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EVALUATING SOIL FERTILITY OF VARIOUS AGRICULTURAL LANDS USING SOIL EVALUATION FACTOR (SEF) AT TROPICAL UPLANDS IN SARAWAK

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INTRODUCTION

Rapid population expansion throughout decades has put tremendous pressure on the agricultural land resources across the globe including Malaysia. With increasing cases of land degradation, the awareness in conserving the soil resources slowly gained attention from policymakers and public society. Soil quality indicators were developed by scientists to quantify large-scale evaluation systems including integrated natural resource management framework and soil fertility capability (Sanchez *et al.* 2003). Soil Fertility Index (SFI) has been implemented by Moran *et al.* (2000) to determine the relationship between soil fertility and rate of secondary forest succession. Subsequently, Lu *et al.* (2002) improved the equation by introducing Soil Evaluation Factor (SEF) to evaluate the secondary forests succession at Brazil under different types of soils (Alfisols, Ultisols, and Oxisols). Few researchers have been adapted these indices to estimate the soil fertility and quality of secondary forests in Southeast Asia (Doi and Sakurai 2004; Arifin *et al*. 2008). Additionally, Panwar *et al.* (2011) further proposed these indices to determine the impact of different land uses including forest plantation, home garden, areca nut plantation and agricultural land on soil fertility of Entisols in India. However, the applicability of these indices in estimating the soil fertility under tropical upland soils has not been commonly practiced in Malaysia. Thus, this study aimed to determine the soil fertility at various agricultural land uses cultivated with rubber, oil palm and pepper using Soil Evaluation Factor (SEF) in comparison with the adjacent secondary forests at tropical uplands in Sarawak.

MATERIALS AND METHODS

Study Area

This study was conducted at Sabal upland area (N 01°04’24.6”, E 110°58’08.6”), Sarawak, Malaysia. Mean annual temperature is approximately 32.5°C while average annual precipitation is about 3585 mm (Meteorological Department 2014). The soils of the study area were derived from non-calcareous sedimentary rock consisting fine and whitish sandstone which is further classified into Oxyaquic or Spodic Quartzipsamments based on USDA Classification System (Soil Survey Staff 1999). The area has been inhabited by Iban people for the past 100 years, where they practiced subsistence farming and cash crop farming mainly by shifting cultivation.

Soil Sample Collection and Analysis

Prior to soil sampling, community survey via household interview was conducted to collect baseline information on land use history and management practices. Subsequently, desirable sites were selected based on the interview for the purpose of field survey and samples collection. Soil samples were collected at the different sites planted with rubber (*Hevea brasiliensis*), pepper (*Piper nigrum*) and oil palm (*Elaeis guineensis*). Moreover, soil samples were also collected from the abandoned secondary forests after series of shifting cultivation as control samples. Less intensified rubber cultivation normally required minimal fertilizers input at first few years after planting while no fertilizers were applied after the 5th year of planting. On the other hand, oil palm and pepper crops required frequent fertilizers application, thus more intensified as compared to rubber cultivation. The amount of fertilizers applied usually increase with increasing age of the crops. Due to the differences in their land management practices, the land uses were divided with reference to harvesting period as showed in Table 1 below. Secondary forests were also further divided into young and old secondary forests based on fallow age.

Table 1 Group division of different land uses with reference to fallow age and harvesting period

Land Uses	Young	Old
Secondary Forests (SF)	Fallow period of 1 to 12 years (Y-SF) n = 20	Fallow period of 35 to 50 years (O-SF) n = 10
Rubber Farmlands (R)	Before tap rubber of 1 to 10 years old (BT-R) n = 13	After tap rubber of 17 to 50 years old (AT-R) n = 21
Oil Palm Farmlands (OP)	Before harvest oil palm farmlands of 1 to 2 years old (BH-OP), n=17	After harvest oil palm farmlands of 3 to 7 years old (AH-OP) n=11
Pepper Farmlands (P)	Before harvest pepper farmlands of 1 to 2 years old, (BH-P) n=13	After harvest pepper farmlands of 3 to 8 years old (AH-P) n=8

Composite soil samples were collected at the depth of 0-10 cm from three random points at the intersection of the diagonal lines between four adjacent points (center point). Soil samples collected were air-dried and crushed to pass through a sieve with 2 mm and 0.4 mm mesh for soil physicochemical properties. The analytical methods for soil analysis are as follow; soil pH was determined in water or 1M KCl in a soil to solution ratio of 1:5 using glass electrodes. The filtrate from pH KCl was used for exchangeable Al + H analysis. Exchangeable Al and H were determined by the titration method with 0.01M NaOH and the content of exchangeable Al with 0.01M HCl. The soil organic matter (SOM) was determined by loss on ignition method (Faithfull 2002). Total-N was determined by Kjeldahl acid digestion method using concentrated sulphuric acid (Bremner and Mulvaney 1982). Exchangeable bases (K, Na, Mg, Ca) were extracted using ammonium acetate at pH 7.00 and was determined using atomic absorption spectrophotometer (Coleman *et al.* 1959). Available phosphorus was quantified using Bray-II method (Kuo 1996).

Computation of the Soil Indices and Data Analysis

In the attempt to quantify the soil fertility, Soil Evaluation Factor (SEF) which reported by Lu *et al.* (2002) was adapted. He further explained that an SEF value with less than 5 indicated extremely poor soil fertility while higher soil fertility can be indicated by higher SEF value. The equation of SEF indices was as follow:

$$\text{SEF} = [\text{exchangeable K } (\text{cmol}_c\ \text{kg}^{-1}, \text{dry soil}) + \text{exchangeable Ca } (\text{cmol}_c\ \text{kg}^{-1}, \text{dry soil}) + \text{exchangeable Mg } (\text{cmol}_c\ \text{kg}^{-1}, \text{dry soil}) - \log(1 + \text{exchangeable Al } (\text{cmol}_c\ \text{kg}^{-1}, \text{dry soil}))] \times \text{soil organic matter } (\%, \text{dry soil}) + 5$$

For comparison of SEF among different land uses, one way ANOVA was performed using SPSS Version 17. The value of SEF index was correlated with selected soil properties using Pearson Correlation Matrix in order to determine the relationship of soil fertility in the study area.

RESULTS AND DISCUSSION

Soil Evaluation Factor under Various Land Uses in Relation to Secondary Forests

Table 2 presented the estimated SEF values of surface soils (0-10 cm) with respect to different land uses in the study area. From the results, it was observed that SEF for surface soils at all the land uses at Sabal area showed no significant differences. Meanwhile, the values of SEF for surface soils at all study sites exceeded 5, suggesting that the soils of the area do not fall under the range of extremely poor soil fertility as mentioned by Lu *et al.* (2002). The SEF was greatest for BH-P farmlands (9.58), followed by Y-SF (9.09), BT-R farmlands (9.04), AH-OP farmlands (8.98), AH-P farmlands (8.58), O-SF (6.84), BH-OP farmlands (6.79) and least for AT-R farmlands (6.62).

Table 2 Soil Evaluation Factors (SEF) at surface soils (0-10 cm) under different land uses in the study area

	Secondary forests		Rubber farmlands		Oil Palm farmlands		Pepper farmlands	
	Y-SF	O-SF	BT-R	AT-R	BH-OP	AH-OP	BH-P	AH-P
SEF	9.09±2.71 ns	6.84±0.91 ns	9.04±3.89 ns	6.62±1.49 ns	6.79±0.98 ns	8.98±3.33 ns	9.58±3.26 ns	8.58±2.16 ns

Means ± standard deviation: values in the same column followed by different letters are significantly different at $P<0.05$ (Scheffe's multiple comparison tests). ns, no significant different.

The average SEF value of the surface soils in Y-SF was higher than those in O-SF, suggesting that higher nutrient contents in Y-SF which probably due to the remaining ash effects from the previous shifting cultivation practices (Juo and Manu 1996; Wasli *et al.* 2009). As for the O-SF, lower SEF values could be attributed to the uptake of nutrients (K, Ca, Mg and P) by the recovering vegetation apart from leaching and erosion loss. Moreover, rubber cultivation at both BT-R and AT-R farmlands showed a similar trend of SEF value to Y-SF and O-SF, indicating the development of soil fertility under rubber cultivation at the study area resembled as those in secondary forests. Except for BH-OP, oil palm and pepper cultivation generally resulted in nutrient enrichment of the surface soils as nutrients were gradually added to the soils in the form of inorganic fertilizers. Such consequences had resulted in higher SEF value in the AH-OP, BH-P and AH-P farmlands, which was comparable to Y-SF. Relatively, similar SEF values among these farmlands with Y-SF indicated that the development of soil fertility status in these farmlands was close to Y-SF.

Relationship between Soil Evaluation Factor and Selected Soil Physicochemical Properties

In order to determine the relationship between SEF and soil properties, the correlation between the SEF values with soil physicochemical properties were conducted using Pearson's correlation matrix (Table 3). Such relationship is considered vital to determine the soil physicochemical properties which affect the soil fertility in the study area.

Table 3 Pearson Correlation Coefficients between soil physicochemical properties with Soil Evaluation Factor (SEF) for surface soils (0-10 cm)

	pH(H_2O)	SOM	T-N	Al	K	Mg	Ca	AvP
SEF Surface (0-10cm)	0.322 **	0.596 **	0.509 **	0.324 **	0.601 **	0.783 **	0.825 **	0.046 ns

** Indicate significant different at $P < 0.01$; ns: not significant.

Pearson Correlation matrix revealed significant correlations ($P<0.01$) between SEF with SOM, Total-N, exchangeable K, exchangeable Mg and exchangeable Ca at the surface soils, indicated that these soil properties act as important fertility indicators for surface soils in the study area. Unlike SOM, the level of N, K, Mg and Ca in the soils could be maintained through the inorganic input from chemical fertilizers. Since SOM was found one of the important indicators which affect the soil fertility within the study area, this indicated that decomposed SOM is one of the main sources of essential nutrients for crops growth. Apart from that, stable organic fraction in the form of humus also adsorbs and holds nutrients which are readily available to plants. Farmers, therefore, should maintain and conserve the level of SOM at their farmlands to ensure the efficient supply of nutrients to the cultivated crops, particularly under intensified, long cultivation of oil palm and pepper crops. Regular mulching practices in these farmlands are one of the possible options in order to maintain the supply of SOM in these farmlands to prevent soil nutrients depletion under long cultivation practices. For instance, the crop residues from pruning practices in oil palm and pepper farmlands are one of the suitable mulch materials.

CONCLUSION

As the SEF values of all land uses were not significantly different to Y-SF and O-SF, current agricultural practices in the study area do not have any adverse effect on soil fertility. However, maintaining the ample supply of SOM at various land uses, especially in oil palm and pepper farmlands are crucial in sustaining the soil fertility at Sabal upland area.

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