content at field capacity, WHC: Water holding capacity, Ksat: Saturated hydraulic conductivity, Min-C: Mineralizable C, SMBC: Soil microbial biomass C and POM-C: Particulate organic matter

When averaged, soils under cassava field had the highest degradation index of 11% (Table 5). The agroforestry improved soil properties up to 59%. In some cases, grassland ecosystem often created deterioration in several soil properties (Table 5). This study shows that most soil improvement occurred when the grassland were converted to agroforestry, legume and banana fields.

CONCLUSIONS

Conversion of *Imperata* grassland to farm changed soil properties differently depending upon the type of land-cover. Cassava cultivation for six years resulted in degradation of soil quality as indicated by the changes in physical, chemical and biological properties. Grassland conversion to agricultural fields increased saturated hydraulic conductivity by 43%, porosity by 7%, soil water content at field capacity by 3%, water holding capacity by 14%, organic C by 6%, total N by 18%, inorganic N by 30%, soil microbial biomass C by 30%, mineralizable C by 16% and particulate organic matter by 44%. Specific respiration activity rates increased about 4% in cassava fields but decreased 26% in agroforestry. Legume fields significantly maintained higher soil C and N levels than the cassava field. Degradation index in cassava field was 11%. The soil improvement was observed in banana field, legume field and agroforestry at 14, 38 and 37% of aggradation index, respectively. Soil dominated by *Imperata cylindrica* grass shows lower soil quality than agricultural fields. Therefore, selecting farming practices that involves more plant biomass, diversity and organic matter supply is required to improve soil and regenerate better ecosystem productivity.

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