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Microbial and physical-chemical properties as influenced by land use change in the conversion of cassava into rubber tree plantation system

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Abstract

Land use change and agricultural management practices could have an impact on soil properties and quality. The aim of this study was to evaluate the effect of land use change from the previous crop (cassava) to a rubber tree chronosequence on soil quality related to microbial and physical-chemical properties. Microbial properties together with physical-chemical properties, including microbial biomass carbon, soil respiration, microbial quotient (q_{mic}) and microbial metabolic quotient-C (qCO_2), which have been considered as effective indicators of the changes in soil quality, were examined. Soil total nitrogen, available phosphorus and exchangeable potassium content were higher in the rubber tree plantation than the cassava plantation, suggesting an improvement in soil microbial biomass efficiency. The highest q_{mic} was found in 11 years rubber tree plantation which indicates most efficiency of converting organic carbon into microbial biomass carbon or carbon losses in soil. Interestingly, no significantly different of qCO_2 was found among treatments. These findings suggested that soil quality related to microbial properties was not responsive to land use change from cassava to rubber tree.
Keywords : *Land use change, cassava, rubber tree, soil respiration, microbial biomass*

1. Introduction

Besides southern Thailand which is the traditional area for planting rubber tree (*Hevea brasiliensis*), the rubber tree can be grown in many areas of Thailand. During the last 30 years, the rubber tree cultivated land was significantly extended. Nowadays, the total area of rubber tree plantation approximately increases from 2.9 M ha^{-1} in 2011 to 3.5 M ha^{-1} in 2013 (1). Expansion of rubber tree cultivated land may result in positive or negative effect on soil structure or soil quality depending on the soils and climatic conditions of the area such as the amount of rainfall, soil characteristics and biological properties. Previous studies showed that land use change, especially the conversion of native forest to cash crop, can alter soil carbon and nutrient available in soil (2, 3). Compared with the secondary forests, soil organic carbon stock decreased by 33% in 3 years old of rubber tree plantation and total soil nitrogen stock decreased by 20.4%. In 2006, Jiang et al. (4) reported that soil organic matter content decreased from 38.02 g/kg to 25.76 g/kg or 68% in the past 20 years (1982-2003) after conversion of native forest to cultivated land. Besides soil carbon, soil organic matter and nutrient available in soil, land use change from native forest to cash crop can also alter soil fertility (5). In addition, conversion of swiddening to continuous annual cropping systems brings about losses of aboveground carbon stocks, reductions of soil organic carbon (SOC) stocks and generally leads to declining soil quality (6). However, data of impact of land use change on soil quality and functioning, in conversion of intensive annual cropping to rubber tree remains insufficient.

To determine the change of soil quality can be done by assessment of physical-chemical properties of soil. Moreover, soil biological parameters will be potential and sensitive indicators of soil management induced changes in soil quality (7) since microorganisms act direct or indirectly on organic matter decomposition and maintenance of several soil properties. In term of biological parameters, microbial biomass, the living part of soil organic matter, is considered one of the most sensitive and effective indicators because it is directly influenced by biotic and abiotic factors (8). Moreover, it functions as a transient nutrient sink and is responsible for releasing nutrient from organic matter which is used by plants (9). Microbial activity included microbial respiration also acts as one of the main biological indicators of soil quality and respond to changes resulting from agronomic practices (10). Similar result was found by Srivastava et al. (8). In their study, they indicated that the microbial biomass of the restoration area was 50 % lower than of the forest. Moreover, soil microbial properties such as the metabolic quotient ($q\mathrm{CO_2}$) (ratio of soil respiration to microbial biomass carbon) and microbial quotient (q_{mic}) (ratio of microbial biomass carbon to soil organic carbon) are also cited in the literature as efficient properties to evaluate soil quality. Lower $q\mathrm{CO_2}$ values indicate that the soil microbial biomass is more efficient in using carbon and energy (11), which is more common in environments with lower levels of disturbance or stress. Organic matter quality is indicated by q_{mic}.

This study aims to investigate the impact of land use change from cassava shift to a rubber tree plantation system on microbial biomass and activity related to main soil functions such as nutrient turnover, mineralization and immobilization, which play a critical role in sustaining soil quality.

2. Materials and Methods

2.1 Study sites

The study site was located in Tha Phra subdistrict, Khon Kaen province. Five treatments used in this research, including 1) cassava plantation (previous crop, 16°29′ N; 102°82 E), 2) 3 years rubber tree plantation (3Y) (16°29′ N; 102°83′ E), 3) 11 years rubber tree plantation (11Y) (16°46′ N; 102°75′ E), 4) 17 years rubber tree plantation (17Y) (9°22′ N; 102°88′ E) and 5) 27 years rubber tree plantation (27Y) (16°29′ N; 102°82′ E). The area of each plot is 1,600 square meters.

Tapping for rubber begins when the trees are 7 years old. The soil is characterized as a Ban Phai soil series which was classified as a sandy or loamy, siliceous, isohyperthermic Arenic Paleustalfs. Soil sampling has been made at 5 locations on soil depth 0-25 cm. The climate is tropical with the dry season (December 2014), the mean rainfall was 8.9 mm and the mean annual temperature was 32°C.

2.2 Soil analysis

Soil studies were conducted by digging for five sample soils in 6-months old cassava plantation and rubber tree plantation cultivar RRIM600 age 3, 11, 17 and 27 years old. Soil characteristic analyses were done by studying the physical and chemical properties of the soil (Table 1). Physical properties studied include soil moisture, total soil density of the soil through the core method with 0-25 cm. of soil depth and particle-size distribution and soil texture by hydrometer method. Chemical properties studied include soil reaction by pH meter method in ratio of 1:1 with water, total nitrogen (total N) by micro Kjedahl method (12), available phosphorus concentration by Bray II and colorimetric method (13), exchangeable potassium level by extracting with ammonium acetate 1N, pH 7.0 and measured by flame photometer, organic carbon in soil by wet oxidation method (14). Calculations of carbon stock were also evaluated (15).

2.3 Microbial biomass carbon

Microbial biomass carbon was measured in fresh soil immediately after sampling by the chloroform fumigation extraction technique (16). Briefly, 20 g of soil was extracted with 100 ml of 0.5 M K_2SO_4. Microbial biomass-C in the extracts was determined after oxidation with $K_2Cr_2O_7$. The calculation was made as the difference between fumigated and unfumigated values and employing K_{EC} factor of 0.33 (17) and K_{EN} factor of 3.1 (16).

2.4 Soil respiration

Alkaline trap method was used to measure field CO_2 emission; a small glass jar (5.5 cm height, 6 cm diameter) containing 20 ml of 1 M NaOH was placed in a closed metal chamber (16 cm diameter and 29 cm height) and left for 24 h. The evolved CO_2 trapped was subsequently determined by back titration with 0.5 M HCl after precipitating the carbonate with excess 0.5 M $BaCl_2$. Soil respiration, i.e., CO_2 emission, was computed according to the equation described by Anderson (18).

2.5 Statistical analysis

This experiment has been designed as the completely randomized design (CRD). F-test along with method of Duncan's multiple range test (DMRT) was used to analyze the differences of the average on each experiment.

3. Results and discussion

3.1 Physical and chemical properties of soil

The data of physical and chemical properties of soil are shown in Table 1. The results showed that soil samples of all treatment were sandy soil with 95.86, 3.31 and 0.83% of sand, silt and clay, respectively for cassava plantation, 93.78, 5.18 and 1.04% of sand, silt and clay, respectively for 3Y, 95.86, 3.38 and 0.76% of sand, silt and clay, respectively for 11Y, 93.78, 5.53 and 0.69% of sand, silt and clay, respectively for 17Y and 95.86, 3.31 and 0.83% of sand, silt and clay, respectively for 27Y. The greatest bulk density as 1.23 g/cm^3 was found in rubber tree after tapping (27Y), however the studies showed that bulk densities did not differ significantly between previous crop (cassava plantation) and rubber tree plantation. Soil moisture at the time of sampling varied among the sites and was highest in 11Y, followed by 27Y, 3Y, 17Y, and cassava plantation (Table 1). Soil pH varied in a moderately acid range, from 5.2 to 5.62, with most acidity in the soils under cassava plantation. The highest total nitrogen as 0.034 % was observed in rubber tree after tapping (27Y) due to nitrogen is the nutrient more intensely returned to the soil with leaf litter fall (19), however the studies showed that total nitrogen did not differ significantly between previous crop (cassava plantation) and rubber tree plantation. Interestingly, the significantly different of available phosphorus was found between cassava plantation and rubber tree plantation. Available phosphorus content is lowest in cassava plantation (previous crop) as 7.75 mg/kg. The highest of available phosphorus concentration was found in rubber tree before tapping (3Y). The mean values of available phosphorus for the 3Y, 11Y, 17Y and 27Y were 19.16 mg/kg, 11.09 mg/kg, 13.14 mg/kg and 17.02 mg/kg, respectively. Available phosphorus seemed limiting in the cassava plantation but showed better concentration in the rubber tree plantation. The highest exchangeable potassium was found in rubber tree plantation after tapping (17Y) as 57.46 mg/kg. Therefore, rubber tree plantation may be encouraged in secondary soils regenerating on degraded cassava plantation to restore the total nitrogen, available phosphorus and exchangeable potassium in the soil. The results indicate that lower C stock in soil was found in rubber tree plantation before tapping (3Y) when compared to cassava plantation (previous crop), however, higher C stock in soil was found in rubber tree plantation after tapping (27Y) which related to higher plantation age (Table 1), suggesting a accumulation of litter fall over a long period which was consistent with data reported by Promraksa and Smakgahn (15) and Puttaso et al. (20).

Table 1. Physical and chemical properties of soil

Treatment	Cassava	3Y	11Y	17Y	27Y	F-test	CV (%)
Soil texture	sand	sand	sand	sand	sand	-	-
Bulk density (g/cm^3)	1.03	0.98	1.05	1.18	1.23	ns	18.08
Soil moisture (%)	1.55^c	2.72^b	6.08^a	2.13^b	3.66^b	*	49.53
Soil pH	5.20	5.62	5.27	5.58	5.42	ns	4.72
Total nitrogen (%)	0.019	0.019	0.013	0.028	0.034	ns	53.48
Available phosphorus (mg/kg)	7.75^b	19.16^a	11.09^a	13.14^a	17.02^a	*	89.8
Exchangeable potassium (mg/kg)	29.41^b	28.24^b	24.31^b	57.46^a	36.47^b	*	47.17
Carbon stock in soil (t C/ha)	5.68^b	3.68^c	3.08^c	8.84^a	11.70^a	**	30.08

In each row, means followed by the same letter do not differ statistically from each other at $p \leq 0.05$ according to DMRT test

3.2 Microbial biomass and metabolic activity

The data of microbial properties of soil are shown in Table 2. The highest microbial-C was found in the soil under young rubber tree plantation (11Y). The highest levels of CO_2 release occurred in 11Y, followed by 3Y, 27Y, 17Y, a similar value was observed in the soil with cassava plantation site. CO_2 emission can also be varied by the effect of soil temperature, moisture, nutrients and plant age. The increase of SOC with time was observed. The accumulation of SOC was highest in 27Y. Reduction in latex yield at later age (27Y) might have resulted in the increase of below-ground organic carbon input (21). The most efficiency of the microbial community, metabolic quotient-C (qCO_2), was also found in cassava plantation indicated that more efficiency of heterotrophic microorganisms to convert organic carbon into microbial biomass (22). Lower qCO_2, suggesting that microbial communities in cassava plantation was more efficient in carbon use than the communities in the other treatment. Interestingly, qCO_2 were higher in treatments under rubber tree plantation showing a small microbial biomass with high respiration. However, no significantly different was found in qCO_2 among treatments. The highest microbial quotient-C (q_{mic}), the ratio of microbial biomass-C to SOC which has been used as an indicator of future changes in organic matter status that will occur in response to alterations in land use (23), was also observed in young age of rubber tree (11Y) suggesting a large proportion of soil organic matter occupied by microbial biomass. However, there was no significantly different of q_{mic} was found between the other ages of rubber tree plantation and cassava plantation.

Table 2. SOC, Microbial biomass-C, CO_2-emission rates, metabolic quotient (qCO_2) and microbial quotient-C (q_{mic}), ratio of microbial biomass-C to organic-C in soils under rubber tree plantations

Treatment	Cassava	3Y	11Y	17Y	27Y	F-test	CV (%)
Soil organic carbon (SOC) (%)	0.21^{C}	0.15^{cd}	0.13^{d}	0.31^{b}	0.39^{a}	**	16.37
Microbial biomass-C (mg/kg)	1480.9^{c}	997.17^{d}	2721^{a}	1768^{b}	1710^{b}	*	68
CO_2-emission (mgCO_2/kg/day)	3.20^{c}	8.61^{a}	8.66^{a}	5.26^{c}	6.09^{b}	*	25.25
Metabolic quotient (qCO_2) (CO_2-emission/Microbial biomass-C)	0.0021^{b}	0.0031^{b}	0.0044^{a}	0.0033^{b}	0.0034^{b}	ns	22.03
Microbial quotient-C (q_{mic}) (Microbial biomass-C/SOC)	0.547^{b}	0.524^{b}	1.197^{a}	0.687^{b}	0.459^{b}	*	44.5

In each row, means followed by the same letter do not differ statistically from each other at $p \leq 0.05$ according to DMRT test

4. Conclusion

Rubber tree plantation results in a higher metabolic quotient than that in cassava plantation, suggesting more stressful conditions for the microbial community. Interestingly, no significantly different of $q\mathrm{CO_2}$ was found among treatments. Moreover, the higher age of rubber plantation shows more carbon accumulation in soil. Greater microbial biomass-C and higher q_{mic} emphasize the importance of nutrient immobilization in rubber tree plantation regarding to soil total nitrogen, available phosphorus and exchangeable potassium content were higher in the rubber tree plantation than the cassava plantation, suggesting an improvement in soil microbial biomass efficiency. However, the conversion from cassava to young rubber plantations (3Y) resulted first in a depletion of some soil fertility parameter such as exchangeable potassium content due to potassium are the nutrients showing the largest retranslocation rates in rubber tree. The soil ecosystem started to recover from the land use change after the closing of the canopy of the plantation. At this stage, aboveground and belowground litter started to accumulate significantly in the system. These findings suggested that soil quality related to microbial properties was not responsive to land use change from cassava to rubber tree with higher ages and planting rubber trees could be a better alternative than cassava crops in terms of soil quality and fertility.

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