Leaflet No. 10/2017

The Republic of the Union of Myanmar

Ministry of Natural Resources and Environmental Conservation

Forest Department

Impact of Forest Disturbances on Soil Properties: A Case Study in Mon State, Myanmar

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December, 2017

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မြန်မာနိုင်ငံရှိပြည်သူတို့သည် သစ်တောများအပေါ်တွင် ကွဲပြားခြားနားသောရည်ရွယ်ချက်များဖြင့် မှီခိုမှုများရှိနေကြသော်လည်း အပူပိုင်းအမြဲစိမ်းတောများနှင့် ပတ်သတ်၍မူကား ကိန်းဂဏန်းအချက်အလက်အနည်းငယ်သာရှိပေသည်။ သစ်တောထိခိုက်ပျက်စီးမှုများသည် မြေဆီလွှာအပေါ် မည်သည့်သက်ရောက်မှုများရှိသည်ဆိုသည့် သတင်းအချက်အလက်များကို ခွဲခြမ်းစိတ်ဖြာခြင်းမှာ ထာဝစဉ် ညီသစ်တောစီမံအုပ်ချုပ်လုပ်ကိုင်မှုစနစ်တွင် အမှန်ပင်လိုအပ်လှသည်။ ယခုလေ့လာမှုသည် အဆိုပါသတင်းအချက်အလက် လိုအပ်မှုကို တစ်ထောင့်တစ်နေရာမှ ဖြည့်ဆည်းပေးနိုင်ရန် ကြိုးစားထားမှုတစ်ခု ဖြစ်ပါသည်။ လေ့လာမှုပြုလုပ်ခဲ့သည့်ဧရိယာအတွင်းတွင် ရွှေ့ပြောင်းတောင်ယာ၊ မြေပြိုကျမှု၊ သစ်ရွေးချယ်ထုတ်လုပ်မှု စသည့် သစ်တောထိခိုက်ပျက်စီးမှုများသည် မြေဆီလွှာ၏ ကာဗွန်၊ နိုက်ထရိုဂျင်၊ ဖော့စဖောရက်စ်လိုအပ်မှု၊ အချဉ်ဓါတ်နှင့် သိပ်သည်းဆများ အပေါ် မည်သည့် သက်ရောက်မှုရှိသည်ကို မြေနမူနာများစမ်းသပ်ကောက်ယူပြီး သက်ကြီးတောနှင့်နှိုင်းယှဉ်၍ လေ့လာခဲ့ခြင်းဖြစ်ပါသည်။ သက်ကြီးတောမြေကြီး၏ကာဗွန်၊ နိုက်ထရိုဂျင်နှင့် ဖော့စဖောရက်စ်လိုအပ်မှု ပမာဏများသည် ထိခိုက်ပျက်စီးမှုရှိထားသောတောများထက် သိသာစွာမြင့်မားနေပြီး မြေကြီး၏ သိပ်သည်းဆမှာမူ နိမ့်ကျလျက်ရှိပေသည်။ မတူညီသောမြေအလွှာများများတွင်မူ မြေကြီး၏ သိပ်သည်းဆမှလွဲ၍ ကျန်မြေကြီးဂုဏ်သတ္တိများမှာ သိသာစွာ ကွဲပြားခြားနားမှုမရှိပေ။ သစ်ရွေးချယ် ထုတ်လုပ်ထားသောနေရာများတွင် မြေကြီး၏ ကာဗွန်၊ နိုက်ထရိုဂျင်နှင့် အချဉ်ဓါတ်တန်ဖိုးများမှာ အနိမ့်ဆုံးဖြစ်နေပြီး ဖော့စဖောရက်စ်လိုအပ်မှုမှာ ရွှေ့ပြောင်းတောင်ယာဧရိယာများတွင် ဆိုးဝါးစွာ နိမ့်ကျလျက်ရှိပါသည်။ ယခုသုတေသနတွေ့ရှိချက်များအရ သစ်တောထိခိုက်ပျက်စီးမှုများသည် မြေကြီး၏ဂုဏ်သတ္တိများအပေါ် ပြောင်းလဲစေနိုင်ပြီး ယင်းသက်ရောက်မှုများသည် သစ်တောထိခိုက် ပျက်စီးမှု အမျိုးအစားများအလိုက် မတူညီကြကြောင်း ကို သက်သေပြလျက်ရှိပါသည်။

Impact of forest disturbances on soil properties: a case study in Mon State, Myanmar

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ABSTRACT

In Myanmar, people had much rely on the forest for various purposes but only few data about the tropical evergreen forest. To clarify the response after disturbances is a growing need for information relating to soil condition aimed at sustainable forest management. This study tried to fill the information gap concerning the impact of forest disturbances on soil properties in a tropical evergreen forest ecosystem, Myanmar. Soil samples were collected from three different types of forest disturbance: 1) shifting cultivation (≥15 years post-abandonment), 2) landslide (20 years post-landslide), 3) selective logging (>30 years post-logging), and 4) old growth forest (no recorded history of disturbance over the last 80 years), to determine the effects of forest disturbances on soil carbon (C), nitrogen (N), available phosphorus (AP), pH, and bulk density (BD). Soil C, N, and AP concentrations were significantly higher in old growth forest soils than in the other disturbed forests, while BD was lowest in old growth forest soils. There were no significant differences in soil properties between soil depths, except in BD. Selective logging area soils had the lowest C, N, pH values and AP may be severely depleted in areas of shifting cultivation. Our results confirm that forest disturbances can alter soil properties and that the impacts differ among forest disturbance types.

Key Words: Forest disturbance, Shifting cultivation, Selective logging, Landslide, Old growth forest

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INTRODUCTION

Disturbance is an important and integral process in many forest ecosystem and can be defined as a relatively discrete event that disrupts the structure of an ecosystem and changes resource availability or the physical environment (Powell, 2000). Since several decades ago, tropical forests were degraded due to natural and anthropogenic disturbances and lead global biodiversity declination (Mishra et al. 2004). As a result of increasing demand for firewood, timber, pasture, shelter, and food crops, natural land cover (particularly tropical forests), is being degraded or converted to cropland at an alarming rate (Hall et al. 1993). Randrianarison et al. (2016) also discussed that historical land use has had a lasting effect on vegetation and even longer-term effect on soils therefore different land use history explain soil and vegetation characteristics of the current secondary forest. Moreover, the duration and type of disturbance, e.g., woodlot, agriculture and grazing, determines the current soil properties (Yesilonis et al., 2016).

Criteria for judging the regeneration success of disturbed ecosystems have been based on the inspection of visual aboveground indicators (Mummey, Stahl, & Buyer, 2002, EPA 2012); soil components, in most cases, have received little attention. Therefore, soil information how they response to natural and anthropogenic forest disturbances became a critical need for sustainable forest management system while conserving soil fertility in the long term. The forest disturbances and associated impacts on the soil condition may lead the forest capacity at both local scales and global scales.

In the early 1990s, Myanmar had a total forest cover of about 442,000 km^2 (Leimgruber et al. 2005). The annual deforestation rate between 1990 and 2015 was 4,071 km^2, representing 0.6percent of the country's total area (MOECAF 2016). According to the Global Forest Resource Assessment conducted in 2015, 42.92percent of Myanmar's total area is still forested. The main causes of land degradation in Myanmar are demographic pressure, expansion of agricultural land, overgrazing, shifting cultivation, illicit logging, excessive use of fuel wood, installation of industrial plants, and mining (UNCCD 2005). To date, very few investigations have examined the impacts of different forest disturbances on the Myanmar soils especially in tropical evergreen forest. Fukushima et al. (2007) stated that the fallow vegetation recovery was sufficient and there were no significant decrease in total carbon (TC) and total nitrogen (TN) in the surface soil to sustain continuous swidden in the area of 12-year fallows lands in the deciduous forest in Bago Yoma region, Myanmar and Thein et al. (2007) also mentioned that if the logging was intended to the deciduous (teak and commercial hardwood) species in the deciduous forest, Myanmar, the impacts of selective logging to vegetation was not negatively affected in terms of basal area but in case of *Dipterocarpus*, the impacts of selective logging to vegetation was higher in terms of basal area logging damage was severe to the soil conditions. Those studies pointed out the vegetation and soil after disturbances were not severely affected in the deciduous forest but so did in tropical evergreen forest. In order to perform sustainable forest management, we need the qualitative data concerning the influence of disturbances. Therefore, in this study we focused on soil physio-chemical properties after disturbances in tropical evergreen forest of Myanmar.

We predicted that old growth forest would possess the high soil nutrient values and different forest disturbance types would have significant impacts on current soil quality and we examined both natural and anthropogenic forest disturbances. The objectives of this study were 1) to analyze the impacts of different forest disturbances on current soil physio-chemical properties and 2) to compare soil quality among forest disturbance types.

METHODOLOGY

Study site

This study was conducted in the Kyaik Htee Yoo forest reserve (17°25'38.20"N, 97°4'39.47"E, Fig. 1), one of the most important watersheds of the Sittaung River, Kyaik Hto Township, Mon State, Myanmar. The forest reserve covers a total land area of 156 km^2. Mon State has a tropical climate. The monthly lowest temperature is 25.6°C in January, and the highest temperature is 29.4°C in April. Annual precipitation is 5500 mm (MOI 2002); precipitation peaks in July and August. According to the first Schematic Soil Map of Myanmar, which is based on a soil classification system used by the International Society of Soil Science (FAO/UNESCO 1965), the soils at our study site are mainly granitic red brown soil. All forest stands share the same climate and parent material, and similar topography. Study site elevations range from 280 to 878 m. The whole reserve forest is occupied by the tropical evergreen forest type (Stamp 1924 and Davis 1960). Based on field observation, the most common dominant species in all disturbance types are *Archidendron jiringa*, *Styrax serrulatum*, *Anisoptera scaphula*, *Abarema bigemina*, *Microcos paniculata*, *Heterophragma adenophylla*, *Ilex sulcata*, *Cedrela serrata*, *Glochidion glaucifolium*, and *Ficus glomerata*. Data were collected during November and December 2015. The detail site information of each disturbance type and old growth forest are described in Table 1.

Areas with four different types of forest disturbance and a old growth as a reference site were selected for this study: 1) shifting cultivation areas (≥15 years post-abandonment), 2) landslide-affected areas (20 years post-landslide), 3) selective logging (>30 years post-logging) and 4) old growth forest areas (no disturbance history over the last 80 years). In our study, the old growth forest is located in high elevation ranges compare with other forest disturbance types. That is the main reason why the old growth forest sites remained undisturbed while forest areas in low elevation ranges were disturbed by anthropogenic activities, like selective logging and shifting cultivation.

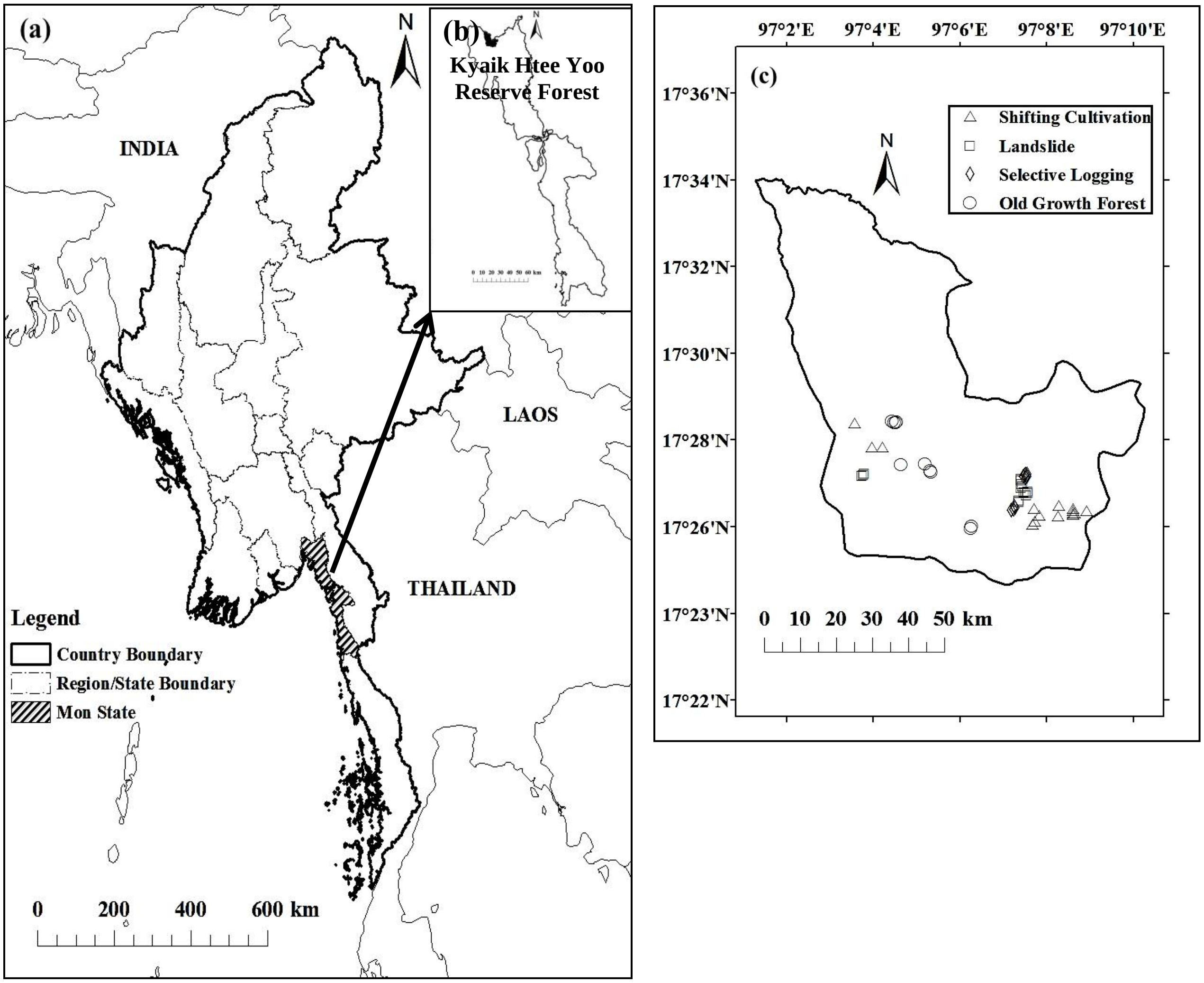


Figure 1. Maps of (a) Myanmar, (b) Mon State, and (c) Study plots

Table 1. Site details for each disturbance type and old growth forest

	Location	Elevation	Top IVI species
Shifting Cultivation	97°03'98.20"E - 97°09'88.59"E 17°26'40.25"N - 17°29'31.40"N	280 m – 434 m	*Microcos paniculata* *Heterophragma adenophylla* *Archidendron jiringa*
Landslide	97°03'22.09"E - 97°09'61.22"E 17°27'26.73"N - 17°28'37.22"N	283 m – 454 m	*Microcos paniculata* *Fiscus glomerata* *Abarema bigemina*

Selective Logging	97°07'98.77 "E - 97°08'58.08"E 17°26'94.95"N –17°28'33.53"N	339 m – 473 m	*Abarema bigemina* *Cedrela serrata* *Anisoptera scaphula*
Old Growth Forest	97°04'39.92 "E - 97°06'43.08"E 17°26'27.72"N - 17°29'38.92"N	413 m – 878 m	*Ilex sulcata* *Styrax serrulatum* *Glochidion glaucifolium*

IVI = Important Value Index

Disturbance history

As early as 1970, the entire study area was covered with natural tropical evergreen forest that had been disturbed by natural and anthropogenic factors. After 1970s, locals in some parts of the natural forest have often practiced shifting cultivation with a short cultivation period of 1 year and all the sample plots were located in ≥ 15 years post-abandonment (means the forest is no more in the fallow cycle). In 1996, severe landslides affected by heavy rains in some areas of the study site. The author tried to get more detail information and data concerning landslide in that area but no scientific data and information were left. Study plots were located in the depletion zone and the surface soil was lost by landslide. The selective logging site was cut more than 30 years ago and mostly targeted for the hardwood commercial species such as *Dipterocarpus alatus* and *Anisoptera scaphula*. All the sample plots were laid out in >30 years post-logging (single harvest only) areas. The distribution of logged areas was related to the placement of crude roads and trails. All selective logging operations proceeded according to the Myanmar Selection System (MSS) and followed the National Code of Practice for Forest Harvesting (MOF 2000). MSS is a method of harvesting tree species with prescribed minimum girth limits within the boundary of the annual allowable cut. Under the MSS, the forests are organized into felling series, each of which is divided into 30 blocks of approximately equal yield capacity, and the entire felling series is worked in the course of a 30-year felling cycle. All of the types of forest disturbance had occurred once.

In 2001, the Myanmar Forest Department, Ministry of Environmental Conservation and Forestry, designated this study area as a forest reserve to conserve the disturbed environment. All information concerning forest disturbances was obtained from two sources: official data from township forest department and extensive interviews with locals.

Soil analysis

Land use changes such as deforestation, conversion of rangeland to cropland, and cultivation are known to cause changes in soil physio-chemical and biological properties (Houghton et al. 1999). Among the physical indicators, soil texture, aggregation, moisture, porosity, and bulk density have been used, while among chemical indicators total TC and TN, mineral nutrients, organic matter, cation exchange capacity, among others are well established (Cardoso et al. 2013). The soil organic carbon affects important functional processes in soil like the storage of nutrients, mainly N, water holding capacity, and stability of aggregates (Gatto et al. 2009). This is also a key component of soil fertility, especially in tropical conditions, which interacts and must be considered in assessments of soil health (Cardoso et al. 2013). Nitrogen is one of the macronutrients needed in the greatest quantities by plants and is generally one of the most limiting to plant growth due to lack of environmental availability (Schoonover & Crim, 2015). Phosphorus is second only to nitrogen in the amount needed for optimal plant growth and one of the essential elements that are categorized as macronutrients (Schoonover & Crim, 2015). Soil pH is a key indicator because it correlates directly with nutrient availability/solubility and also affects microbial activity (Cardoso et al. 2013). Therefore, study of pH allows to predict the potential for nutrient availability in a given production system (Cardoso et al. 2013). Bulk density can better represent the effects of soil use and management (Beutler et al. 2002).

Başaran et al. (2007) proved that soil properties (C, BD and pH) were affected by land use changes. The geostatistics indicated that the dynamic relationships between soil properties and land use types. There are studies pointed out that land use history has effects on soil properties and forest biodiversity (Dupouey et al. 2002) and decreasing of soil nutrients in the forests that develop after abandonment of cultivation have examined the long term (>50 years) (Compton & Boone, 2000). In this study, to clarify the basic information of the influences of soil characteristics after disturbances, the authors selected and focused on the basic information of soil nutrients; TC, TN and AP and soil physio-chemical properties; pH (H_2O, KCl) and BD.

Soil sampling

In November and December 2015, soil samples were collected from 50 sample plots. We established 50 plots of 30 × 30 m in each type of forest disturbance area: 15 plots in shifting cultivation areas, 15 plots in landslide-affected areas, 10 plots in selectively logged areas, and 10 plots in old growth forest areas. In each plot, triplicate soil samples were collected from two soil depths (0–10 cm and 10–20 cm) by 100 ml soil core.

Laboratory analysis

In total, we got 300 soil samples and did 300 samples separately for all soil analysis. Soil bulk density (BD) was determined by a core method. Field-moist soil samples were air-dried and gently sieved through 2-mm screens to remove stones, roots, and large organic residue prior to chemical analysis. Dry soils were milled and TC and TN were analyzed using an NC analyzer (SUMIGRAPH NC-22A; Sumika Chemical Analysis Service, Ltd.). Available phosphorus (AP) was determined using the Bray II method (Sparks et al. 1996). Soil pH (H_2O) and pH (KCl) were measured in 1:2.5 (soil:water) and (soil:KCl) by a glass electrode pH meter (HM-30 P, TOA-DKK, Ltd.).

Statistical analysis

One-way analysis of variance (ANOVA) was used to compare soil properties (TC, TN, AP, pH (H_2O) and pH (KCl), and BD between different forest disturbance types. $P \leq 0.05$ was considered to indicate a significant difference. Significant differences between forest disturbances at two soil depths were tested using Fisher's least significant difference (Turkey's HSD) post hoc tests for each soil property. Relationships between soil property indices were determined by Pearson's correlation matrix. For Principle Components Analysis (PCA) analysis, the soil (0 -20 cm) variables of TC, TN, AP, BD and pH (H_2O) were standardized and normalized ($\bar{X}$ = 0 and σ = 1). All the statistical analyses were performed with SPSS ver. 23.0.0 and PCORD ver. 5.

RESULTS

Soil chemical and physical properties

Several significant effects were found within the different forest disturbances (Table 2). Soils under old growth forest presented the highest TC, TN, and AP values and there were significant differences between old growth forest and disturbed forests for these soil properties. TC and TN values were lowest in selective logging areas. The soils of the study site were acidic within a pH

(H_2O) range of 4.68-5.84 (0-10 cm) and 4.86- 5.82 (10-20 cm). The lowest pH values were found in selective logging areas. The pH values in landslide and old growth forest soils were higher than those of all other disturbed forests.

The subsoil layer (10–20 cm) had lower concentrations of the soil chemicals than upper layer that we measured. Soil properties of different soil layers were similar among disturbed forests in terms of total TC, TN, AP, and pH, and there were no significant differences among concentrations of the elements that we measured. The C:N ratios under all plots were clearly formed into two groups: old growth and disturbed forest groups while C:AP ratios were grouped into three: old growth forest, shifting cultivation and other disturbed forests in one group and all the ratios for old growth forest soils were highest (Fig. 2). The ratio between C and N generally declined with increasing soil depth. Only BD was significantly different between soil layers, under shifting cultivation and landslide areas. Soil was most compact (highest BD value) in selective logging areas. The pH distribution patterns for the two soil depths did not differ statistically.

Table 2. Soil properties for different disturbance types by soil layer (mean ± SE), N = 300

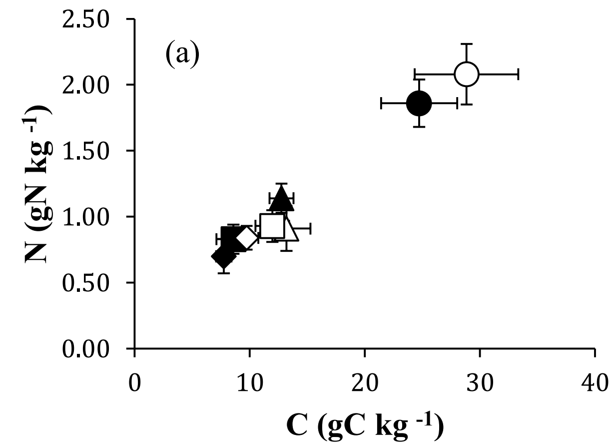
	Soil depth (cm)	Shifting Cultivation (N = 15)	Landslide (N = 15)	Selective Logging (N = 10)	Old Growth Forest (N = 10)	
C (gC kg $^{-1}$)	0-10	13.19 ± 2.11 ^{b}	11.97 ± 1.46 ^{b}	9.74 ± 1.01 ^{b}	28.85 ± 4.51 ^{a}	*
	10-20	12.76 ± 1.04 ^{b}	8.59 ± 1.49 ^{b}	7.75 ± 0.68 ^{b}	24.73 ± 3.30 ^{a}	*
		ns	**ns**	**ns**	**ns**	
N (gN kg $^{-1}$)	0-10	0.91 ± 0.67 ^{b}	0.93 ± 0.12 ^{b}	0.84 ± 0.09 ^{b}	2.08 ± 0.73 ^{a}	*
	10 - 20	1.14 ± 0.43 ^{b}	0.83 ± 0.11 ^{bc}	0.70 ± 0.13 ^{c}	1.86 ± 0.18 ^{a}	*
		ns	**ns**	**ns**	**ns**	
AP (gP kg $^{-1}$)	0-10	0.02 ± 0.00 ^{b}	0.04 ± 0.01 ^{ab}	0.04 ± 0.02 ^{ab}	0.06 ± 0.01 ^{a}	*
	10-20	0.01 ± 0.00 ^{b}	0.04 ± 0.01 ^{ab}	0.04 ± 0.01 ^{ab}	0.07 ± 0.02 ^{a}	*
		ns	**ns**	**ns**	**ns**	
pH (KCl)	0-10	4.32 ± 0.04 ^{bc}	4.47 ± 0.04 ^{a}	4.23 ± 0.05 ^{c}	4.44 ± 0.07 ^{ab}	*
	10-20	4.29 ± 0.04 ^{a}	4.39 ± 0.03 ^{a}	4.16 ± 0.03 ^{b}	4.38 ± 0.07 ^{a}	*
		ns	**ns**	**ns**	**ns**	
pH (H_2O)	0-10	5.56 ± 0.18 ^{a}	5.84 ± 0.18 ^{a}	4.75 ± 0.15 ^{b}	5.90 ± 0.10 ^{a}	*
	10-20	5.50 ± 0.18 ^{a}	5.84 ± 0.19 ^{a}	4.89 ± 0.20 ^{b}	5.74 ± 0.16 ^{a}	*

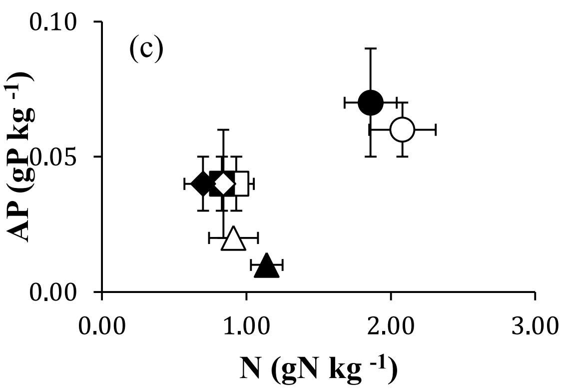
		ns	**ns**	**ns**	**ns**	
BD (g cm $^{-3}$)	0-10	2.09 ± 0.06 [a]	2.00 ± 0.06 [a]	2.16 ± 0.06 [a]	1.80 ± 0.05 [b]	*
	10-20	1.80 ± 0.67 [ab]	1.56 ± 0.05 [c]	1.85 ± 0.17 [a]	1.56 ± 0.06 [c]	*
		*	*	**ns**	**ns**	

Results of ANOVA are given for among-site (post-hoc tests) comparisons.

* Difference between means is significant at 5 percent alpha level.

Different letters in a row denote significant differences between disturbance types.





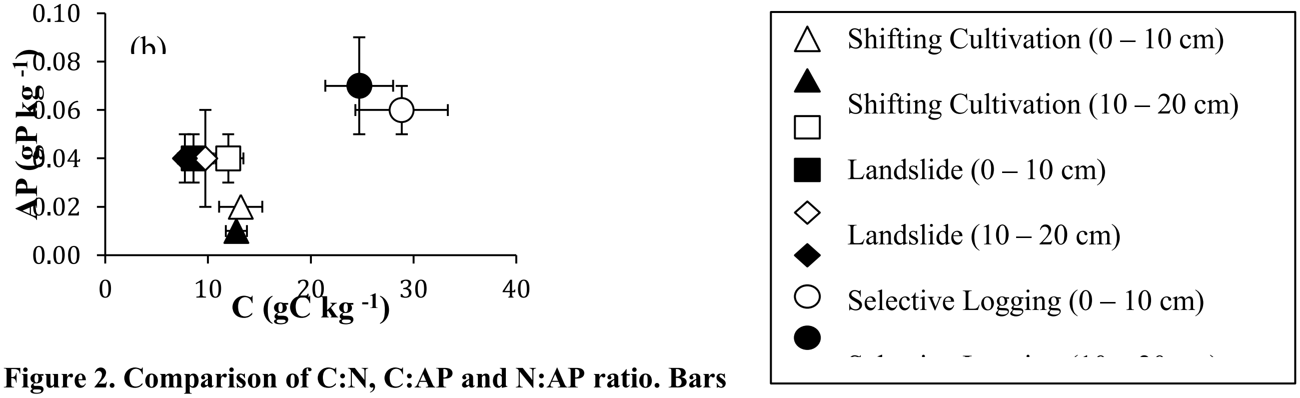


Figure 2. Comparison of C:N, C:AP and N:AP ratio. Bars indicate Standard error.

Standard error value is relatively small in available phosphorus concentration of shifting cultivation area.

The PCA revealed two main soil gradients in the study area as they showed eigenvalues ≥1 (Table 3). The first two principal components in the PCA explained 72percent of the total variance in the observations (Fig. 3, Table 3). The highest loadings for PC1 (51percent of the total variance) included TC, TN, BD and pH (H_2O). The only significant factor in PC2 (21percent of the total variance) was AP.

Nutrient storage pools in different forest disturbance types

Old growth forest yielded the highest TC, TN, and AP storage values (Table 4). Under shifting cultivation, TC and TN values were higher than those under landslide and selective logging areas. Old growth forest TC and TN values were about two times higher than those from shifting cultivation and three times higher than those from landslide and selective logging. Under shifting cultivation, the AP value was three times lower than in old growth forest and two times lower than in landslide and selective logging areas.

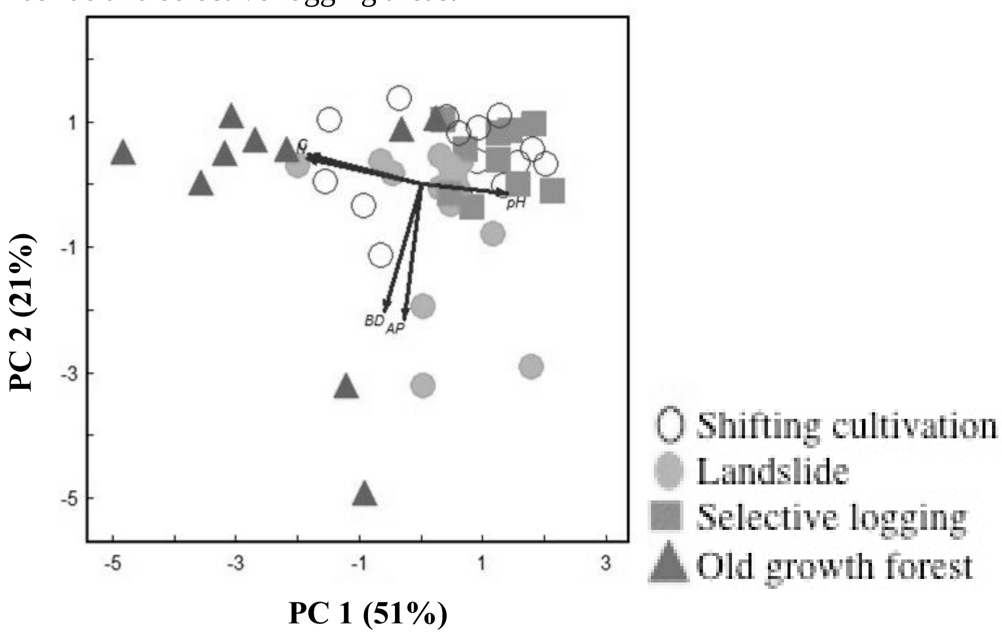


Figure 3. Distribution of 5 soil variables from 4 disturbance types in 50 plots on PCA axes 1 and 2

Table 3. Results from the principal component analysis, soil (0 -20 cm) variables of C, N, AP, BD and pH were standardized and normalized ($\overline{X}$ = 0 and σ = 1). Only principal components with eigenvalues >1 were extracted and variables having a correlation coefficient of greater than I 0.7 I with extracted PCs were judged to be significant. Asterisks indicate soil variables that are strongly correlated with axis. PC = principal component

	PC1	PC2
Eigenvalue	2.530	1.069
Percentage of variance explained	51	21
Cumulative percentage	51	72
Variables	**Eigenvectors**	
C*	**0.945**	0.005
N*	**0.962**	-0.041
AP*	-0.015	**-0.880**
BD*	**-0.670**	0.307
pH (H_2O)*	**-0.513**	-0.444

PC = principal component

Table 4. Soil C, N and AP storage pool for different disturbance types (kg ha $^{-1}$) (mean ± SE), N = 150

	Soil Depth (cm)	Shifting Cultivation (N = 15)	Landslide (N = 15)	Selective Logging (N = 10)	Old Growth Forest (N = 10)	
C (kg ha $^{-1}$)	0 - 20	73518 ± 7485 ^{b}	55946 ± 7880 ^{b}	48249 ± 2109 ^{b}	149315 ± 20456 ^{a}	*
N (kg ha $^{-1}$)	0 - 20	5991 ± 630 ^{b}	4935 ± 557 ^{b}	4269 ± 335 ^{b}	11033 ± 1080 ^{a}	*
AP (kg ha $^{-1}$)	0 - 20	112 ± 18 ^{b}	231 ± 59 ^{ab}	216 ± 43 ^{ab}	374 ± 132 ^{a}	*

Results of ANOVA are given for among-site (post-hoc tests) comparisons.

* Difference between means is significant at 5 percent alpha level.

Different letters in a row denote significant differences between disturbance types.

DISCUSSION

Impacts of forest disturbance on soil properties

Soils integrate long- and short-term history through their physical and chemical characteristics, biological activity, and spatial landscape arrangement (Fanning et al. 1989). PC1 best separated the soil properties from disturbed forests and old growth forest (Fig. 3) forming two main groups of disturbed and undisturbed forests. The PC1 indicators with the highest loading values are well known for their close relationship with soil nutrient. The PCA results also indicated that the disturbed forests were found to have soil properties variations among the sites and most of the disturbed forest sites possessed lower soil nutrients values. The old growth forest possessed the highest values of TC and TN and the disturbed forests were found in lower values of soil nutrients and high BD values areas. Finding from PCA analysis indicated that soil nutrients could clearly reflect the history of forest disturbance. Compton et al. (2000) also pointed out that important ecosystem processes, such as C storage and N retention, were influenced by soil properties and reflected historical land use types. From the PCA results, it was included some outliers in landslide and old growth forest. But, there were similar range in terms of topography, soil types and vegetation type among all sample plots. This result pointed out that we need to explore more concerning the vegetation in the study area. From this study, forest disturbance type has been shown to be a critical factor in determining current soil TC, TN, and AP conditions following conservation initiatives.

We expected to find a strong impact in the selective logging areas due to the removal of large amounts of biomass and found that there were also differences in the mean values of soil physio-chemical properties according to forest disturbances. TC, TN, and AP values were highest in old growth forest, in line with our hypothesis. Though there are limitations to the interpretation of our results because of no baseline soil data in our study site before forest disturbances, our results indicate that most soil properties are strongly influenced by forest disturbance types.

Soil physio-chemical properties

Carbon and nitrogen

We expected TC and TN to be correlated because they are both related to the amount of organic matter in the soil (Kahle et al. 2002, Takoutsing et al. 2014). The clear group separation pattern found in Fig. 2 also stated that forest disturbances were found to be a critical factor in determining soil TC and TN change. According to Pal et al. (2013), higher organic C concentrations were found in soils under forest land than under equivalent cleared sites and soil organic carbon was rapidly lost following the removal of trees in such environments. It is consistent with our result (Fig. 2) that soils in old growth forest that has not been cleared canopy cover for 80 years possessed the highest value of TC and TN. Higher C and N concentrations in surface layers under forest land reflect the larger quantity of biomass input to the soil surface under forest land and hence organic matter accumulation (Wilson et al. 2008). Soil properties such as the organic TC and TN content in selective logging soil had the lowest values compared with the soils under other disturbed forests (Table 2, Fig. 2). This suggests that selective logging causes the most severe damage in terms of TC and TN accumulation among the forest disturbance types we examined. The major impact of selective logging is not only the removal of tree biomass but also the removal of the topsoil as a result of log dumps, haulage roads, elephant skidding, and large skid trail construction, all of which result in the loss of soil nutrients.

Available phosphorus

The AP was grouped into three; old growth forest, disturbed forests except shifting cultivation and shifting cultivation (Fig.2). The soil under shifting cultivation was lower in AP values among the disturbed and old growth forests. The reason of showing relatively lower AP compare to other disturbed and old growth forests may be because the AP requirement of cultivated crops was higher and the absorbed AP was removed from the field in the cultivated soil compared to other disturbances. Another reason is the occupation of fast-growing species which uptake nutrient after shifting cultivation. This is in line with the finding of George & Buvaneswaran (2001) who mentioned that the rapid nutrient absorption by fast-growing species would lead to decrease in soil nutrients. This pointed out that the ability of soils to recover soil P performs that longer periods of time are required.

pH and bulk density

Soil acidity in the study area may be due in part to high annual precipitation. Precipitation has been shown to eliminate base cations from the surface horizon through leaching, thereby decreasing pH and increasing soil acidity. The pH(H_2O) values under shifting cultivation and selective logging were relatively low compare to others and the difference between pH (H_2O) and pH (KCl) of those were also small. It would be expected that practicing shifting cultivation and selective logging might reduce basic cations due to the uptake, leaching and loss of soil organic matter through the removal of biomass. The pH (H_2O) values was around 4.5 after 20-30 years of abandonment in the evergreen forest of Madagascar and the pH value was not related to the age of abandonment (Randrianarison et al. 2016). In this study, the difference between pH (H_2O) and pH (KCl) were large compare to the values in the study of Randrianarison et al. (2016) so it can be discussed that the soil of study area contains a lot of exchangeable cations and there is a possibility that the soil could be acidic after using the exchangeable cations by plants. Therefore, we need to measure and explore more about the exchangeable cations.

BD varied significantly not only depending on forest disturbance type but also between the topsoil and subsoil layers. Soil was the most compact, with the highest BD values, in selective logging areas. This is caused by elephant logging operations and the construction of skid trails. BD values were lowest in old growth forest, where the C concentration was highest (Table 2). Normally, BD values decrease where soil C is relatively high (Başaran et al. 2008). The high BD associated with selective logging influences both the physical and chemical properties of soil.

CONCLUSION

Ecological implications

We have shown that forest disturbances influenced soil chemistry in our study site. The impacts of forest disturbance on soil chemistry reflect the characteristics of each forest disturbance type. Differences in soil properties may be the results of the complex interactions of forest disturbances. Forest areas were slashed and burn for cultivation, cleared for landslide, selectively logged during harvesting time and after abandonment, soil condition led to the recovery pattern.

There was a significant difference in TC and TN concentrations between old growth forest and all other forest disturbance types (Table 2). These differences may indicate that TC and TN contents require several decades or more of development to return to their original state before the disturbance time. This is consistent with the findings of Zarin et al. (1995) and Cheng et al. (2016). The lowest AP value, found in soils under shifting cultivation, reflected AP removal by agricultural practices and uptaking of more nutrients by fast-growing species. However, soil under shifting cultivation showed not only the lowest AP value but also the second-lowest N concentration (Table 2).

The lowest TC and TN concentrations, found in selective logging areas, resulted from a combination of lower C inputs due to limited biomass C return on harvested land and greater C losses due to aggregate road construction and disruption by elephants during log milling (Fig. 3a). In comparison, low values of TC and TN in landslide areas demonstrate the changes in soil properties that typically follow landslides (Adams et al. 1987). The similar patterns of TC, TN, and AP in the landslide and selective logging areas indicated that the disturbance caused by selective logging on soil chemistry was as strong as those caused by the collapse of the surface soil with a landslide. Many studies (Brouwer et al. 1996, Hedin et al. 1995, Hughes et al. 2000, Keller et al. 2001) have suggested that a 30-year logging cycle in humid tropical forests may be too short for atmospheric nutrient deposition to restore all lost base cations, which could result in nutrient depletion to these forests over time (Zarin et al. 1995, Cheng et al. 2016). The MSS 30-year rotation harvesting practice is entirely based on only the increment of stand growth without taking into consideration about soil conditions. To date, research on the impacts of selective logging on soil nutrients in Myanmar has been very limited and most of the studies were focused on the forest vegetation. According to our results, a logging cycle of more than 30 years is essential to mitigate the influences of logging on soil nutrients. Further study on nutrient budgets under selective logging is therefore needed.

This study has shown that different forest disturbance types influence soil chemistry in different ways. The results obtained from this study would be the pioneer and essential information required by regional and state and government agencies in order to practice effective forest management and improve soil resource. We suggest further quantitative study of nutrient change following forest disturbance to be consistent with sustainable forest use. In this study we assumed that the vegetation was similar among sites based on the vegetation category and field observation. However, the further study of vegetation in each site is also needed.

ACKNOWLEDGMENTS

This study was financially supported by the Ministry of Education, Culture, Sports, Science and Technology (Monbukagakusho: MEXT), and the Japan Society for the Promotion of Science (JSPS) 15 (H) 04516. We thank students of the University of Forestry for their help in the field and all members of the Kyoto University silviculture laboratory for their help during various stages of this research.

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