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Full Length Research Paper

Impact of the presence of subterranean termites *Macrotermes gilvus* (Termitidae) to physico-chemical soil modification on the rubber plantation land

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A study on the existence of subterranean termites nest *Macrotermes gilvus* (Hagen) and its effect on soil circumstance around the nest were conducted in a rubber plantation land managed using organic fertilizers and without the use of pesticides. The study aimed to determine the impact of the presence of the termites nesting on land to the quantity of soil nutrients, as nitrogen (N-total), phosphate (P-available), potassium (K-exchange), C-organic and soil textures. Termite nests were grouped into 3 groups, namely small (100 to 2000 cm²), medium (2001 to 4000 cm²) and large (4001 cm² >) sizes. Soil samples points were taken on the land adjacent to the nest, on the land away from the nest, and on the nest wall. Soil nutrient values were analyzed following the standard procedures for soil analysis. The result show each quantity of the soil nutrients and soil fractions between soil reference are different. It was showed that this termite influence on the soil was sufficiently large to change characteristic of soil on termite mound and their adjacent soil. So, the presence of subterranean termites nesting in the rubber plantation land were the positive effect on the agroecosystem or sustainable agricultural practices of rubber plantation land.

Key words: C-organic, Phosphate, *Macrotermes gilvus*, Nitrogen, Potassium, rubber-plantation.

INTRODUCTION

It seems natural to dislike termite, because most of them cause damage to wooden structures and vegetation. Hence, many previously studies demonstrated that termite influence soil properties inside their mounds relative to a reference soil (Leveau, 2000; Lee and Wood, 1971b). Besides an effect on single chemical properties, termites might alter soil characteristics (Sarcinelli et al., 2009). With the intensification of agriculture over recent decades and environmental imperative to develop sustainable

agricultural practices, there is now a sharp focus on the influence of cultural systems on soil and role biodiversities in mediating the main ecological functions of the system. The primary concept for this purpose is the ability of a key subset of the organism to create soil biogenic structures with biological, physical and chemical properties different from those of surrounding soil system (Jouquet et al., 2006). In one life cycle, termite can produce many individuals. Therefore, on the optimal

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environmental conditions and availability of food, termites can reproduce million insects. Previous study stated that termite populations densities can reach up to 10,000 individuals/m² and 100 g/m² biomass (Ackerman and Lice, 2009). One of the termites species is *Macrotermes gilvus*, as a termite which builds and maintains their nest and grow fungus inside. This behaviours were contributed to changes on soil chemical properties and modified the physical properties of the soil where they inhabitant (Brune et al., 1995a; Brune and Kuhl, 1996; Donovan et al., 2001). The termites behaviour to collect organic matter and soil particles then use them as matter to form their mound. These termites activities can increase the content of organic carbon, clay, and soil nutrients. Termites are known as "ecosystem engineers" because of their ability to transform the soil (Dangerfield et al., 1998).

In general, termites are important decomposers in an arid environment, capable of recycling nutrients, to form and maintain soil moisture (Mujinya et al., 2010; Ackerman and Lice, 2009). Termites are able to modify the physico-chemical soil environment through the formation of biogenic structures (nest). Generally, most of the former research on termites were conducted on forest lands, savannas, grasslands, other polycultures. The rubber plantation land, where study was conducted was managed naturally by using organic fertilizers and without the use of pesticides. There were found many termites mound which spread relatively uniform on the land. The termite was identified as a species of *Macrotermes gilvus* (Arifin et al., 2014). This environment was regarded as a rubber plantation land inhibited by the termite as their habitat. Yet, this study was designed to understand the impact and importance of termites found in this region to the number of nitrogen, organic carbon, phosphorus, potassium and fraction of soil texture of the rubber plantation land.

MATERIALS AND METHODS

Study site

The study was conducted from December 2013 to May 2014 in a public rubber plantation, in the village of Tanjung Batu, Ogan Ilir regency. The plantation is located approximately 60 km from the city of Palembang, and 20 km from the district capital, Ogan Ilir, Inderalaya. Sub district of Tanjung Batu is a temperately wet tropic region. The dry season occurs between May and October, while the rainy season starts from the months of November to April. The average rainfall ranges from 2,000 to 3,000 mm and the number of rainy days ranges from 66 to 100 days per year. Daily air temperature ranged from 23 to 32°C. Average daily humidity ranges from 69 to 98%. The area of rubber plantation is about 2 ha. Rubber plantation site was selected intentionally or purposively on managed lands by using organic fertilizers and without pesticides. The rubber plantations are expected to describe the condition of natural ecosystems and with relative human disturbance to the existance of the termites population on the study area. The age of rubber plants growing in this garden are between 6 to 7 years and productive while the research was conducted. Rubber plantation

has standing crop in row of 3 and 4 m in line spacing.

Procedure

Primary data were addressed in the form of field observations, measuring and testing number of soil properties in the laboratory. Soil analyses were addressed in the laboratory of Soil Science Department, Faculty of Agriculture, Sriwijaya University. Soil nutrient and fraction analysis followed a standard procedures of soil analysis as cited in (Burt, 2004). Soil nutrients measured were nitrogen (N-total), potassium (K-exchange)), phosphate (P-available), C-Organic and soil fractions. Soil samples were taken using a Belgy soil drill, 10 cm in diameter. About 2 kg of soil from each soil sampling site were collected and stored in plastic bag. Soil sampling sites were devided into; sub sites away from nests, the soil samples were taken in point at radius of 3 m or more out of termite nests or no nest. From site on the ground near the nest, soil samples were taken in point at the distance 1 m from the middle part of the nest and finally the site of soil nest, the soil samples were taken on the mound or nest wall. Soil nutrients and soil fractions were determined in the following ways:

- i) Determination of N-total by method Kjeldhal.
- ii) Determination of available P by P Bray I method.
- iii) Determination of K – exchange by method 1N ammonium acetate flamephotometer.
- iv) Determination of C-organic by Walkley Black.
- v) Determination of soil fractions by method of hydrometer.

Parameters observed and data analysis

The independent variables were in the form of the nutrient content of nitrogen (N), phosphate (P), potassium (K), C-organic, and soil textures while the dependent variable were the ground without nests (GWN = 10 samples), the ground near a small nest (GNSN = 8 samples), the ground near a medium nest (GNMN= 10 samples), ground near a large nests (GNLN= 15 samples), and ground nest wall (GNW = 10 samples). Soil sampling sites were considered as the dependent variables, because the nest constituents can spread through the soil surface whenever eroded among the rains and termite behaviour. Data observed were analyzed by Kruskal-Wallis test by using statistical computation program SPSS 18.0.

RESULTS

The properties of the soil references are significantly different for some mean soil properties relevant to sampling site observed. The termites influenced show not only on restricted to the nesting area as termite activity concentrated or a relocation of nest material but also both interfere to the adjoining soil. Moreover, stastical analysis showed that the X^2 values of each data observed is higher than Chi-square (X^2) table. This indicated all variable observed of each sampling site are different as shown in Table 1.

Characteristic of soil chemical properties

The difference of chemical characteristics of the soil of each soil sampling site were evident of termite impact.

Tabel 1. Average value of N,P,K, C-org, fractions of soil textures and statistical analysis obtained.

Variables	Average content of N,P,K, C-org and soil textures					X ²
	GWN n=10	GNSN n=8	GNMN n=10	GNLN n=15	GNW n=10	
Nitrogen (%)	0.324	0.287	0.311	0.234	0.203	16.424*
Potassium (K-dd/ me/10 g)	0.131	0.106	0.160	0.144	0.100	15.833*
Phosphate (P/ppm)	15.76	51.11	35.01	34.35	29.71	11.517*
C-organic (%)	4.20	3.73	4.11	3.04	2.55	15.009*
Sand (%)	69.83	72.04	70.62	64.38	68.82	10.692*
Silt (%)	21.57	19.13	19.21	18.90	16.40	11.773*
Clay (%)	8.58	8.82	10.11	16.74	14.77	14.370*

Chi-square (X²) table α 0.05 df. 4 = 9.488 * = significantly different

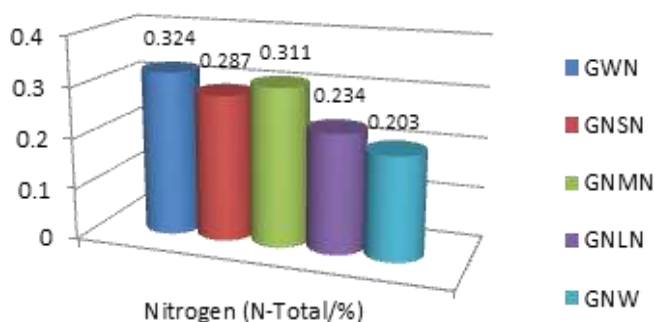


Figure 1. Comparison of average number of total nitrogen values of the soil adjoining with the nest, soil away from nest and the soil nest wall.

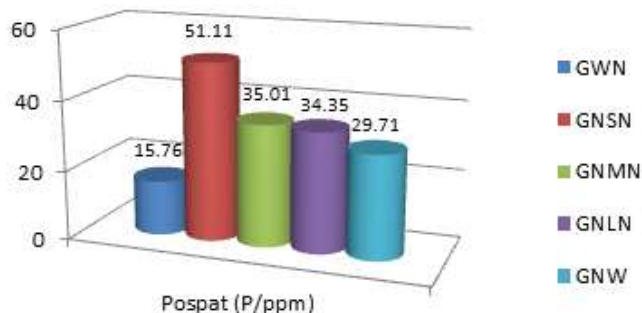


Figure 2. Comparison of the average number of phosphate (P/ppm) on the land away from termite nest, the land adjoining each nest size and soil nest wall.

Average number of total nitrogen content on the soil nest wall was (0.203%), lower than the land adjacent to the nest of large size (0.234%), medium size (0.311%), small size (0.287%) and land away from nest (0.324%), respectively. Average number of total-N value of the adjoining soil to all size nests was (0.277%). This exhibited higher than soil nest wall but lower than the land away from termite nest. Comparison between the average numbers of N- total values of each soil samples

are shown in Figure 1. Sum total of nitrogen content in soil of termite nest wall was lower than the adjacent land. Assume, the contents were made possible because of surface of nest wall eroded by rain and spreaded nest wall materials to the adjacent land. So, nitrogen value on soil nest wall become lower than the surrounding land.

The average values of phosphate (P-available) content of soil nests was 29.71 ppm, land adjacent to the nest large size was 34.35 ppm, medium size was 35.01 ppm, small size was 51.11 ppm and land without nest was 15.76 ppm, respectively. Average value of P-available in the adjoining soil of all nest sizes was 40.15 ppm were higher than on the soil nest wall and soil away from or without termite nest. Average amount of phosphate (P-available) consecutively from the highest to the lowest were on the land adjoining to the small size nest, medium size nest, large size nest, soil nest wall, and on the land away from nest. Hence, we deduce that influence on this certain soil properties also depend on the respective termite nest size. The highest enrichment compared to the control soil was found in mature nest or large size nest. In older nests, the values of this chemical properties tend to decline, but still remained higher than in the soil control or soil away from nest or without nest. Comparison of the average number of P-available provided between each soil sample is shown in Figure 2. The average content of phosphate (P) between variables with soil sampling is significantly different. Increasingly enlarge size nest, the phosphate content on the adjacent land being decreased. This is suggested because of the soil taken from land close to the smaller nest size, exposed more to impact of termite activity inside of the nest.

Average value of potassium (K-dd), on the land adjoining to medium size nest was the highest (0.160), followed consecutively by large size nest (0.144), land away from nest (0.131), land adjoining to small size nests (0.106) and the lowest in the land of nest walls (0.100). Average number of potassium on the soil adjacent to all size nests is 0.136 ppm was still higher than the land away from nests. Comparison of the average values of potassium between each soil samples are shown in

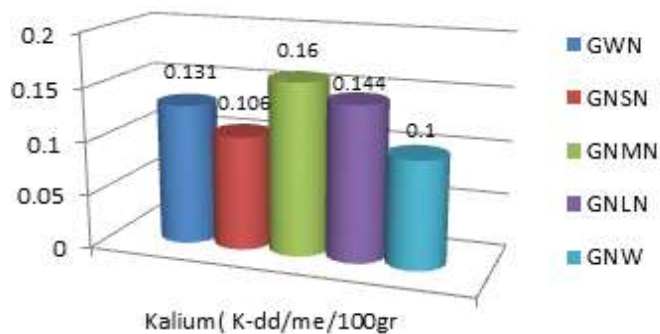


Figure 3. Comparison of the average values of potassium (K-dd/me/100 g) of land adjoining to a nest, away from nest and nest soil.

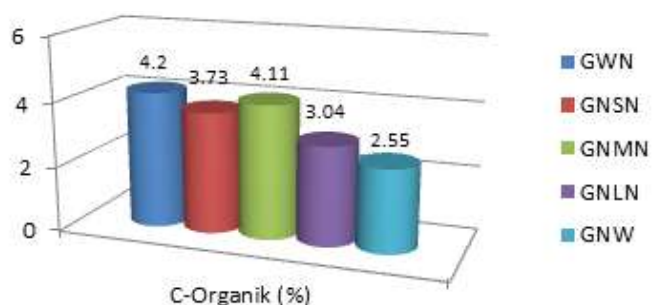


Figure 4. Comparison of the average values of C-organic (%) on the land adjoining to the nest, away from a nest and soil nest

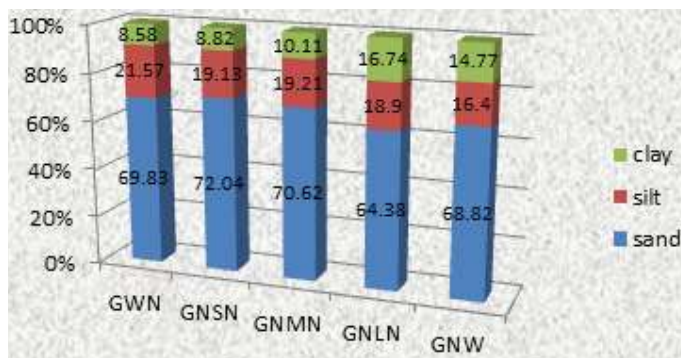


Figure 5. Proportion of the soil fraction of the soil texture of each soil sample.

Figure 3. The values of organic carbon (C-organic) between reference soil sites were different. Average values of Carbon organic on the soil away from nests was the highest (4.20%), followed consecutively by the adjoining land to medium size nest (4.11%), to small size nest (3.73%), to the large size nest (3.04%), and the lowest was on the soil nest (2.55%). But, average values of organic Carbon on the adjacent soil to the nest of all sizes was (3.62%) higher than on soil nest but lower than on the soil away from nest. The highest Carbon-organic value is on the land away from nest, followed

consecutively by land adjoining to medium-size nest, small size nest, large size nest, and the lowest was on the soil nest. Comparison of the average values of Carbon-organic between each reference soil sites are shown in Figure 4.

Chemical conditions of the soil between the soil nest, land close to termite nests and the land without termite nest were different. On the soil near to the nest, the number of phosphate and potassium were higher than the amount in the land without the nest, while the amount of nitrogen and organic carbon in the soil were lower than that on the land close to the nest and away from nest.

Characteristics of soil physical properties

M. gilvus does not only have effect on the chemical changes but also can modify soil physically, which led to the proportion of the soil fraction being change. The content of sand in the soil adjacent to termite nests tends to decrease among the size of the termite nest growth enlarge while soil clay content being increase. The increase of clay content supposed to cause by the proportion of sand content on the soil near to the nest decrease. The highest clay value is on the land adjoining to the large size nest (37.5%), consecutively followed by soil nest (14.74%), land near to the medium size nest (10.11%), land near to small size nest (8.82%) and the lowest on the land away of nest (8.58%).

The values of the soil clay fraction increased as the nest grows enlarge compared to the land away from a nest. This difference indicates that the termites (*M. gilvus*) accumulated clay particles while the nest development process so that clay content increase among the nest growing larger. Comparison of the proportions of sand, silt and clay in each soil samples are shown in Figure 5.

DISCUSSION

Termite activity and chemical soil properties

Sum total-Nitrogen number of the each soil sampling site are different. Low value of nitrogen in soil nest was suggested due to the nests away from vegetation cover and piles of organic materials of rubber plants. Hence, on the land with a high number of total plant biomass, the total nitrogen content of the soil were higher (Schwiede et al., 2005; Schaefer, 2001). On the other hand, other study showed an enrichment of available nitrate, and amonium inner the mound of African soil-feeding termites but not at the mound edge or at the land away from the mound or nest (Millago et al., 2011). Average value of total nitrogen, the highest was on the ground without termite nest, then followed consecutively on the ground near to the medium size nest, small size nest, large size nest, and the lowest is on the soil nest. Previous studies state that low nitrogen value in the soil nest suggested due to

the nest was clean of vegetation and organic matter falls of rubber plants. Parker et al. (1982) suggested that in the soil, sprayed with insecticide, to negate termite soil, total nitrogen content is higher. This situation is due to the total amount of biomass crops on the soil surface is higher than on the surface of the termite nest. Two aspects of termite behaviours were of particular importance to the cycling of Nitrogen; first, the removal of surface plant litter to underground galleries, exposing it to bacterial and fungi decomposition, and second, enrichment of this high cellulose litter with N by symbiotic hindgut bacteria that can fix atmospheric N (Curtis and Waller, 1995). So, nitrogen value on the soil inner nest where termite activity concentrate was higher than soil nest wall.

The content of phosphate of soil in termite nests abortion were higher than the surrounding soil, there is also caused most of the termite activity occurs inside the nest. Number of phosphate in soil nest associated with the number of organic matter produced by termites and the high total cation-exchange with clay particles (Dangerfield et al., 1998; Coventry et al., 1988; Lopez-Hernandes et al., 2006). High number of P and exchangeable cations (K^+) correspond to the incorporation of organic matter into the mound, so the cation content can be enhance by consumption of plant by termite. The amount of exchangeable bases could also enhance by modification of exchange site following a chemical alteration of the organic matter or minerals by termite, (Parker et al., 1982; Mujinya et al., 2010). Termite can alter such matters by passage through their gut and use of saliva and faeces for nest construction (Wood et al., 1983). Content of total P suggested because of termite did not change the total P where available P was not preferentially collected but that the availability of P was change by termite activity. The higher P availability in nest of soil-feeding termite was with a dissociation of organic and inorganic complexes in extreme alkaline hindgut of the termite (Wood et al., 1983). Additionally, that the high content of organic matter in soil nest influences the P sorption-desorption processes. So, the termite influence is not restricted to the nesting area as termite activity or a relocation of nest material both interfere with surrounding soil or adjoining soil (Lopez-Hernandes et al., 2006).

The highest average value of K was on the land adjacent to medium size nest, then followed consecutively, on large size nest, land away from nests, small size nest and lowest on the soil nest wall. Number of potassium on the soil nests was lower than the land adjoining to the nest. This suggested that there were an active transportation of termites to carry out matters from the nest out. In relation to potassium, related study proposed that termites were transformed K into kaolinite and synthesizes it into organometal complex and amount of potassium in the soil nests, so this cause value of K inside the nest to be higher than the surrounding soil (Millago et al., 2011; Kaschuk et al., 2006).

The values of N, P, K and soil organic Carbon on the soil nest were different with the surrounding land. The differences were possibly because of termites eating behavior; the behavior to build and maintain the nest, utilize organic materials, mineral soil and saliva. Termites will not only collect and mix the soil organic matter but also digest the material and extract the mineral of soil nutrients contained. During these processes, litter was broken into fine particles which were assisted by symbiotic bacteria in their digestive tract causing the decomposition of the organic materials. Termites were in collaborated with mutualistic symbiont of various microorganisms in their digestive tract and termites remove residual nitrogen in the form of uric acid and excrete it into the digestive tract. Uric acid will be degraded by microorganism's symbionts that live in their digestive tract (Ohkuma, 2003). The organic material pass through the digestive tract of termites were they undergo various processes of physics, chemistry and biology of the matter. These can change the nature of the organic matter. The processes that occur in the digestive tract were helped to speed up the formation of humus substances. As organic matter pass through the termite digestive tract will be faced with a variety of chemical and biological processes that change the amount of organic material contained (Brauman, 2000).

Different study which focus on the soil beneath or inner the nest stated that the value of organic matter on the soil inner nest, as *Macrotermes* termite activity concentrated, was higher than the surrounding land without termite activity (Brauman, 2000). The differences in the values of C-organic, nitrogen (N) and phosphorus (P) on the soil nest wall, land inside the nest compared to the adjoining to the nest, due to subterranean termites were able to modify the land where termites nesting (Sarcinelli et al., 2009). Supporting study stated that soil nutrient values below termite nest was 1.5 times higher than the land away from termites nest (Coventry et al., 1988). The content of N, P, K and C-organic which relatively different suggested as impact of the termite behaviour to digest food of soil organic matter and return them as faecal.

Faecal was an organic material protected by physico-chemical form of stable soil aggregates. Then, the acceleration of decomposition of organic matter due to the action of termites that can improve aggregate stability and porosity of the soil, in addition, also to improve soil water retention. Furthermore, that grower fungus termite (Termitidae; Macrotermitinae) symbionized mutualistically with fungi that grow in the nest and fungus also used as a food source for termites. Number of C, P and N which relatively higher on the soil inner the mounds rather than on the adjacent land related to the behavior of termites which mostly occur inner the nest, so the organic material pellets which were mixed with saliva accumulated inside termite nests (Sarcinelli et al., 2009).

As noted by Brauman (2000), the content of soil organic matter of the termite *Macrotermes* nest wall was

lower than the surrounding soil without termite activity and organic matter which pass through the termite digestive tract will be faced with a variety of chemical and biological processes that can change the amount of organic materials contained. So, the carbon and nitrogen content are lower from the soil around the nest (Arshad, 1981).

Termite activity and physical soil properties

Termites collect soil organic matters and mineral particles from the surrounding environment and their burial land as nest building material. Such behaviour allow to increase Carbon organic content, clay content and nutrients in the surrounding soil. Due to an increase in nest building materials were scattered to the land around the nest to when rain. Nest surface, can be continuously eroded by rain water so will cause a damage on nest, and the termite reconstructed by means of redistributing land on the surface of the nest. Nest surface erosion was possibly because of the clay quantity on soil nest was low, only 6.19%. Clay contents were related to soil stability. Clay content in the soil termite nests can reach 20% higher than in the surrounding soil (Jouquet et al., 2002a). Furthermore, high clay content will increase holding capacity of soil particles so that the nest soil aggregates more stable. In addition, the high number of clay causes soil porosity and water diffusion were decreased, so that the water takes longer to sink in (Jouquet et al., 2005). Disturbances in the soil profile changes soil textures and organic material distribution seems to be more important to compare with the changes in the chemical properties (Wood, 1988). The organic matters that accumulated by the subterranean termites in nest can be distributed to the soil environment around the nest by erosion, thus affecting the soil microstructure and soil fertility (Dangerfield, 1998; Schaefer, 2001).

Clay content of soil of small size nest was lower than the land away from nest, these was possible because of the population number of individuals in small size nests were still a minute, nature of nest construction still unstable. Soil volume of *Macrotermes* nests were positively correlated with the number of individuals occupy (Josens and Soki, 2010). Furthermore, the small size nest seemed easier eroded and damaged by rain while large size nest more stable. Construction of nest with clay particles was common to termite of subfamily Macrotermitinae. Most species of termites were less selective in the choosing of materials rather than termite nest builders of Macrotermitinae subfamily, which nest mound builder material has higher clay content than the surrounding soil (Dangerfield, 1998). Species of *M. bellicosus* are examples of related species to these termite choosing fine soil particles as builders of material mounds, so the nest structure was more stable and higher capacity of the standing water (Josens and Soki, 2010). Therefore, these behavior of subterranean

termites *Macrotermes* were result enrichment of clay and mud for mound builder materials (Zhang et al., 2013).

The content of the clay fraction of land adjacent to the nest seem increase with growing to the size of the nest. This difference indicates that subterranean termites *M. gilvus*, where was accumulated clay particles in the process of building the nest so the content of nest soil clay fraction was increasing with the size of the nest growing. Soil mineral used to build the nests, and compositions of the soils were modified by termites through eating activities and these working synergistically with symbiont bacteria in the termite gut. An important role of subterranean termites is mainly in the engineering process of soil fertility and plant diversity on the land inhabited by termite. Besides mound building of a termites nest, termite also built galleries outside or inside termite nests as a way for their movement. Such behaviour also causes porosity and water infiltration in the soil to be increased. Galleries can also be filled in by the material of the upper soil when rained (Zhang et al., 2013). Furthermore, galleries created by subterranean termites contribute to the process of soil formation in the deeper part (Schaefer, 2001). The related study was proposed that *Macrotermes michaelsoni* build nests using soil with a higher clay content with a higher cation exchange capacity rather than the adjoining land. These increased the soil fertility, especially to soil with low organic matter content (Dangerfield, 1998). The proportion of nest builders' material content varies, so these determine the chemical and physical properties of nests (Wood, 1988). In *M. bellicosus* who choosing fine soil particles as the material builders of nest, so the nest structures are more stable and the water holding capacity higher (Josens and Soki, 2010), subsequent behavior of subterranean termites such as *Macrotermes* that this resulted in to enrichment clay and silt in the nest builders materials (Abe et al., 2009b).

Conclusion

The presence of subterranean termites *M. gilvus* (Hagen) nesting in a rubber plantation land impact on the changes of characteristic of the soil nest and their surrounding soil. Quantity of soil properties observed; total N, P-available, K-dd and C-organic content and soil fraction of each soil references are different. This study showed that this termite influence on the soil was sufficiently large to change characteristic of soil on termite mound and their adjacent soil. So, the presence of subterranean termites nesting in the rubber plantation land were giving effects positively on the agroecosystem or sustainable agricultural practices of rubber plantation land.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Soil organic carbon stocks in Mount Cameroon National Park under different land uses

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Increasing effects of climate change has led to an urgent need for reliable estimates of the soil carbon pool (SOC) which is one of the carbon sinks in the world. This is especially true in Africa where there is lack of basic data. This study conducted in the southern part of Mount Cameroon National Park (MCNP) seeks to determine SOC patterns and estimate CO₂ equivalence from SOC pool following land-use changes. Nine prominent land-use types were identified (under rubber, virgin forest reserve, oil palm, cassava, mixed cropping, tea, maize, banana and sugar cane). Soil samples were collected from 98 plots of 2,500 m², each spread over the different land uses in five villages at 0 - 30 cm of soil. The collected Soils samples were analyzed for SOC and other physicochemical properties. Mean SOC ranged from 56.1± 11.00 t ha⁻¹ (for rubber) to 225.24 ± 33.65 t ha⁻¹ (for forest) giving an average for the area of 130.80 Mg/ha. The mean SOC in forest soil was significantly higher than that for cassava (p=0.038), oil palm (p=0.045) and rubber (t=4.849, p=0.0046). Losses in CO₂ equivalence, as a result of land use change from forest to other land use systems, ranged from 234.15 (for mixed cropping) to 620.74 t/ha (for rubber). The study provided estimates of carbon pools for different land uses in MCNP. Mixed cropping was only second to forest in terms of SOC values indicating that agroforestry can mediate between food production and environmental protection.

Key words: Soil organic carbon, land use systems, CO₂, carbon sequestration, soil quality.

INTRODUCTION

Climate change is one of the most important challenges to sustainable development bearing more negative than positive effects on aquatic and terrestrial ecosystems. The leading factor of climate change is attributed to CO₂ accumulation in the atmosphere (IPCC, 2001).

The reductions of atmospheric CO₂ by artificial means are very expensive and so carbon sequestration by soils,

oceans and plants turn out to be the simplest and most economically practical way to face the climate change crises (FAO, 2001). Terrestrial ecosystems play an important role in the global carbon cycle and hence modify the atmospheric CO₂ mixing ratio because they can act as carbon sink due to net carbon uptake during vegetation growth and as carbon source through land use

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changes, or deforestation or forest degradation (Schulze, 2006). Conversion from forests to agricultural and grazing lands and deforestation are examples of human induced land use change that lead to the increasing amount of CO₂ in the atmosphere (Shrestha et al., 2004). By the end of the 20th century, changes in land use and deforestation were responsible for the emission of over 498 Gt of CO₂ to the atmosphere, approximately half of which has been lost from soils (Lal, 1999; IPCC, 2000). Each tonne (tMg) of C stored in soils removes from the atmosphere about 3.67 tonnes of CO₂. The rate of increase in atmospheric carbon pool as a result of fossil fuel combustion and land use change at the start of the 21st century stood at 0.5% year⁻¹ (Lal, 2002).

Though photosynthesis by plants will convert atmospheric CO₂ into organic soil material, agricultural practices such as chemical spraying, tillage and burning may have an impact on the efficiency of plant conversion. Further results in a decrease in soil organic matter. This is because microorganisms feed on crop residue and soil organic matter exposed by tillage, and readily converts the organic matter into CO₂ as end-product. When the soil is tilled, a "burst" of CO₂ is released into the atmosphere. Simultaneously, oxygen enters the soil and shifts the whole reaction process to enhance organic decomposition, which is an undesirable result (Jones et al., 2006).

The total global C-stock (organic and inorganic C) in terrestrial systems is estimated to be about 3,170 GT (where 1 GT = 1 petagram = 1 billion metric tons) out of which 2,500 GT is in the soil and 560 GT and 110 GT in plant and microbial biomass, respectively (Jansson et al., 2010). Soil C pool is 3.3 times the size of the atmospheric C pool (760 GT) but soil still has the capacity to hold much more (Lal, 2004). Soil C includes about 1,550 GT (62%) of soil organic carbon (SOC) and 950 GT (38%) of soil inorganic carbon (SIC), (Lal, 2008). Of the C present in the world's biota, 99.9% is contributed by vegetation and microbial biomass; animals constitute a negligible C-reservoir (Jansson et al., 2010). SOC constitutes approximately 60% of all soil organic matter (SOM) (Wilkes, 2005) correlated with productivity and defines soil fertility and stability (Herrick and Wander, 1998).

Adoption of appropriate crop management practices can yield considerable enhancements of the soil carbon pool. Lemus and Lal (2005) reported a model based on more than 50% of US cropland which predicted a 15% increase in SOC with reduced tillage practices, and 50% with no-till farming. A pan-tropical study in 52 tropical countries, suggested that reforestation practices could result in additional C sequestration of 56 GT by 2050 (Butcher et al., 1998). Globally, appropriate forest policies could increase the amount of C sequestered in terrestrial biomass by up to 100 GT, or up to 2 GT/year (Dahlgren et al., 2001).

Soil organic carbon (SOC) has long been of interest to scientists, technical advisers and land managers, as an

indicator of soil health. The link between the C cycle and global climate change is providing increased impetus for quantification and, ultimately, management. Few attempts have been made in Cameroon, to relate soil carbon pool with land use/management practices.

Mt Cameroon National Park (MCNP) is an area of dense forest and shrubs threatened by agricultural land use practices in the area, but even then, there have so far been no quantification studies of the soil carbon of this area. Quantifying the soil carbon will add more impetus to the conservation of the park and suggest better land use practices that will enable Cameroon to contribute positively, its quota in the reduction of atmospheric CO₂, while providing sufficient food yields to the locals. This study has as objective, to determine a baseline for SOC under different land use types in the southern parts of the MCNP, and to calculate CO₂ equivalents of SOC in each of these land use types. The working hypothesis is that changing from forest land use to cultivated agricultural land uses leads to significant changes in SOC.

MATERIALS AND METHODS

Study site

The Mt Cameroon region supports forests known to be of exceptional scientific, economic and social value, containing a great variety of endemic and endangered flora and fauna species, supplying many commercial and subsistence forest products, as well as providing valuable ecosystem services such as watershed protection (MINEF, 2006). The forest resources constitute an important asset supporting rural livelihoods for the approximate 300,000 people living within the area; however, the forest resources and high biodiversity are under threat from unplanned land use (MINEF, 2006). Land clearing for local farming and agro-business expansion, urbanization, and uncontrolled exploitation of forest resources are major practices in this region. The natural vegetation of this area ranges from evergreen lowland rainforest at sea level, through montane forest, to montane grassland and alpine grassland near its summit. The area is currently being threatened by increasing human populations but it is the most diverse ecosystem in Cameroon and presented as the 10th most conservable places in the world (IUCN, 1994). This link between ecosystems largely accounts for the biological diversity of the region.

Mt Cameroon lies on the coast, in the Gulf of Guinea, between 3°57' - 4°27' N and 8°58' - 9°24'E. It is a huge volcanic mass with its long axis (about 45 km long and 30 km wide) running SW to NE and the main peak is at 4°7'N, 9°10'E, at 4,100 m. Its western slope is probably the most diverse and richest area (MINEF, 2006). Soils on Mt Cameroon are principally of recent origin, mostly on young and older tertiary volcanic rocks, and are relatively fertile but often with poor water retention capacity (Payton, 1993). The soils are thus non allophanic Andosols and classify as Aluandic Andosols (leptic) by Yerima and Van Ranston (2005) based on the WRB system of soil classification.

Mt. Cameroon area has an equatorial climate of four seasons, as indicated by data from the weather stations across this area, over the past 11 years, from 2001- 2011. The dry season runs from December-February, dry-wet season from March-May, wet season from June-August and wet-dry season from September - November. This study is limited to the buffer zone in the southern parts of Mount Cameroon, that is, from Ekona through Likomba to Idenua

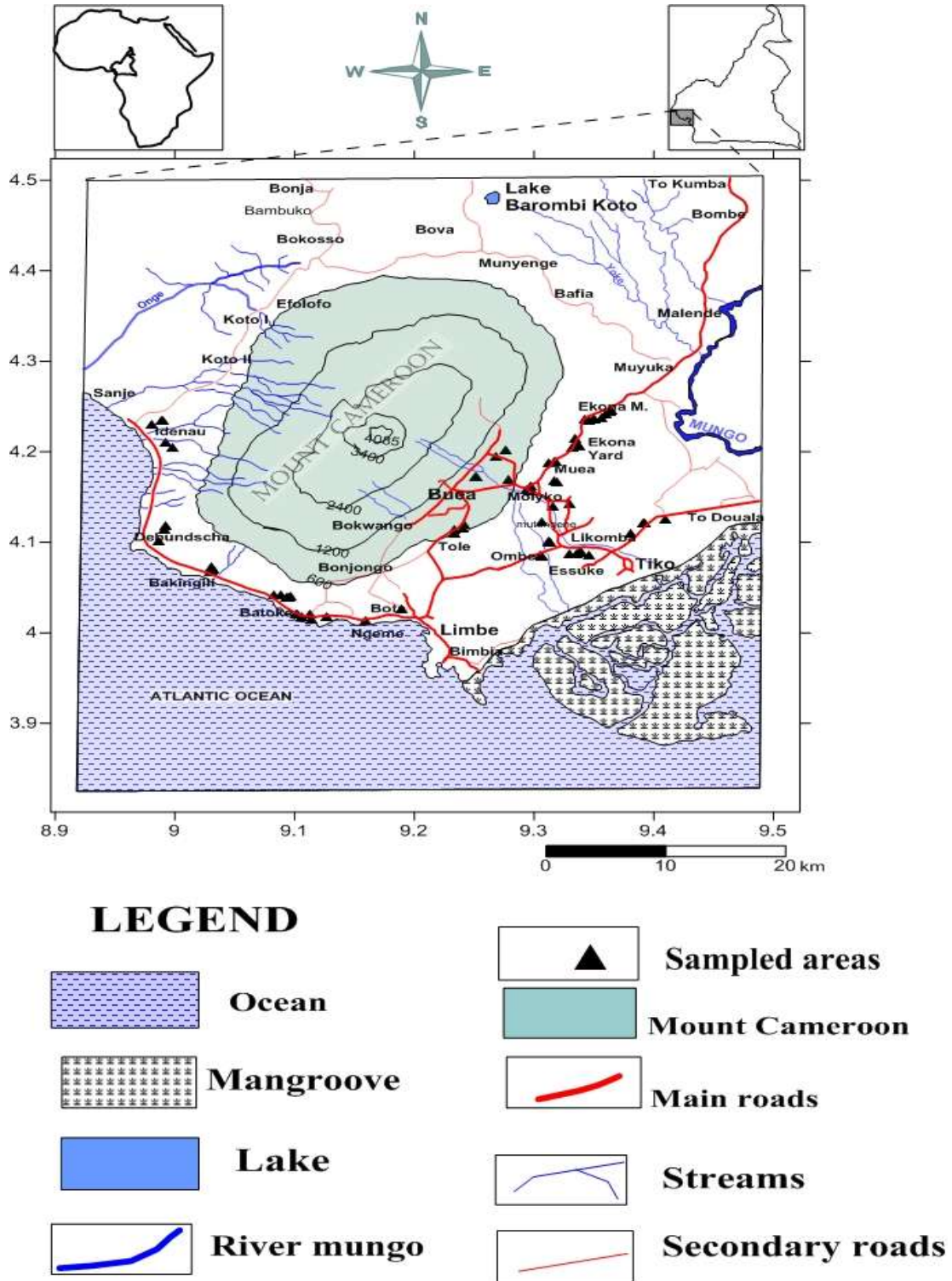


Figure 1. Map of Cameroon with the MCNP indicated and magnified to show the southern area of the park which is the study site.

(Figure 1). This is because of immense pressure from the local population as a result of agricultural and settlement land constraints, and also because the Cameroon Development Cooperation (CDC) has various plantation land concessions around

this area. These factors are making land more scarce for the rising local human population, making the population to exert more pressure on the forest which has been deserted as the MCNP and is being protected.

Table 1. Eleven-year average annual rainfall and temperature at various weather stations around the southern parts of the Mt. Cameroon National Park from 2001-2011.

Parameter	Temperature (°C)	Rainfall (mm)
Idenau	27.3	7410.4
Batoke	25.4	4971.2
Ekona	26.1	1685.4
Buea	25.1	2027.8
Likomba	27.2	1918.4

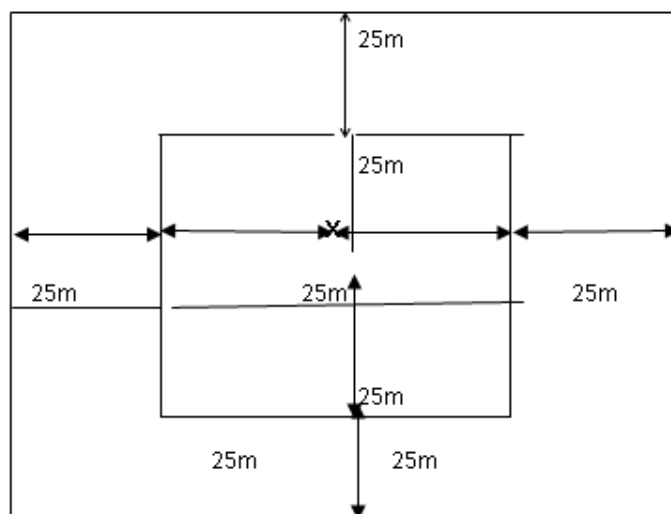


Figure 2. Layout of sample collection in selected land-use plots. Samples were collected at the Centre and at mid points from the centre to each side of the square (25 m from centre to each side of the square).

Land-use/management types in the southern part of the MCNP

In the study area, nine different land-use/management types were identified to be highly practiced. These included: cassava (*Manihot esculenta* Crantz) farms, maize (*Zea mays*) farms, banana (*Musa sapientum* Linn) farms, oil palm (*Elaeis guineensis* Jacq.) farms, mixed cropping systems (comprising of plantain, cocoa yams, maize, cassava and trees), tea farms, sugar cane farms, rubber farms and virgin forest areas. Oil palm had the largest farm area probably because large areas are required for its establishment (planted at least 9 m distance apart for better crop performance).

Most of the oil palm, rubber and banana are owned by the Cameroon Development Corporation (C.D.C.), who have land consensus for such large demarcated areas to cultivate these economic crops. The tea estate is a whole area demarcated for sole cropping of tea for commercial purposes. Cash crops like sugarcane; maize, mixed cropping; and cassava were cultivated by the locals and were characteristically smaller in farm size probably due to the enclaved nature of most of the villages which makes transportation to and from the market very difficult. Another reason could be that the local farms are used to provide basic family needs but not for commercial purposes. The type of farming method employed by indigenous people and farmers in establishing their farms is of importance to the Mt. Cameroon forest. This is because

land use changes are a major factor to ecosystem degradation and habitat loss. Initially, the farmers apply slash and burn to convert from the forest to the desired land-use type. After that, there is spraying with chemicals at the beginning of each planting season to control weeds, diseases and pest. This greatly affects the ecosystem of the MCNP and the soil microorganisms.

Selection of land-use/management types

A transect was drawn across the study area, from which five major villages were selected for sample collection, based on microclimatic difference (Table 1 and Figure 1). The prominent land-use types were selected in each village base on land use history of at least 5 years. Four of the nine land use types were found in all five villages (virgin forest, maize, mixed cropping and oil palm), one was found in four villages (cassava), two in two villages (banana and rubber), and two in just one village (tea and sugar cane). All the land use types selected were under no tillage and non-fertiliser application management system. This is due to the fact the soils in this area are basaltic volcanic soils very fertile and result in high yields even without application of fertilisers. There is high application of pesticides and herbicides to kill pest and grass.

Soil collection

In each selected land use type, a plot of 0.25 ha was chosen and samples were collected from 0 to 30 cm depth (Figure 2) with the aid of a soil auger. The five samples from each plot were later mixed to form a composite sample for that plot. Three plots were chosen, for every land use type, in each of the five villages, giving rise to 90 samples. These samples were air dried and sieved through a 2 mm screen. In all five villages, the three samples from each village (corresponding to one land use type) were bulked to give a composite sample for that land use type. This resulted now to 30 experimental replications for analysis. Samples for bulk density were collected separately following dimensions of the hand auger and depth of soil collection.

Analysis of samples

The parameters analysed included the following: pH, bulk density (BD), cation exchange capacity (CEC), weatherable elemental ions (Ca^{2+} , Mg^{2+} , Al^{3+} , K^+ , Na^+ , etc.), available P, total N and SOC content. They were sent to the Institute for Agricultural Research and Development (IRAD), Ekona for analyses as previously used by Djomo et al. (2011). Organic carbon (OC) was determined following the method described by Walkley-Black (1934). Soil organic carbon (SOC) pool and total SOM was estimated using the conversion formula given by Wairiu and Lal (2003):

$$\text{SOC} = \text{C}\% \times \rho \times V$$

Where: C% is the weight percentage of carbon in the soil depth, ρ is the bulk density of the soil in Mgm^{-3} and V the volume (m^3) of soil per hectare.

$$\text{SOM} = \text{SOC} \times 1.78$$

To estimate the amount of CO_2 equivalence being held in the soil from the atmosphere, the ratio of 12 g of C : 44 g of CO_2 was used, based on mass of carbon in the molar mass of CO_2 . Deterioration

Table 2. Mean values of sand, silt and clay for the various land use types in the southern parts of MCNP.

Land-use type	Sand (%)	Silt (%)	Clay (%)	Textural type
Banana	52.19	26.50	21.32	Sandy clay loam
Cassava	37.54	39.06	23.39	Loam
Forest	46.65	27.72	25.63	Loam
Maize	35.64	36.41	27.95	Clay loam
Mixed cropping	45.17	34.15	20.66	Loam
Oil palm	41.21	31.95	26.84	Loam
Rubber	50.95	22.35	26.70	Sandy clay loam
Sugar cane	46.45	24.90	28.64	Clay loam
Tea	58.51	24.90	28.64	Sandy clay loam

index (DI) was applied according to Awotoye et al. (2011) to compute the rate of deterioration of the soil properties to those of the forest in the study.

$$DI = \frac{\bar{x} - x_i}{\bar{x}}$$

Where: \bar{x} = mean value of soil parameter in forest site, while x_i = mean value of soil parameter in compare site (mixed cropping, maize, cassava, banana, oil palm, rubber, tea and sugar cane).

Statistical analysis

Results from the laboratory were all keyed into Microsoft Excel 2010 and computed into secondary parameters (mean, standard deviation and standard error) to facilitate comparison between soil properties. These parameters were imported to SPSS 17 and R i3862.15.2 statistical packages to test for significant differences, compute box plots and inferential statistics. A one way ANOVA was carried out to test the level of significance between SOC of the different land-use practices for cases where the number of samples (N) is greater than two, while an independent sample t test was used for cases where the number of samples is exactly two.

RESULTS

Soil properties

Soil bulk density, texture and pH

Particle size analysis revealed variability in the textural properties in the soils of the land use types. The soils of all the land use types were generally loamy. Banana, rubber and tea farm, land use types revealed a sandy clay loam textural type, while the rest were purely loam (Table 2).

Bulk density values ranged from 1.15 (maize) to 2.9 g/cm³ (rubber) with no significant differences among the BD values of the different land uses at $\alpha = 0.05$ (Table 3). The values were however, higher in forest and continuous cultivated lands (rubber, palm, tea, cassava, banana and sugarcane).

Mean soil pH ranged from 3.8 (tea) to 4.87 (forest); however, the pH values did not differ significantly among different land uses ($\alpha = 0.05$).

Soil organic matter content

The highest and lowest SOC values were encountered in forest (5.92%) and rubber land uses, respectively (1.45%). Soil fertility values (OC, total N and average P) are generally high with significantly difference recorded between available P of forest and maize at $\alpha = 0.05$ (Table 3). Table 3 also reveals that the highest CEC and moisture content values were found in forest and the least in rubber.

Table 4 shows the index of deterioration of the soil properties under the various land uses from forest. Deterioration indices of SOC, CEC and total nitrogen contents were highest in the soils of sole cultivated plantations, while available P was highly degraded under mixed cropping land but more than rubber and oil palm soils (Table 4).

Soil carbon dynamics

The mean SOC density in kgC/m² ranged from 5.61±1.10 for rubber land-use to 22.53±3.36 for forest land-use (Table 5) and the range of values in each land use are shown in Figure 3. Mean total SOC in t/ha for 30 cm depth gave a maximum 225.24±33.65 t/ha for forest and a minimum of 56.1±11.00 t/ha for rubber giving an average for the area of 130.80 t/ha (Table 5). Total average soil organic matter (SOM) in t/ha for the 0-30 cm depth for the land-use systems ranged from 99.86±19.58 t/ha in Rubber land-use to 401.28±59.89 t/ha in forest landuse (Figure 4). Estimated amounts of CO₂ equivalence from the SOC values in each land-use type revealed highest values of 826.63±123.37 t/ha by forests and lowest values of 205.89±40.33 t/ha by rubber plantations (Table 5).

Comparison of SOC density (kgC/m²) for various land-use types (cassava, maize, banana, mixed cropping, rubber and oil palm,) against forest using one way ANOVA test, revealed that SOC for forest is significantly higher than for cassava, oil palm, and rubber at $\alpha = 0.05$ (Table 6). SOC for forest had a mean value of 22.53 kgC/m² with N=5. SOC for mixed cropping was also found to be significantly higher than rubber ($p=0.013$, $df=5$).

Table 3. Mean values of soil properties (physical and chemical).

Land use types	Moisture (%)	BD (g/cm ³)	OC (%)	Total N (%)	C/N	Av. P (mg/kg)	pH CaCl ₂	Na ⁺ (cmol/kg)	K ⁺ (cmol/kg)	Mg ²⁺ (cmol/kg)	Ca ²⁺ (cmol/kg)	Al ³⁺ (cmol/kg)	CEC
Banana S. E.	10.86 2.61	1.22 0.03	3.63 1.11	0.39 0.13	9.50 0.05	62.50 23.50	4.42 0.28	0.04 0.01	0.96 0.56	3.41 1.63	4.12 2.13	0.25 0.13	24.18 7.92
Cassava S. E.	12.03 1.91	1.23 0.05	2.94 ^b 0.68	0.38 ^c 0.07	8.75 1.11	39.00 ^c 8.87	4.60 0.18	0.03 0.00	0.86 0.18	2.36 0.67	3.21 0.88	0.27 ^c 0.06	23.57 6.10
Forest S. E.	14.43 1.34	1.27 0.064	5.92 0.86	0.72 0.17	9.20 1.16	17.80 4.53	4.87 0.19	0.03 0.004	0.81 0.135	2.61 0.60	3.88 0.866	0.13 0.02	37.30 8.06
Maize S. E.	12.96 1.74	1.15 ^c 0.03	4.20 0.78	0.50 0.11	8.75 0.48	38.80 ^b 8.16	4.85 0.09	0.03 0.003	0.81 0.04	2.54 0.43	3.95 0.39	0.17 0.03	23.24 4.34
Mixed cropping S. E.	13.11 1.79	1.21 0.02	4.48 0.75	0.59 0.10	7.60 0.40	33.00 11.67	4.75 0.17	0.03 0.003	0.95 0.33	2.701 1.02	3.71 1.21	0.15 0.03	29.19 4.57
Oil palm S. E.	11.88 1.31	1.17 0.05	3.46 ^b 0.66	0.40 ^c 0.08	8.80 0.73	30.80 ^c 5.60	4.55 ^c 0.11	0.03 0.003	0.46 ^b 0.10	1.53 ^c 0.19	2.59 0.31	0.27 ^c 0.06	19.83 ^b 3.06
Rubber S. E.	5.47 ^b 1.22	1.29 0.01	1.45 ^b 0.33	0.26 ^b 0.04	8.50 0.50	17.00 8.00	4.41 0.61	0.02 ^c 0.00	0.34 ^b 0.06	1.54 0.48	2.46 0.81	0.59 0.29	12.56 ^b 2.69
Sugar cane	11.21 nd	1.22 nd	2.39 nd	0.32 nd	7.00 nd	54.00 nd	4.57 nd	0.03 nd	1.55 nd	3.08 nd	4.76 nd	0.78 nd	16.31 nd
Tea	12.94 nd	1.25 nd	3.72 nd	0.70 nd	5.00 nd	54.00 nd	3.80 nd	0.03 nd	0.38 nd	1.13 nd	1.38 nd	0.76 nd	36.51 nd

b = Significantly different from control (forest) at $\alpha=0.05$, c = significantly different from control (forest) at $\alpha= 0.1$, nd= not determine (this is because one way ANOVA compares data with more than two values, but sugarcane and tea were located in just one of the five villages, hence had just single values).

DISCUSSION

Plot design

Research relating to carbon estimations are often associated with uncertainties that need due consideration to minimize them. The first source of errors is plot design and the method in which it is establish. The probability of errors in results decreases with increasing plot size (Keller et al., 2001). The minimal plot size for biomass estimations including SOC as stated by Chave et

al. (2004) is one quarter of a hectare. Plot sizes below this are associated with large error proportions. The plots used in this study were exactly 0.25 ha, large enough to minimize large errors.

Another source of uncertainty are the environmental and physical factors including topography, vegetation types and climatic gradients, which can create serious bias on SOC estimates (Chave et al., 2004). The plots were located based on climatic, topographic and land cover variations to minimize these errors and get

a true homogenous sample for the area.

Soil properties

Soil bulk density, texture and pH

Land use types affect soil texture characteristics which in turn affect the fertility status of a field (Yao et al., 2010). The variation recorded in the soil texture of these land uses from the results agrees with the fact that land use types can be

Table 4. Deterioration indices (DI) in percentages of some soil properties.

Soil properties (%)	Land use types						
	Moisture	Bulk density	Total nitrogen	Organic carbon	pH	Available phosphorus	CEC
Banana	24.7	3.9	45.8	38.7	9.2	-251.1	35.2
Cassava	16.6	3.2	47.2	50.3	5.5	-119.1	36.8
Maize	10.2	9.4	30.5	29.1	0.004	-118.0	37.7
Mixed cropping	9.2	4.7	18.1	24.3	2.5	-85.4	21.7
Oil palm	17.7	7.8	44.4	41.6	6.6	-73.0	46.7
Rubber	62.1	-1.6	63.9	75.5	9.5	4.5	66.3
Sugar cane	22.3	3.9	55.5	61.2	6.2	-203.4	56.3
Tea	10.3	1.6	2.8	37.2	22.0	-203.4	2.1

Values above 50% show high deterioration and negative indices for bulk density depict highly compacted.

Table 5. Soil carbon dynamics for the various land-use types around MCNP.

Land use types \pm S.E	SOC Den (kgC/m^2)	TOC (t/ha)	SOM (t/ha)	CO ₂ Eq. SOC (t/ha)
Banana	13.15 \pm 3.72	131.68 \pm 37.2	234.43 \pm 66.22	483.27 \pm 136.40
Cassava	10.77 \pm 2.95	107.72 \pm 29.49	191.62 \pm 52.49	395.33 \pm 108.12
Forest	22.53 \pm 3.36	225.24 \pm 33.65	400.96 \pm 59.89	826.63 \pm 123.37
Maize	14.64 \pm 2.89	146.40 \pm 28.87	260.55 \pm 51.40	537.29 \pm 105.87
Mixed cropping	16.14 \pm 2.54	161.44 \pm 25.43	287.29 \pm 45.27	592.48 \pm 93.26
Oil palm	12.16 \pm 2.79	121.60 \pm 27.89	216.41 \pm 49.64	446.27 \pm 102.25
Rubber	5.61 \pm 1.10	56.10 \pm 11.00	99.86 \pm 19.58	205.89 \pm 40.33
Sugar cane*	8.75	87.48	155.71	321.05
Tea*	13.95	139.52	248.35	512.04

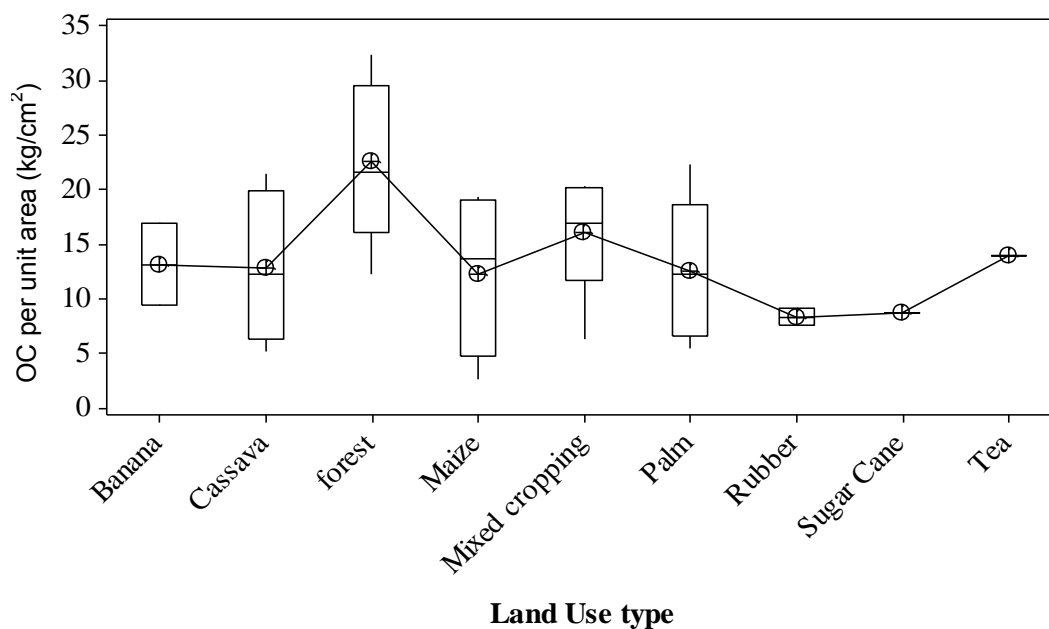


Figure 3. Box plots of OC showing range of C in each land-use and their mean on the southern part of the MCNP. Sugar cane and tea are not in boxes because there were only single values for them. The points in the boxes represent the mean values while the boxes represent the range of the values.

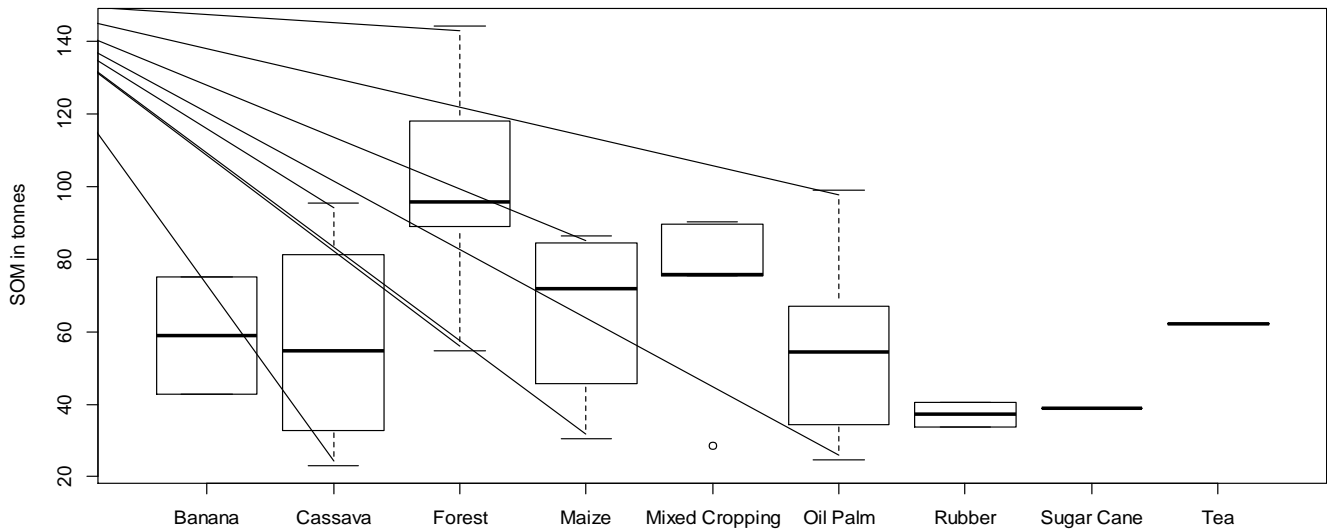


Figure 4. Total SOM values for the different land-uses in the southern parts of the MCNP.

Table 6. One way ANOVA results for SOC between forest and the other land-uses.

Land-use	Mean SOC	Df	p-value
Banana (N=2, t=1.638)	13.17	5	0.0.2430
Cassava (N=4)	10.77	7	0.0381*
Maize (N=4)	14.64	7	0.0600
Mixed cropping (N=5)	16.14	8	0.1686
Oil palm (N=5)	12.16	8	0.0451*
Rubber (N=2, t=4.849)	5.61	5	0.0046*

*Significant at $\alpha=0.05$.

shown by Omotoso and Akinbola (2007) even though no significant differences were found between forest texture and any of the land uses. The higher BD values revealed in forest and the cultivated lands are in accord with those of Sahani and Behera (2001) and Hajabbasi et al. (1997), who also reported higher BD in deforested and continuously cultivated lands. The BD values increased from maize to forest exempting rubber which is in line with the work of Murphy et al. (2004). This could be as a result of heavy illegal logging in the forest which may be responsible for compaction of soil particles and resulting in higher bulk densities. Since the soils had high clay content, it is possible that particles will compress and compact easily with the movement of this logging equipment. However, this trend could be further researched on to reveal the detailed reason for this increase from other land uses to forest.

The low variability in pH (3.8 to 4.87) across all land use types indicates that the pH is uniform or homogenous in the study area. This agrees with the work of Omotoso and Akinbola (2007). This homogeneity can be attributed to the management practices by farmers where use of

chemical fertilizers is almost non-existence in the area. The more acidic nature of soils under banana, rubber, oil palm, and tea indicates the effects of some spraying with chemicals on these land uses. This acidic nature of the soils under cultivated land is in conformity with the findings of Ndukwu et al. (2010) whose results revealed low pH for soils under continued cassava and oil palm cultivation.

Soil organic matter content

There were high differences in SOC across the different land use types. According to research, these differences in SOC distribution depend on large scale factors at regional climate, vegetation, soil type and topography (Wang et al., 2010; Wiesmeier et al., 2013). In the study, samples were collected following the different microclimates and at various elevations of the area to get a homogenous sample for each land use. The study area is relatively small and made of single soil type, as such, these variables could be overlooked. Hence, this conforms to the assumption that land use type patterns will largely contribute to any significant differences in SOC content (Su et al., 2006).

The SOC range of 2 to 6% are slightly less than the results of Sieffennan (1973), which stood at 4 to 8% SOC on the volcanic soils at the base of Mt. Cameroon. Lower values in this study are probably due to increased land-use changes and cultivation practices by the growing populations. These activities open up the soil to the atmosphere and increase the breakdown of SOM to yield CO_2 .

Soil fertility (SOC and total N) values were highest in forest, mixed cropping, maize, tea, banana, oil palm, cassava, sugarcane and rubber in that order with

significant differences between forest; and cassava, oil palm and banana at $p < 0.05$ (Table 3). Higher soil fertility under forest is possibly due to the higher accumulation and decay of leaf litter and roots within the forest than the cultivated lands in accordance with Awotoye et al. (2011). The observed losses of SOC and N in the cultivated land uses could also be attributed to rapid mineralization of SOM following cultivation, which disrupts soil aggregates, and thereby increases aeration and microbial accessibility to organic matter (Solomon et al., 2000). Another possible reason for lower soil fertility in the cultivated lands could be the lack of understory vegetation in the land uses which leaves the soil exposed and vulnerable to erosion that washes away topsoil nutrients (Boley et al., 2009).

Considering the critical value for phosphorus in soils (around 15 mg/kg for Bray-II), all these land-use types are rich in phosphorus, indicating the good soil quality of the zone and making the area suitable for agriculture. The higher average P values in the cultivated land uses (except rubber) than in the forest are probably due to higher input of organic manure. This is in accord with the results of Shrestha et al. (2007) who also attributed higher values of P in Bari soils to application of organic manure and chemical fertilizers.

The soil deterioration index revealed that soils under sole plantations are the most degraded except for P where mixed cropping is degraded more than some sole plantations. This could be the case because P is needed in large amounts for healthy plant growth as such can be easily depleted in mixed cropping where we have diversity of plants.

Soil carbon dynamics

This research goal is to set a baseline for SOC stocks in the area. Setting the baseline is important for future SOC stock estimation and comparing the C sequestration potential of various land use systems. In Cameroon, a national SOC database is not available and this could limit the country's ability to access funds from the Clean Development Mechanism (CDM) as proposed under article 12 of the Kyoto Protocol of the UNFCCC. This implies that SOC density estimation at local levels could serve as a starting point for large scale estimations and help provide some accuracy for a national SOC data.

Soil carbon density ranged from 5.6 ± 1.10 (rubber) to 22.53 ± 3.36 kg/m² (forest) and is a key indicator for SOC stock estimation. Average SOC pool (130.8 t/ha) for the area studied was higher than the value of 101 mg/ha obtained during the study of Djomo et al. (2011) for below-ground carbon over different vegetation types and land uses of a moist evergreen forest. The SOC stock range from 56.1 ± 11.00 (rubber) to 225.24 ± 33.65 t/ha (forest) was higher than those of Nasi et al. (2009) in their compilation of SOC from various sources and ecosystems in the Congo basin obtained with a mean

value of 38 t/ha (range 35 to 82 t/ha). This higher SOC stock could be explained to be the result of basaltic volcanic soils, rich in SOM of the study area.

Forest system showed the highest organic C stocks, followed by mixed cropping, maize, tea, banana, oil palm, cassava, sugarcane and rubber in that reverse order. The significant difference observed in SOC density of forest from those of rubber, oil palm and cassava ($p < 0.05$) (Table 6) is an indication that SOC pool changes in response to changes in land use or land management practices. This is because the conversion of forest land to cultivated land increases mineralisation in soils, leading to SOC decline and consequently soil degradation (Lal, 2003, 2004). In the forest, land use with highest SOC stock, was also recorded the highest moisture content and cation exchange capacity (CEC). High moisture content and CEC might explain this high SOC found in forest, since moisture and CEC play an important role in the determination, mineralization rates and conservation of SOM in the soils.

Soils under mixed cropping follow those under forest in SOC content as was expected because plant species diversity is known to enhance SOC (FAO, 2001). This is probably due to diversity in residue that decays directly into the soil. Soils under maize follow as the first in single crops. This was probably because farming practices in the study area are such that maize plants stems are left standing in the farms after harvest (and are later ploughed in or buried in the ridges) to degrade and become humus. This kind of activity will enhance the SOC.

Conclusions

The land use types identified in this study are not exhaustive of the area. There are others, such as tomatoes and other garden crops, cocoa and other mixed cropping systems. These were not considered because of lack of information on the various farm practice carried out during their cultivation. Values of SOC for tea and sugarcane were not used during the comparison for significant differences with forest. This is because each of these land use types was found in only a single village.

The potential ability to sequester carbon in the soils as SOC was found to be in the order: forest > mixed cropping > maize > tea > banana > cassava > oil palm > sugar cane > rubber. This trend reflects the current management practice. The forest here is part of the MCNP, which is protected by forest guards who enforce law by preventing human activities and illegal cuttings. Even then, there are still some signs of human activities in some areas. Agro-forests (here referred to as a mixed cropping system) are currently an open access area, where the uses vary from illegal cutting to clear cutting for agriculture.

Cassava, oil palm and rubber land-use systems indicated significantly lower amounts of SOC, an indication

that these land use types are detrimental to SOC sequestration and possibly contributing to rising levels of atmospheric CO₂. Rubber land-use systems were found to be exceptionally poor in SOC and highly degraded in other soil properties. The rest of the land-use systems contained reasonable amounts of SOC, which could be improved through better soil management practices such as the use of organic manure. The CO₂ equivalent held by soils of these land-uses types follow the same order as SOC, with forest having the highest value and rubber the least. The significant difference between virgin forest, and rubber, cassava and palm proves that forest conservation is important and needed, if the fight against climate change is to be faced. This therefore gives additional reasons for the protection of the MCNP (for the forest helps to hold reasonable amounts of CO₂ in the soil in the form of SOC).

Conflict of interest

The authors have not declared any conflict of interest.

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