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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 circumtance 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 cm^2), medium (2001 to 4000 cm^2) and large (4001 cm^2 >) 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 strutures and vegetation. Hence,many previously studies demonstrated that termite influence soil properties inside their mounds relative to a reference soil (Levage, 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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*Corresponding author. E-mail: zarifin14458@yahoo.co.id 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/m^2 and 100 g/m^2 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 purposivelly 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 (X^2) table α 0.05 df. 4 = 9.488 * = significantly different

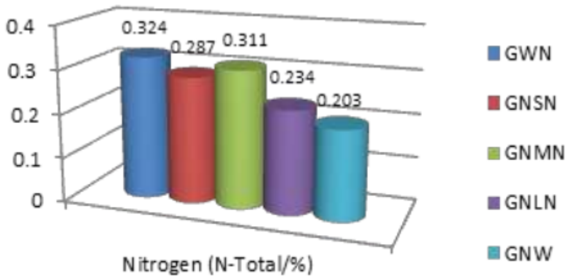

Figure 1. Comparison of average number of total nitrogen values of the soil adjoining with the nest, soil away from nest and the soil nest wall.

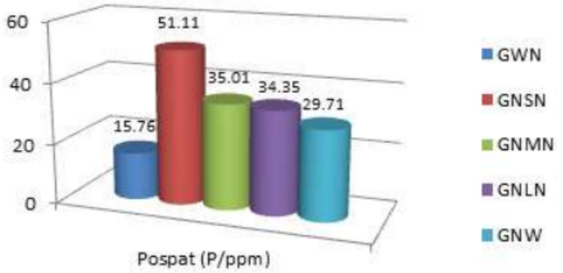

Figure 2. Comparison of the average number of phosphate (P/ppm) on the land away from termite nest, the land adjoining each nest size and soil nest wall.

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

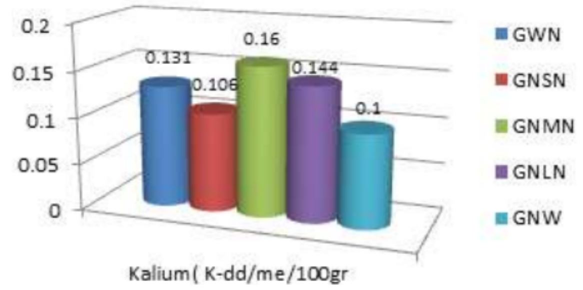

Figure 3. Comparison of the average values of potassium (K-dd/me/100 g) of land adjoining to a nest, away from nest and nest soil.

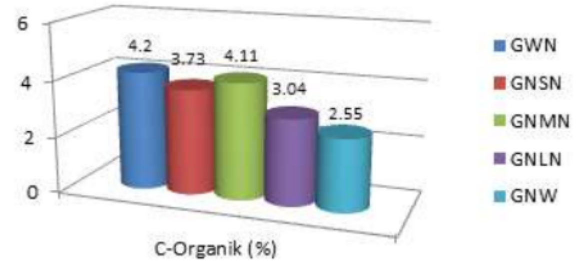

Figure 4. Comparison of the average values of C-organic (%) on the land adjoining to the nest, away from a nest and soil nest

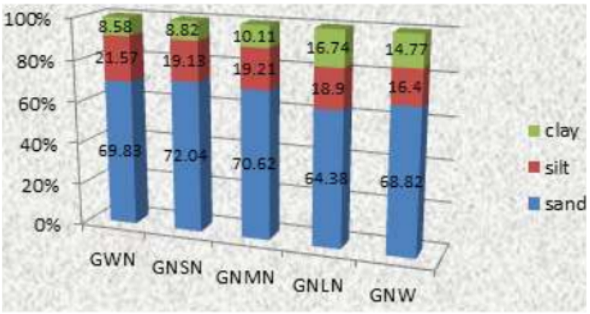

Figure 5. Proportion of the soil fraction of the soil texture of each soil sample.

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 matteral 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 with hindgut bacteri that can fix atmosferic 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 (Dangerfied 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 enhence by consumption of plant by termite. The amount of exchangable 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 throug their gut and use of saliva and feases for nest constraction (Wood et al., 1983). Content of total P suggested because of termite did not change the total P where available P was not preferencially 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 alkalin hindgut of the termite (Wood et al., 1983). Additionallly, that the high content of organic matter in soil nest influences the P sorption-desorption proceses. So, the termite influence is not restricted to the nesting area as termite activity or a relocation of nest material both interfere with sorrounding 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 matterial 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.

Feacal 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 mutualitically 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 difusion 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 fromt nest, these was possible because of the population number of individuals in small size nests were still a minute, nature of nest constuction 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 bacterials 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 michaelseni* 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 presense 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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