Available online at:
http://journal.unila.ac.id/index.php/tropicalsoil
DOI: 10.5400/jts.2013.18.2.149

Characteristics of Soil Fauna Communities and Habitat in Small-Holder Cocoa Plantation in South Konawe

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Received 15 January 2013 / accepted 10 May 2013

ABSTRACT

The composition of soil fauna community have played an important role in regulating decomposition and nutrient cycling in agro-ecosystems (include cocoa plantation). Changes in food availability and conditions in the soil habitat can affect the abundance and diversity of soil fauna. This study aimed: (i) to analyze the pattern of changes in soil fauna community composition and characteristic of soil habitat based on the increasing age of cocoa plantation, and (ii) to identify taxa of soil fauna and factors of soil habitat which differentiate among the cocoa plantations. Sampling of soil, roots and soil fauna was conducted from cocoa plantation aged of 4, 5, 7, 10, and 16 years. Difference in composition of the soil fauna community between ages of the cocoa plantation was significant. Profile of soil habitats was differ significantly between the cocoa plantations, except 5 and 7 years aged. A group of soil fauna had relatively limited in its movement, and sensitively to changes in temperature, soil acidity, and the availability of food and nitrogen were taxa differentiating between soil fauna communities. Soil physic-chemical conditions that affected metabolic activity, movement, and the availability of food for soil fauna were a distinguishing factors of the characteristics of the soil habitat between different ages of smallholder cocoa plantations.

Keywords: Abundance, arthropod, composition, nematodes

INTRODUCTION

Composition of soil fauna communities have played an important roles in regulating of decomposition and nutrient cycling in agro-ecosystems (Allen *et al*. 2005; Nielsen *et al.* 2010). In agricultural practices, enhancing the capacity of the soil to support a high biomass productivity in the "Green Revolution" period causes to loss of soil fauna beneficial to sustain of soil ecosystem process in the agricultural area concerned (Doran and Zeiss 2000; Susilo *et al*. 2004; Saha 2010). As a result, the ability of the soil ecosystem functions, such as decomposition and nutrient recycling, was significantly reduced (Hunt and Wall 2002; Blagodatsky and Smith 2012).

The changes in the abundance and diversity of soil fauna are not only caused by factors of disturbance, such as tillage, fertilizer and pesticide application (Bloem *et al*. 1994), but also through changes in soil habitat conditions with increasing in the age of agro ecosystem (Bardgett 2005). Presence of the significant correlation between the characteristics of the soil with density of soil fauna, was used by some researcher as a basic to asses of soil quality status (Kibblewhite *et al*. 2008). Using the soil fauna density and diversity as indicators of soil quality changes appli the assumption that similar soil habitats will have similar soil fauna community anyway (Ruf *et al.* 2003). Characteristics of physic-chemical soil habitats, such as bulk density, moisture, total carbon, nitrogen, pH, P, Ca, Mg, quality of plant litter and root can changed in time, which in turn will alter the conditions and availability of food for soil fauna along with increasing in the age of agro-ecosystems (Hopkins and Gregorich 2005; Marhaning *et al*. 2009; Sharma *et al*. 2009). Meanwhile, the accumulation of organic matter contribute to changes in humidity, temperature, pH, total carbon, N, P and P-inorganic soil during the development of agro-ecosystems (Van Eekeren *et al*. 2009; Yadav *et al*. 2011). Changes in soil habitat conditions can affect directly and indirectly the distribution and abundance of soil fauna (Bardgett

2005). For example, Moco *et al.* (2010) found out a direct positive effect of pH on taxa richness, while the bulk density has indirect positive effect, vice versa C and N has negative indirect effect mediated by the pH on soil fauna taxa richness in cocoa plantations (cocoa agro-forestry).

In Indonesia, the area covered by the small-holder cacao plantation reached 1.64 million ha or about 94% of the total area of cocoa plantation at year 2011 (Directorate General of Estate, Agricultural Ministry, RI 2012). Many conservation biologists recommended a small-holder cocoa plantation as an approprite system for the soil fauna conservation (Delabie *et al*. 2007; Bos *et al*. 2007; Moco *et al*. 2009; Shahabuddin 2010). Studies related to the diversity of soil fauna (especially ecosystem engineers group) were reported by Kilowasid *et al*. (2012) and variation in soil organic carbon and some parameters of soil habitat were reported by other researcher (Isaac *et al*. 2005 and Smiley; Kroschel 2010) from different ages of cocoa plantation. The study of how the pattern of changes in the composition of the soil fauna communities and patterns of change in the characteristics of the soil habitat in small-holder cocoa plantation is neglected.

This study aimed: (i) to analyze the pattern of changes in soil fauna community composition and characteristic of soil habitat based on the age increasing of cocoa plantation, and (ii) to identify taxa of soil fauna and factors of soil habitat which differentiate among the age of cocoa plantations.

MATERIALS AND METHODS

Study Site

The research was conducted in the small-holder cocoa plantation aged of 4, 5, 7, 10, and 16 years at the Mowila and Konda sub-districts in Sotuh Konawe District, and located at 040^{o}7'04.9'' - 040^{o}8'50.5'' south latitude and 122^{o}15'02.8'' - 122^{o}31'40.5'' east longitude. Topography of area research was categorized as a flat with slopes about 0-3%. Average of rainfall was 175.58 mm month^{-1} and air temperature was 26.74^{o}C. Soil type in the area studies was categorized into Dystrudepts Typical, coarse clay, Isohypertermic.

Samples Collection of Soil, Roots and Soil Fauna

Soil, roots and soil fauna were sampled from the square measuring 2.500 m^2 (50 m x 50 m) at each place. All samples were taken using a cylindrical stainless steel to a depth of 15 cm from the soil. Samples for physical and chemical analysis were taken by using a soil core with a cylinder of 7.4 cm in diameter on each corner of the square from each place. Every time sampling of roots and soil fauna, constructed four sub-squares (each sub-square was 0.5m x 0.5m) were placed between planting cocoa trees within 3m x 3m, and the distance between the sub-squares as far as 10 m in the each square at the every place. Active roots and soil fauna were collected five times in a one year period on August 15th 2009, November 21st 2009, January 26th 2010, April 22nd 2010, and June 13rd, 2010 (details of the sampling design be refered to Kilowasid *et al*. 2012). There were also three different cylinders of 4.8 cm in diameter and each of them was used to collect active roots (Kummerow *et al*. 1982), meso-fauna and nematodes. Enchytraeidae was collected using a cylinder of 7.4 cm in diameter, and macro fauna by a cylinder of 20 cm in diameter.

Analytical Procedures

Dried soil-wind pass a 4 mm sieve per hole was used for the determination of pH (in water extraction), % sand, % silt, and % clay (pipetting method), organic carbon (spectrophotometer), total nitrogen (Kjehdahl method), total P (extraction in HCl 25%), available P (Bray 1 method), and the organic fraction of labile and recalcitrant with the two-step procedures of H_2SO_4 hydrolysis (Rovira and Vallejo 2002; Belay-Tedla *et al*. 2009). Ammonium and nitrate were extracted by 2*M* KCl solution (Shinner *et al.* 1996). Soil bulk density followed the procedure of Wilke (2005). The measurements of soil temperature (using a digital thermometer with a thermocouple) and humidity (using meter soil moisture) at a depth of 7.5 cm from the soil were carried out every five days.

Soil suspension was filtered using a filter size of 4 mm per hole which was placed on the top sieve size of 0.5 mm per hole. Roots retained on both sieves were transferred to Petri dishes, and the dirt and dead roots were aside from the fresh root. After that the fresh roots were dried at a temperature of 70^{o}C for 48 hours (Muñoz and Beer 2001).

Macro-fauna was removed from soil core using the hand sorting method and preserved in 70% alcohol. Except for earthworms, other macro fauna was cleaned with 10% KOH before identification under a dissecting microscope. Acari, Collembolan and Dipterans adults were extracted in Berlese-Tullgren at room temperature of extractor ranged of 38^o - 40^{o}C (Winter and Behan-Pelletier 2008) for 5 days. Each meso-fauna was sorted and counted under a dissecting microscope (Adejuyigbe *et al*. 1999). Collembolan and Acari were cleared in 10% KOH solution and a mixed-mounting with chloral hydrate, gum Arabic, glycerol, and distilled water (Kasprzak 1993), and then all specimens were dried at a temperature of 70°C. Identification of morphology character of Collembolan followed a guide from Christiansen (1990) and Acari followed Gerson *et al*. (2003). Enchytraeidae was extracted using Baermann Funnel extractor modified under temperature of 38 - 40°C for 5 days, and individual of Enchytraeidae was counted under a dissecting microscope (Adl. 2008). Nematodes were extracted using a technique modified by Baermann Funnel. Nematodes were filtered using a filter size of 38 μm per hole, and nematodes in water temperature of 70°C. Individual of nematodes were counted under a dissecting microscope, after that nematodes were prepared for identification following the procedures from Forge and Kimpinski (2008), and minimum 100 individual of nematodes were identified up to order level under light microscope at 400 times magnification following the guide instructions from Panesar *et al*. (2005).

Measurement of Soil Fauna Community and Statistical Analysis

The abundance of each taxa of soil fauna is expressed in the number of individual m^{-2}. Taxa richness, Shannon diversity index and Simpson evenness index were calculated by using the formula of Camargo (2008). Kruskal-Wallis nonparametric analysis was used to detect significant differences in the abundance and diversity of soil fauna habitat and nature of the soil between the cocoa plantations that had different age (Zar 1999).

Construction of the cluster chart that summarizes the degree of similarity between the attributes of soil habitat or soil fauna composition from the plantation that had different ages used the algorithm of Ward's method and measurement of similarity of distance Euclidean was applied. To estimate the degree of similarity between cocoa plantation from dendrogram of the soil habitat attributes and the soil fauna community composition, test of Squared Mahalanobis Distance was applied. To select the taxa of soil fauna, parameters of soil habitat that differentiating between different ages of cocoa plantation in its soil fauna composition and factors of soil habitat were analyzed with a discriminate analysis. Forward stepwise method was applied to select significant variables in the discriminate model. A value of Wilks' Lambda from the analysis method was applied to determine a significant difference between groupings of age of the cocoa plantation. If, the value of Wilks' Lambda is close to 0 showed that the data for each age group from cocoa plantation is likely to be different, meanwhile, if their value is close to 1, the data for each age group of the cocoa plantation is likely to be similar according to the soil habitat or composition in their soil fauna (Sanchez-Moreno *et al*. 2008).

RESULTS AND DISCUSSION

Abundance of Soil Fauna Taxa

Soil fauna taxa in smallholder cacao plantation from five different ages are presented at Table 1. A total of 13,649 soil fauna specimens were collected during the study period, which consist of the nematode and arthropod phylum. This study found that a total abundance of soil fauna was about 53,900 - 72,819 individual's m^{-2}. The total abundance of soil fauna was mentioned it is higher than the total abundance of soil fauna (about 716 - 930 individuals m^{-2}) reported by Moco *et al*. (2009) from cacao agro-forestry and the total abundance of soil fauna (about 1,790 – 2,940 individuals m^{-2}) reported by Widyastuti (2006) of several types of terrestrial ecosystems (teak forests, gardens and rain fed). A higher abundance of soil fauna was caused by the nematode phylum was also analyzed in this study.

Kruskal-Walis test showed taxon abundance of the nematode phylum, namely Aphelenchida ($p < 0.0009$), Araeolaimida ($p < 0.0021$), Chromadorida ($p < 0.0094$), and Monhysterida ($p < 0.0388$) that was most dominant in the soil from cocoa plantation aged 7 years, while the abundance of other nematode taxa among five different ages of cocoa plantation was similar ($p > 0.05$). Studies related to the dynamics of soil nematode communities in cocoa plantation are still rarely published in the literature. To get a description about variation in abundance of nematodes which was occurred at this study, this result will be compared to the abundance of nematodes in tropical forest soils. The abundance of soil nematodes in some tropical forests are greatly varied. Pradhan and Dash (1987) reported about 150,600 – 661,100 individuals m^{-2}, Lawton *et al*. (1996) reported an average of 304,000 individual's m^{-2}, and Bloemers *et al*. (1997) reported about 297,000 - 2,442,000 individuals m^{-2}. The abundance of nematodes in this study ranged from 50,103 – 70,267 individuals m^{-2}, which it abundance was least than the abundance of nematodes in the soil of tropical forests. Generally, the abundance of soil nematodes in the agricultural land was lower than in the forest soils, for example, Todd *et al*. (2006) also showed the abundance of soil nematodes from

Table 1. Comparison of abundance of soil fauna (individual m^{-2}), number of taxa, Shannon and Simpson Evenness indices from five different ages of small-holder cocoa plantation.

Taxa	Age of small-holder cocoa plantation (years)				
	4	5	7	10	16
Nematodes					
Aphelenchida	536±1,191c	0±0a	114±289b	0±0a	0±0a
Araeolaimida	2,512±2,434b	2,855±1,963b	1,221±1,566ab	693±945ab	367±431a
Chromadorida	402±893ab	459±103ab	815±12,03b	414±853ab	0±0a
Dorylaimida	9,461±1,830a	11,835±21,300a	7,616±15,946	6,960±1,032a	4,572±9,596a
Enoplida	17,007±20,686a	7,706±8,083a	5,709±6,093a	4,063±6,617a	5,463±5,522a
Monhysterida	8,018±4,493ab	10,521±11,943b	10,309±12,851ab	4,970±5,059a	7,924±7,311ab
Mononchida	15,907±11,780a	29,428±15,647a	24,649±17,282a	26,947±21,562a	27,867±28,714a
Rhibditida	16,424±19,392b	4,259±5,298a	9,542±9,050ab	6,056±8,542a	8,230±9,605a
Acari					
Astigmata	127±325a	204±418a	127±280a	128±227a	51±157a
Mesostigmata	153±373a	331±602a	153±373a	179±250a	128±227a
Oribatida	77±187a	51±157a	102±267a	102±20a9	51±157a
Prostigmata	153±335a	204±347a	76±249a	255±453a	204±384a
Collembola					
Entomobryidae	51±228a	204±347a	127±280a	127±365a	51±157a
Isotomidae	26±114a	51±228a	26±114a	51±157a	26±114a
Onychiuridae	0±0a	0±0a	26±114a	0±0a	26±114a
Sminthuridae	102±355a	26±114a	51±157a	0±0a	0±0a
Macro-Arthropod					
Aranae	3±10a	2±7a	3±10a	5±12a	5±12a
Blattodea	3±14a	0±0a	0±0a	0±0a	2±7a
Chilopoda	3±14a	3±10a	18±22ab	27±53b	5±12a
Coleoptera	22±26a	21±30a	43±44a	38±86a	27±35a
Dermaptera	8±23a	2±7a	2±7a	6±17a	2±7a
Diplopoda	0±0a	0±0a	13±36b	6±13ab	6±17ab
Diplura	2±7a	0±0a	6±17a	19±24b	6±13a
Diptera	385±615a	847±1,899a	433±1,262a	379±674a	312±449a
Formicidae	454±938a	32±45a	126±337a	156±506a	166±359a
Isopoda	5±21a	0±0a	0±0a	2±7a	2±7a
Isoptera	3±14a	0±0a	5±21a	107±266a	170±696a
Lepidoptera	0±0a	3±10a	0±0a	0±0a	2±7a
Glossocolecidae	61±84a	33±70a	48±62a	22±47a	62±125a
Enchytraeidae	897±1,380a	351±616a	741±1,034a	2,158±3,869a	455±965a
Opiliones	5±12a	0±0a	0±0a	3±10a	2±7a
Orthoptera	0±0a	0±0a	0±0a	3±14a	0±0a
Protura	0±0a	0±0a	0±0a	2±7a	2±7a
Pseudoscorpion	0±0a	0±0a	2±7a	2±7a	5±12a
Psocoptera	2±7a	5±16a	2±7a	3±14a	3±10a
Symphyla	8±29a	3±10a	2±7a	8±20a	8±14a
Thysanoptera	0±0a	0±0a	2±7a	0±0a	0±0a
Uropygi	0±0a	0±0a	0±0a	0±0a	2±7a
Others	5±12a	13±24a	5±16a	10±26a	0±0a
Total	72,819±40,413	69,447±35,755	62,112±40,728	53,900±32,551	56,200±37,865

Samples number = 20, mean ± SE. Different letter following number in the same row shown significant according to Kruskal-Wallis test at the level $p < 0.05$.

some management practices of agricultural land were much lower than in forest soils. Abundances of Aphelenchida, Araeolaimida, Chromadorida, Monhysterida, and Rhabditida between different ages of cocoa plantation were significantly different. Also, this study found that change in the density of each taxa nematode did not shown a pattern according to sequence by the age of cocoa plantation. A similar pattern was also shown by Hanel (2001) which studied changes in nematode community succession in the sandy soil at pine forest from ex-area of coal mining activities in Germany, and Kardol *et al*. (2005) which also examined changes in the nematode community succession on former of agricultural land in the temperate (Netherlands). These facts indicated that the plant age is a complex factor in estimating a direction in change of composition of soil nematode community along with increasing age of cocoa plantation. From this results, it can be argued that the initial composition of the nematode community in the soil before cocoa tree planted and the survival of each nematode taxa are due to changes in soil habitat factors as a factor which determining the composition of soil nematodes along with the increasing in age of cocoa plantation.

Based on the calculation of the abundance from every of phylum, it was obtained that total abundance of arthropods ranged from 1,777 - 3,797 individual's m^{-2}. Minimum total abundance of arthropods was found in this study within the range of the total abundance of arthropods which reported by Widyastuti (2006) and Moco *et al*. (2009), while maximum total abundance of their arthropod was higher than both researchs. Total abundance of arthropods (individual's m^{-2}) of this study and Widyastuti (2006) were higher than reported by Moco *et al*. (2009). This difference was sourced from abundance of Acari and Oligchaeta (Glossoscolecidae and Enhytraeidae) which were not analyzed by Moco *et al*. (2009). In this study, abundance of Glossoscolecidae was ranged of 22-62 individual's m^{-2}, Enchytareidae was ranged of 351 - 2,158 individuals m^{-2}, and Acari was ranged of 434 - 664 individuals m^{-2}. Three taxa of mentioned soil fauna were found in all ages of cocoa plantation. Widyastuti (2006) reported that earthworms were only in found a teak forest land which was 6 individual m^{-2}, Enchytraeidae was only found in garden soil which was 13 individuals m^{-2}, while Acari was found in all three types of ecosystems with an abundance was ranged of 261 - 440 individuals m^{-2}.

Abundance of Chilopoda and Diplopoda between ages of cocoa plantation were significantly different ($p > 0.05$), while the abundance of Acari, Collembolan and other taxa among different ages of cacao plantation was similar ($p > 0.05$). The highest in abundance of the Chilopoda and Diplopoda in all ages of the plantation in this study was in the ranged of 4 - 19 individuals m^{-2} for Diplopoda and 3 - 31 individuals m^{-2} for Chilopoda and it was similar from some type of cocoa agro-forestry reported by Moco *et al*. (2009). Chilopoda was found in all ages of the cocoa plantation, while the Diplopoda was only found in the plantation aged 7-16 years. The highest abundance of Chilopoda was 27 individual's m^{-2} in the plantation aged 10 years; meanwhile the highest abundance of Diplopoda was 13 individual's m^{-2} in the plantation aged 7 years. These fact indicated that the life history characteristics determined the response of each taxon of soil fauna to change soil habitat factors. For example, Sileshi and Mafongoya (2007) found an abundance of Diplopoda was correlated to high-quality organic ingredients, while the distributions of Chilopoda and Aranae were more influenced by environmental factors than the quality of the organic materials.

Diversity of Soil Fauna Communities

Differences in taxa richness (S), Shannon diversity indices (H ') and Simpson evenness indices (e') among five different ages of cocoa plantation are not significantly at the $p > 0.05$ level (Table 2). These results indicated that the all of three diversity measured are less sensitive to detect changes in the abundance and distributions of taxa in communities of soil fauna from cocoa plantation differing in their ages. This fact reaffirmed the

Table 2. Comparison number of taxa, Shannon and Simpson evenness indices from five different ages of small-holder cocoa plantation.

Measures of diversity	Age of small-holder cocoa plantation (years)				
	4	5	7	10	16
S	10±3a	9±2a	11±2a	10±3a	10±3a
H'	2.635±1.037a	2.507±0.598a	2.595±0.465a	2.480±0.476a	2.505±0.477a
Evenness	0.313±0.082a	0.301±0.088a	0.265±0.076a	0.289±0.117a	0.341±0.134a

Samples number = 20, mean ± SE. Number in the same row followed same letter shown not significant according to Kruskal -Wallis test at the $p > 0.05$ level.

analysis of Beisel et al. (2003) that the sensitivity of each measurement of ecological diversity depends on changes in the status of taxon abundance (rare, median or common taxa) in the communities. Urzelai *et al*. (2000) applied the Simpson diversity indices for common taxa and Shannon diversity indices for rare taxa to analyze variations ecological diversity within soil nematodes communities among types of ecosystems. Rare taxa within soil fauna community in cocoa plantation are most dominant (Aeckerman *et al*. 2009; Moco *et al*. 2009). Furthermore, Moco *et al*. (2009) found variations in the diversity of soil fauna communities across cacao agroforestry systems was detected using Shannon diversity indices. Recently, Kilowasid *et al*. (2012) reported that variations in the ecological diversity of soil fauna communities as ecosystem engineers of cocoa farm folk in this study was detected with Simpson indices for dominance and evenness. It indicated the importance of the selection of ecological diversity measurement which are most sensitive to analyze the temporal changes in the structure of soil fauna community in the small-holder cocoa plantation system.

Variation of Soil Properties Habitat

Root dry weight, the fraction of silt, clay, and soil temperature and soil moisture between the ages of cocoa plantation was significantly different, while other parameters of soil habitat conditions were not significantly different between the ages of cocoa plantation (Table 2). It was shown that the food resources and habitat conditions in the soil from different ages of cocoa plantation were different. Root dry weights in the plantation aged of 5, 7, 10, and 16 years were higher than the plantation aged of 4 year ($p < 0.05$). It showed that the quantity of roots as a source of food for soil fauna (root herbivores) were changed along increasing age of cocoa plantation. In terms of its quantity, the root dry weights in the older plantation were higher than in the younger plantation. However, the capacity of roots to provide food for root herbivores were mostly dependent on root could, within meaning on ease of root can be accessed by soil fauna grouped as root herbivores (Wardle *et al*. 2004) in cocoa plantation system.

Percentage of sand fraction between the different ages of cocoa plantation was not significantly different ($p > 0.05$). Meanwhile, the silt fraction in the plantation aged of 7 years was higher than in aged of 16 years ($p < 0.0365$). While, the clay fraction in the plantation aged of 10 years was higher than in aged of 16 years ($p < 0.0240$). Both the percentages of silt and clay fraction between other ages of the plantation was not significantly different ($p > 0.05$). Previously, some study used the chronosequence approach which was expected that soil organic carbon and total nitrogen will be increase due to the accumulation of soil organic matter along with increasing in age of the trees plantation (Lavelle and Spain 2001; Bardgett 2005). But in this study, the content of organic carbon and total soil nitrogen did not show any consistent trend with increasing or decreasing the age of cocoa plantation. Elsewhere in Indonesia, similar studies were also found that the levels of organic carbon and total nitrogen did not significantly increase with the increasing age of cocoa plantation (Smiley and Kroschel, 2008; Smiley and Kroschel 2010; Syaf 2010). The same phenomenon was also reported by Hairiah *et al*. (2006) and Evizal *et al*. (2012) that soil organic carbon was not significantly different between the different ages of coffee agro ecosystems in Lampung. Although soil organic carbon and total nitrogen did not differ between the ages of cocoa, but the indirect effect through the soil pH was greatly contributed to soil fauna communities in cocoa plantation (Moco *et al*. 2010). For the silt fraction, the findings in this study were in contrast to Isaac *et al*. (2005) that the percentage of silt and clay fraction did not show a tendency in decreasing or increasing by the increasing age of cocoa plantation. The difference from both results were due to the difference, in the composition of the soil particle fraction because the difference of their parent soil material properties (Zornoza *et al.* 2008; Syaf 2010).

The soil temperature in the older cocoa plantation aged was lower than in the younger aged. Otherwise, soil moisture in the younger cocoa plantation aged was higher than in the older aged. The soil temperature was likely to decline with the increasing age of cacao plantation, allegedly associated with the increasing in size of the tree cocoa cover with the plantation age (Isaac *et al*. 2005; Korhonen *et al*. 2007), which is the vegetation cover is an instrumental to reduce solar thermal radiation that reaches the soil (Zheng *et al*. 1993; Lavelle and Spain 2001; Hairiah *et al*. 2006). Thus, it can be interpreted that the decrease in soil temperature was associated with increasing age of cocoa plantation. Soil moistures in all ages of the plantation were very low with an average of about 3.49 to 7.07%, which was equivalent to the soil matrix potential <-200.00 MPa or > 6.30 pF (Lavelle and Spain 2001). The low in soil moisture in the younger cocoa plantation aged, and the highest in the middle-aged and the old-aged of the cocoa plantation, means that the low water availability for soil fauna survivorship in younger cocoa plantations are particularly at risk than in older. The variations in soil moisture were due to the influence by the composition of the soil particle size through its influence on distribution of soil pore size (Voroney 2007; Lukac and Godbold 2011).

Characteristics of Soil Fauna Communities and Soil Habitat

The cluster analysis shown that soil fauna community in cocoa plantation aged of 4 and 7 years was apart from the group cocoa plantation aged of 5, 10, and 16 years. From dendrogram in Figure1A, it is presented that composition of soil fauna communities in cocoa plantation aged 16 years was located in the transition between the group of cocoa plantation aged of 5 and 10 years and cocoa plantation aged of 4 and 7 years group. Unlike the case in the characteristics of the soil habitat, the dendrogram of cluster analysis showed that characteristics of the soil habitat in cocoa plantation aged 16 years was apart from the other four different ages of the cocoa plantation. The characteristics of the soil habitat in cocoa plantation aged of 4, 5, and 7 years were more similar to each other. The characteristics of the soil habitat in cocoa plantation aged 10 years was located at the transition between the characteristics of soil habitat in cocoa plantation aged of 4, 5, and 7 years and the cocoa plantation aged 16 years (Figure 1B). Refer to concept that sites which have similar soil properties are assumed to have a similar composition in their soil fauna community (Ruf *et al*. 2003; Voroney 2007), so it can be expected that pattern in soil fauna composition group following the pattern in soil habitat characteristic group in the cocoa plantation which their ages were different. The fact, which patterns in clustering based on soil fauna composition were different from the pattern in clustering based on the characteristic of the soil habitat from different ages of cocoa plantation. Shifting patterns of clustering were occurred in cocoa plantation aged of 4, 5, and 7 years, meanwhile patterns in clustering of soil fauna composition suitable with patterns in clustering of soil habitats characteristic was occurred in the cacao plantation aged of 10 and 16 years. Inconsistency in the patterns in clustering of the soil fauna composition and soil habitat characteristic at the cocoa plantation aged of 4, 5, and 7 years indicated that response of each soil fauna taxa on changing environmental conditions and food depended on the characteristics of the life history and the mobility of the soil fauna taxa (Hemmsbergen *et al*. 2004).

The composition of soil fauna community among all five different ages of cocoa plantation was significantly different ($p < 0.05$) (Table 3). Values of Squared Mahalanobis Distance shown the greatest differences in the composition of the soil fauna was occurred between the cocoa plantation aged ages of 10 years and 16 years, while the smallest was occurred between the cocoa plantation aged of 4 years and 5 years. Based on the model of forward stepwise discriminate function of the soil fauna abundance, it was found that Araeolaimida, Mononchida, Chromadorida, Aphelenchida and Monhysterida of the nematodes phylum, and Diplopoda and Isopteran of arthropods phylum were differed in soil fauna community composition among cocoa plantation which differed in ages (Wilks' Lambda: 0.00000; $F (56.9) = 287.11$, $p < 0.0000$). From the discriminate analysis, it can be said that the taxa which have limitation in their mobility and relatively sensitive on changing in the conditions and the availability of food resources will be successful

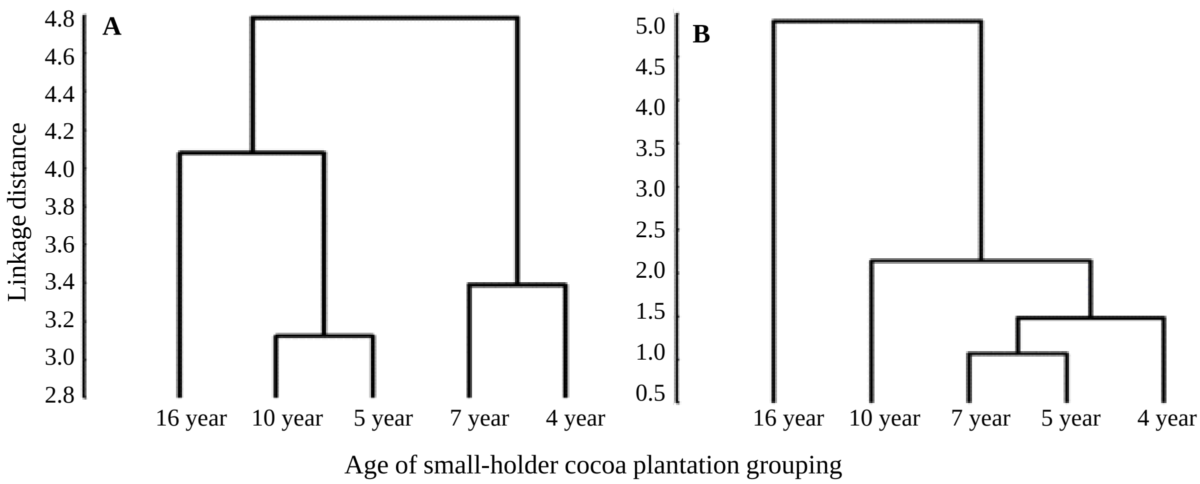

Figure 1. Dendrogram of similarity from age of cocoa plantation based on: (A) soil fauna communities; (B) soil habitat attribute.

Table 3. Comparison of each parameter of soil habitat among different ages of small-holder cocoa plantation.

Soil habitat attribute	Age of small-holder cocoa plantation (years)				
	4	5	7	10	16
Root dw (g m^{-2})	0.8±0.5a	1.8±1.1b	1.7±1.2b	1.5±0.8b	1.4±1.0b
FOL (g 100 g^{-1})	11.1±0.9a	10.4±1.6a	10.3±1.2a	11.0±3.7a	10.3±3.7a
FOR (g 100 g^{-1})	6.0±2.1a	7.8±3.8a	7.0±2.4a	6.3±4.8a	4.1±0.8a
Org-C (%)	1.7±0.3a	1.8±0.3a	1.7±0.1a	1.7±0.1a	1.4±0.4a
Tot- N (%)	0.12±0.02a	0.13±0.03a	0.13±0.02a	0.14±0.02a	0.13±0.03a
C:N	14.2±0.8a	14.4±1.8a	13.7±1.6a	12.4±0.7a	11.3±4.1a
pH	4.7±0.1a	4.63±0.2a	4.58±0.2a	4.5±0.1a	4.6±0.2a
Tot- P (mg kg^{-1})	181.4±38.6a	200.9±20.8a	195.7±103.2a	164.8±20.8a	284.4±53.6a
P-avail (mg kg^{-1})	4.4±1.0a	4.8±1.8a	10.6±12.6a	3.5±1.1a	4.3±0.8a
NH_4^+ (mg kg^{-1})	11.2±15.7a	4.6±2.7a	5.1±2.8a	4.4±2.3a	4.2±2.8a
NO_3^-(mg kg^{-1})	5.9±8.7a	3.3±2.1a	2.9±1.9a	3.4±1.6a	3.0±1.3a
FP (%)	31.6±2.1a	27.7±8.3a	27.3±3.9a	36.4±1.8a	40.4±12.1a
FD (%)	41.7±2.3ab	40.1±3.7ab	44.2±3.4b	30.7±3.6a	35.3±8.9a
FL (%)	26.8±1.7ab	32.2±7.0ab	28.5±2.9ab	32.9±2.2b	24.3±3.8a
BD (g cm^{-3})	1.4±0.1a	1.4±0.1a	1.5±0.1a	1.41±0.1a	1.4±0.1a
Temperature (^{0}C)	30.9±2.0b	29.5±2.1b	29.3±2.28b	29.1±2.3b	28.2±1.7a
Moist (%)	3.5±3.1a	4.3±2.6a	6.0±2.9b	6.3±3.3b	7.1±3.4b

Notes: root dw = root dry weight; moist. = soil moisture; FP = sand; FD = silt; FL = clay; Org-C = organic-C; FOL = labile organic fraction; FOR = recalcitrant organic fraction; Tot-N = total N; Tot-P = Total-P; P-avail = P-available; BD = bulk density. Sample number = 20, mean ±sd. Number in the same row followed different letters shown significant according to Kruskal-Wallis test at the $p < 0.05$ level.

Table 4. Difference of soil fauna composition among five different ages of small-holder cocoa plantation.

	Age of small-holder cocoa plantation				
	4 year	5 year	7 year	10 year	16 year
4 year	-	**7.342***	**5.561.802***	**2.006.141***	**9.332.205***
5 year		-	**5.915.802***	**2.218.216***	**9.790.195***
7 year			-	**890.096***	**486.496***
10 year				-	**2.690.743***
16 year					-

Notes: Bold number followed symbol* indicated significantly difference in soil fauna community composition among five different ages of small-holder cocoa plantation according *Squared Mahalanobis Distance* test at the $p < 0.05$ level

Table 5. Differences in attributes of soil habitat from different ages of small-holder cocoa plantation.

	Age of small-holder cocoa plantation				
	4 year	5 year	7 year	10 year	16 year
4 year	-	**106.86***	**105.35***	**359.76***	**497.98***
5 year		-	6.13	**90.41***	**167.31***
7 year			-	**95.36***	**162.77***
10 year				-	**25.92***
16 year					-

Notes: Bold number followed symbol * indicate significantly differences in attributes of soil habitat from different ages of small-holder cocoa plantation according *Squared Mahalanobis Distance* test at the $p < 0.05$ level

distinguishing characteristics of the soil fauna community in the cocoa plantation of different ages. Those soil fauna characteristics, generally used as a conceptual basis for analyzing biotic index of soil quality with soil fauna community as a bio-indicator (Bongers and Ferris 1999; Yan *et al*. 2012).

The differences in profile of the soil habitat characteristic in cocoa plantation from different ages was significantly ($p < 0.05$), except in plantation aged 5 years and 7 years ($p > 0.05$) (Table 4 and 5). From 17 parameters of soil habitat tested by model of forward stepwise discriminate function, it was shown that soil temperature, root dry weight, clay, silt, and nitrogen was known as factors in soil which distinguishing habitat characteristic between cocoa plantation (Wilks' Lambda = 0.00164; F (20.37) = 11.078; p <0.0000). These parameters indicated the soil habitat factors that were often correlated with the abundance of soil fauna in agro-ecosystem, included cocoa plantation (Peck *et al*. 1998; Moco *et al*. 2010).

CONCLUSIONS

The pattern of changes in composition of soil fauna communities has not consistent with the patterns in changes of the soil habitat characteristic during development of the smallholder cocoa plantation. In different ages of cocoa plantation, taxa has limitation in movement and sensitive on changing in soil condition which differentiating in composition of their soil fauna community. Component which differentiating in characteristic of soil habitat of different ages of cocoa plantation are factors influencing metabolic activity, movement, and the availability of food and nitrogen for the soil fauna.

ACKNOWLEDGEMENTS

We would like to thank The Directorate General of Higher Education, National Ministry of Education of the Republic of Indonesia for funding this research through a Competitive Grant.

REFERENCES

Adejuyigbe CO, G Tian and GO Adeoye.1999. Soil microarthropod populations under natural and planted fallows in Southwestern Nigeria. *Agroforest Sys* 47: 263-272.

Adl SM. 2008. Enchytraeids. In: Carter MR and Gregorich EG (eds.) *Soil Sampling and Methods of Analysis*. Canadian Society of Soil Science. pp. 445-453.

Aeckerman IL, R Costantio, HG Gauch, J Lehman, SJ Riha and ECM Fernandes. 2009. Termite (insecta: isoptera) species composition in a primary rain forest and agroforests in Central Amazonia. *Biotropica* 41: 226-233.

Allen AP, JF Gillooly and JH Brown. 2005. Linking the global cycle to individual metabolism. *Func Ecol* 19: 202-213.

Bardgett R. 2005. The biology of soil: A community and ecosystem approach, Oxford University Press Inc., New York. 242p.

Beisel JN, P Usseglio-Polatera, V Bachmann and JC Moreteau. 2003. A comparative analysis of evennes index sensitivity. *Inte Rev Hydrobiol* 88: 3-15.

Belay-Tedla A, X Zhou, B Su, S Wan and Y Lou. 2009. Labile, recalcitrant, and microbial carbon and nitrogen pools of tallgrass prairie soils in the US Great Plains subjected to experimental warming and clipping. *Soil Biol Biochem* 41: 110-116.

Blagodatsky S and P Smith. 2012. Soil physics meet soil biology: towards better mechanistic prediction of greenhouse gas emissions from soil. *Soil Biol Biochem* 47: 78-92.

Bloem J, G Lebbink, KB Zwart, LA Bouwman, SLGE Burgers, JA de Vos and PC de Ruiter .1994. Dynamics of microorganisms, microbivores and nitrogen mineralization in winter wheat fields under conventional and integrated management. *Agric Ecosys Environ* 51: 129-143.

Bloemers GF, M Hodda, PJD Lambshead, JH Lawton and FR Wanless. 1997. The effects of forest disturbance on diversity of tropical soil nematodes. *Oecologia* 111: 575-582.

Bongers T and H Ferris. 1999. Nematode community structure as a bioindicator in environmental monitoring. *TREE* 14: 224-228.

Bos MM, P Höhn, Shahabuddin, B Biiche, B Damayanti, I Steffan-Dewenter and T Tscharntke. 2007. Insect diversity responses to forest conversion and agroforestry management. In: Tscharntke T, Leuschner C, Zeller M, Guhardja E, and Bidin A (*eds.*) *The Stability of Tropical Rainforest Margins, Linking Ecological, Economic, and Social Constraints of Land Use and Conservation*. Springer Verlag, Berlin, pp. 279-296.

Camargo JA. 2008. Revisiting the relation between species diversity and information theory. *Acta Biotheor* 56: 275-283.

Christensen KA. 1990. Insecta collembolan. In: DL Dindal (ed) *Soil Biology Guide*. John Willey & Sons, Singapore, pp. 965-995.

Directorate General of Esatate, Agricultural Ministry, RI. 2012. Area and Production by Category of Producers. http://ditjenbun.deptan.go.id/cigraph/index.php/viewstat/komoditiutama/4-Kakao. Accessed on 6 June 2012.

Delabie JHC, B Jahyny, IC do Nascimento, CSF Mariano, S Lacau, S Campiolo, SM Philpott and M Leponce. 2007. Contribution of cocoa plantations to the conservation of native ants (Insecta: Hymenoptera: Formicidae) with a special emphasis on the Atlantic forest fauna of Southern Bahia, Brazil. *Biodivers Conserv* 16: 2359-2384.

Doran JW, MR Zeiss. 2000. Soil health and sustainability: managing the biotic component of soil quality. *Appl Soil Ecol* 15: 3-11.

Evizal R, Tohari, ID Prijambada, J Widada and D Widianto. 2012. Soil bacterial diversity and productivity of coffe-shade tree agro-ecosystem. *J Trop Soils* 17: 181-187.

Forge TA and J Kimpinski. 2008. Nematodes. In: MR Carter and EG Gregorich (eds). *Soil Sampling and Methods of Analysis*. Canadian Society of Soil Science, pp. 415-425.

Gerson U, RL Smilet and R Ochoa. 2003. Mites (acari) for pest control. Blackwell Science, UK.

Hairiah K, H Sulistyani, D Suprayogo, Widianto, P Purnomosidhi, RH Widodo and M van Noordwijk. 2006. Litter layer residence time in forest and coffee agroforestry systems in Sumberjaya, West Lampung. *For Ecol Manage* 224: 45-57.

Hanel L. 2001. Succession of soil nematodes in pine forests on coal-mining sands near Cottbus, Germany. *Appl Soil Ecol* 16: 23 -34.

Hopkins DW and RW Grogorich. 2005. Carbon as a subtrate for soil organisms. In: RD Bardgett, MB Usher and DW Hopkins (eds). *Biological diversity and function in soils*. Cambridge University Press, New York, pp.57-83.

Hemmsbergen DA, MP Berg, M Loreau, JR van Hal, JH Faber and HA Verhoef. 2004. Biodiversity effects on soil processes explained by interspecific functional dissimilarity. *Science* 306: 1019-1020.

Hunt HW and DH Wall. 2002. Modelling the effects of loss of soil biodiversity on ecosystem function. *Global Change Biol* 8: 33-50.

Isaac ME, AM Gordon, N Thevathasan, SK Oppong and J Quashie-Sam. 2005. Temporal changes in soil carbon and nitrogen in West African multistrata agroforestry systems: a chronosequence of pools and fluxes. *Agroforest Systs* 65: 23 -31.

Kardol P, TM Bezemer, A van der Wal and WH van der Putten. 2005. Successional trajectories of soil nematode and plant communities in a chronosequence of ex-arable lands. *Biol Conserv* 126: 317-327.

Kasprzak K. 1993. Methods for fixing and preserving soil animals. In: M Górny and L Grüm (eds). *Methods in Soil Zoology*. Elsevier, Amsterdam, pp.321-345.

Kibblewhite MG, K Ritz and MJ Swift. 2008. Soil health in agricultural systems. *Phil Trans R Soc B* 363: 685-701.

Kilowasid LMH, TS Syamsudin, FX Susilo and E Sulistyawati. 2012. Ecological diversity of soil fauna as ecosystem engineers in small-holder cocoa plantation in South Konawe. *J Trop Soils* 17: 173-180.

Kummerow J, Kummerow M and WS Da Silva. 1982. Fine-root growth dynamics in cacao (*Theobroma cacao). Plant Soil* 65: 193-201.

Korhonen L, KT Korhonen, P Stenberg, M Maltamo and M Rautiainen. 2007. Local models for forest canopy cover with beta regression, *Silva Fennica* 4: 671 – 685.

Lavelle P and AV Spain. 2001. *Soil ecology*. Kluwer Academic Publisher, New York.

Lawton JH, DE Bignell, GF Bloemers, P Eggleton and ME Hodda. 1996. Carbon flux and diversity of nematodes and termites in Cameroon forest soils. *Biodiver Conserv* 5: 261-273.

Lukac M and DL Godbold. 2011. *Soil Ecology in Northern Forests: a Belowground View of a Changing World*. Cambridge Univerasity Press, New York.

Marhaning AR, AAS Mills and SM Adl. 2009. Soil community changes during secondary succession to naturalized grasslands. *Appl Soil Ecol* 41: 137-147.

Meserve PL, DA Kelt, B Milstead and JR Guitierrez. 2003. Thirteen years of shifting top-down and bottom-up control. *BioScience* 53: 633-646.

Moco MKS, EF Gama-Rodrigues, AC Gama-Rodrigues, RCR Machado, and VC Baligar. 2009. Soil and litter fauna of cocoa agroforestry systems in Bahia, Brazil. *Agroforest Syst* 76: 127-138.

Moco MKS, EF Gama-Rodrigues, AC Gama-Rodrigues, RCR Machado and VC Baligar. 2010. Relationship between invertebrate communities, litter quality and soil attributes under different cacao agroforestry systems in the South of Bahia, Brazil. *Appl Soil Ecol* 46: 347-354.

Munoz F and J Beer. 2001. Fine root dynamics of shaded cacao plantations in Costa Rica. *Agroforest Syst* 51: 119-130.

Nielsen UL. E. Ayres, D.H Wall and R.D Bardgett. 2010. Soil biodiversity and carbon cycling: a review and synthesis of studies examining diversity–function relationships. *Eur J Soil Sci* 62: 105-116.

Panesar TS and VG Marshall. 2005. Monograph of soil nematodes from Coastal Douglas-Fir Forests in British Columbia. Royal Roads University, Canada. Available at: http://www.royalroads.net/nematodes.

Peck SL, B Macquaid and CL Campbell. 1998. Using ant species (Hymenoptera: Formicidae) as a biological indicator of Agroecosystem condition. *Environ Entomol* 27: 1102-1110.

Pradhan GB and MC Dash. 1987. Distribution and population dynamics of soil nematodes in a tropical forest ecosystem from Sambalpur, India. *Proc Indian Acad Sci (Anim Sci)* 96: 395-402.

Rovira P and VR Vallejo. 2002. Labile and recalcitrant pool of carbon and nitrogen in organic matter decomposing at different depth in soil: an acid hydrolysis approach. *Geoderma* 107: 109-141.

Ruf A, L Beck, P Dreher, K Hund-Rinke, J Römbke and J Spelda. 2003. A biological classification concept for the assessment for soil quality:"biological soil classification scheme" (BBSK), *Agric Ecosyst Environ* 98: 260-271.

Saha S. 2010. Soil functions and diversity in organic and conventional farming. In: Lichtfouse E (eds). *Sosiology, organic farming, climate change and soil science*. Sustainable Agriculture Review 3, Springer Sciene + BussinesMedia B.V. pp. 275-301.

Sanchez-Moreno S, S Smukler, H Ferris, AT O'Geen and LE Jackson. 2008. Nematode diversity, food web condition, and chemical and physical properties in different soil habitats of an organic farm. *Biol Fertil Soils* 44: 727-744.

Sileshi G and PL Mafongoya. 2007. Quantity and quality of organic inputs from coppicing leguminous trees influence abundance of soil macrofauna in maize crops in eastern Zambia, *Biol Fertil Soils* 43: 333-340.

Shahabuddin. 2010. Diversity and community structure of dung beetles (Coleoptera: Scarabaeidae) across a habitat disturbance gradient in Lore Lindu National Park, Central Sulawesi. *Biodiversitas* 11: 29-33.

Schinner F, R Öhlinger, E Kandeler and K Margesin. 1996. Methods in soil biology. Springer, Berlin. 426p.

Sharma G, R Sharma and E Sharma. 2009. Impact of stand age on soil C, N and P dynamics in a 40-year chronosequence of alder-cardamom agroforestry atands of the Sikkim Himalaya, *Pedobiologia*. doi:10.1016/j.pedobi.2009.01.003.

Sharon R, D Degani and M Warburg. 2001. Comparing the Soil macro-fauna in two oak-wood forests: does community structure differ under similar ambient conditions. *Pedobiologia* 45: 355-366.

Smiley GL and J Kroschel. 2008. Temporal change in carbon stock of cocoa-gliricidia agroforest in Central Sulawesi, Indonesia. *Agroforest Syst* 73: 219-231.

Smiley GL and J Kroschel. 2010. Yield development and nutrient dynamics in cocoa-gliricidia agroforest of Central Sulawesi, Indonesia. *Agroforest Syst* 78: 97-144.

Susilo FX, AM Neutel, M van Noordwijk, K Hairiah, G Brown and MJ Swift. 2004. Soil biodiversity and food webs. In: M van Noordwijk, G Cadisch and CK Ong. *Below-Ground Interactions in Tropical Agroecosystems: Concept and Models with Multiple Plant Components*, CAB International Publishing, pp. 285-308.

Syaf H. 2010. Analisis sumberdaya lahan tanaman kakao di Kabupaten Kolaka Provinsi Sulawesi Tenggara [Disertasi]. Universitas Padjajaran. (in Indonesian).

Todd TC, TO Powers and PG Mullin. 2006. Sentinel nematodes of land-use change and restoration in tallgrass prairie. *J Nematol* 38: 20-27.

Urzelai A, AJ Hernández and J Pastor. 2000. Biotic indices baded on soil nematode communities for assessing soil quality in terrestrial ecosystems. *Sci Tot Environ* 247: 253-261.

van Eekeren N, H de Boer, J Bloem, C Schouten, M Rutgers, R de Goede and L Brussaard. 2009. soil biological quality of grassland fertilized with adjusted cattle manure slurries in comparison with organic and inorganic fertilizers. *Biol Fertil Soils* 45: 595-608.

Voroney RP. 2007. The soil habitat. *In:* Paul EA (ed.). *Soil Microbiology, Ecology, and Biochemistry*. Elsevier, Amsterdam, pp.25-49.

Wardle DA, RD Bardgett, JN Klironomos, H Setälä, WH van der Putten and DH Wall. 2004. Ecological linkage between aboveground and below ground biota. *Science* 304: 1629-1633.

Widyastuti R. 2006. Feeding rate of soil animals in different ecosystem in Pati, Indonesia. *Hayati* 13: 119-123.

Wilke BM. 2005. Determination of chemical and physical soil properties. In: R Margisen and F Schinner (eds). *Manual for Soil Analysis –Monitoring and Assessing Soil Bioremediation*. Springer-Verlag Berlin Heidelberg, pp.47-94.

Winter JP and VM Behan-Pelletier. 2008. Microarthropods. In: Carter MR and Gregorich EG (eds). *Soil sampling and methods of analysis*. Canadian Society of Soil Science, pp.399-414.

Yadav RS, BL Yadav, BR Chhipa, SK Dhyani and M Ram. 2011. Soil biological properties under different tree based traditional agroforestry systems in a semi-arid region of Rajasthan, India. *Agroforest Syst* 81: 195-202. doi: 10.1007/s10457-010-9277-z.

Yan S, AN Singh, S Fu, C Liao, S Wang, Y Li, Y Cui, and L Hu. 2012. A soil index for assessing soil quality. *Soil Biol Biochem* 47: 158-165.

Zar JH. 1999. *Biostatistical analysis*. Prentice Hall, New Jersey. 663 p

Zheng D, Jr ER Hunt and SW Running. 1993. A daily soil temperature model based on air temperature and precipitation for continental applications. *Clim Res* 2: 183-191.

Zornoza R, J Mataix-Solera, C Guerrero, V Arcenegui, J Mataix-Beneyto and I Gómez. 2008. validating the effectiveness and sensitivity of two soil quality indices based on natural forest soils under mediterranean conditions. *Soil Biol Biochem* 40: 2079-2087.