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Soil invertebrate diversity in coffee-pine agroforestry system at Sumedang, West Java

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Abstract. *Kinasih I, Cahyanto T, Widiana A, Kurnia DNI, Julita C, Putra RE. 2016. Soil invertebrate diversity in coffee-pine agroforestry system at Sumedang, West Java. Biodiversitas 17*: *473-478.* In order to maintain natural habitat while provide economic benefit for community near forest, some agroforestry systems were developed. This system depends on service provided by ecosystem such as nutrient cycling by soil invertebrates. One of important factors of healthy ecosystem services at particular agroecosystem is local biodiversity of the area. In this study we carried out biodiversity survey of soil invertebrates at local coffee - pine agroforestry system at Rancakalong Sub-district, Sumedang District, West Java, Indonesia. Soil invertebrates were collected from coffee plantation, coffee and pine (*Pinus merkusii*) plantation and pine plantation by 40 pitfall trap per location. Results showed the highest abundance was recorded at coffee plantation (2477 individuals) and the lowest was at pine plantation (1372 individuals). All collected soil invertebrates grouped into 3 classes (Arachnida, Chilopoda and Insecta), 16 orders, 47 families, and 124 morphospecies. Soil invertebrates were dominated by Formicidae, Scarabaeidae, Blattidae, Forficulidae, and Phalangiidae. The average diversity index of soil invertebrates was 2.25 (coffee plantation), 2.64 (coffee and pine plantation) and 1.85 (pine plantation). The evenness value was 0.30 (coffee plantation), 0.49 (coffee and pine plantation) and 0.39 (pine plantation). This study showed agroforestry may improve soil invertebrate abundance and diversity of monoculture pine forest through creation of additional and alternative nutrition and microhabitats.

Keywords: Agroforestry, biodiversity, coffee, soil invertebrate

INTRODUCTION

Agroforestry is land management where trees, shrubs, field crops and/or animal production are intentionally integrated on the same area at the same time. This integrated farming system takes the advantage of the productive, protective, and other services provides by its local biodiversity. This practice is a classic system in which farmer have long applied intercropping of economic crops with surrounding forest as a way to satisfy their need for food, wood products, fodder, and economic stability (Gliessman 2007). Among various crops, coffee is, along with cocoa, the most commonly cultivated crops in this system.

This perennial and woody plant (Bagyaraj 2015) is originated from Ethiopia, where they found grows as a natural understorey shrub of rainforest (De Beenhouwer 2014). In Indonesia, at coffee production region, they are grown under shade of canopies of trees in agroforestry system (Verbist et al. 2005; Hanisch et al. 2011; Evizal et al. 2016). Plants cultivated in agroforestry will have advantage from ecosystem services provided by plants and animals of surrounding forest, namely protection from excess sunlight (Felipe dos Santos et al. 2015), nutrient cycles (Lopez-Rodriguez et al. 2015), conservation of soil fertility (Lin and Richards 2007), waste regulation (Evizal et al. 2009), and pollination (Philpott et al. 2006).

Some studies showed agroforestry systems could improve biodiversity as they served as a refugia and buffer zone for mobile species (Cullen et al. 2001, Cruz and Sutherland 2004). Furthermore, this system also believed to improve soil fertility and microclimate of crop plantation area while provide more habitats for wild organisms than conventional monocultures (Tscharntke et al. 2011). Improvement of soil quality, as results of organic material input from both tree and crop species will stimulate establishment of soil invertebrate community. These invertebrates, with different proportion and function, maintain soil fertility through their interaction with each other and microbial community (Bardgett 2005; Bardgett et al. 2005; Lavelle et al. 2006). However, soil invertebrates population are sensitive to changes in plant cover (Barros et al. 2003), management regime (Aquino et al. 2008; Farska et al. 2014; Zaitsev et al. 2014), and microclimate (Vasconcelos et al. 2009).

West Java has long history of conversion of natural forest into plantation forest, i.e. pine forest (*Pinus merkusii*). This management practice may affect soil invertebrate diversity and function through direct (litter quality) and indirect effects (microhabitats and environmental factors like pH, soil humidity, soil fertility). In last 10 years, as part of community development and protection of plantation forest, pine forests have been utilized as part of agroforestry. Previous study on pine forest showed high level of soil nitrification of Indonesia pine forests (Krave et al. 2002). Soil nitrification results in instability of nitrogen supply to plants as nitrate is easily removed from soil by denitrification and leaching (Watts and Seitzinger 2000). Furthermore, high nitrification rates in N-saturated soils, which in common in Indonesia, can produce soil acidification which affect soil invertebrate population (Abeliovich 1992; Zaitsev et al. 2014). However, despite their importance in ecosystem processes, very few studies focused on the diversity of soil invertebrates on this agroforestry especially on under pine forest. Thus, the objectives of this study were to explore the diversity of soil invertebrates of coffee-pine plantation and the effect of this diversity to soil quality.

MATERIALS AND METHODS

Study area

The research was conducted from September to December 2015 at an urban coffee plantation located 500 meters from Rancakalong Sub-district, Sumedang District, West Java, Indonesia. The plantation was located at 6°49'27.2"S and 107°48'34,7"E, and about 1100-1200 m above sea level.

Soil invertebrates were sampled at three regions, (i) coffee plantation without shade/under direct sun (C), (ii) coffee plantation under the shade of *Pinus merkusii* (CP), and (iii) pine forest dominated with *P. merkusii* (P) (Figure 1).

Procedures

Soil invertebrates sampling

Pitfall traps were used to obtain surface soil invertebrates (Maftu'ah et al. 2005). Samples were collected from 4 pitfall traps placed at 10 subplots, selected randomly. Each trap's distance was 2 meter. Thus, total number of sample per land use type was 40 samples (Table 1). Samples were collected 10 times during study period (which further referred as sampling effort in this study). During study period, total number of 1200 samples from all study areas was collected.

All sampled specimen was grouped by hand sorting and then was identified its morphospecies level based on Borror et al. (1989) and Dindal (1990).

Environmental factors measurement

At each habitat, three soil samples were collected and several soil characteristics were measured, both the characters of physics and chemistry, namely: (i) physical characteristics (soil texture, soil humidity, soil temperature); (ii) chemical characteristics (soil pH, C, N, C/N, and P) (Table 2).

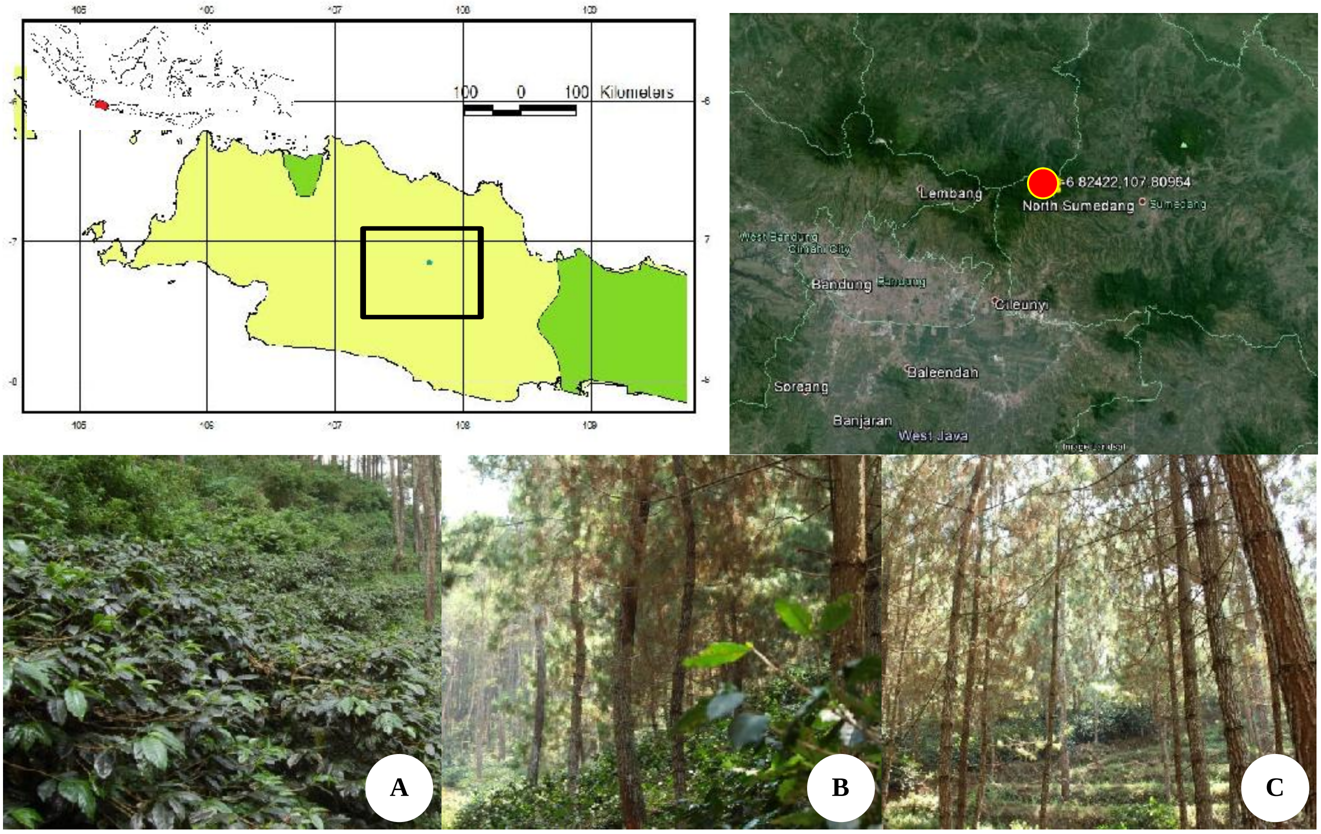

Figure 1. Study site in Rancakalong Sub-district (●), Sumedang District, West Java, Indonesia. A. Coffee plantation without tree shade, B. Coffee plantation under shade of *Pinus merkusii* trees, C. *Pinus merkusii* forest

Table 1. Sampling area characteristic and sampling effort

Habitat	Habitat code	Area size	Total no. of samples	Litter thickness (cm)
Coffee plantation	C	3,375 ha	40	1.13
Coffee-pine agroforestry	CP	4,572 ha	40	1.46
Pine forest	P	3,112 ha	40	0.98

Table 2. Soil characteristics of sampling area

Site	Soil pH	Soil temperature (°C)	Soil humidity (%)	Soil texture			C	N	C/N	P_2O_5
				Sand	Dust	Clay				
C	5	27	27	42	54	5	7.99	0.79	10	73.4
CP	4.5	26	28	48	45	8	9.59	0.66	14	8.9
P	5.4	28	26	35	24	41	5.61	0.62	9	52.1

Data analysis

Species diversity index was calculated to compare diversity among sampling areas. Species diversity was represented by Shannon diversity index (Ludwig and Reynolds 1988) by:

$$H' = -\sum_{i=1}^{R} p_i \ln p_i$$

Where, *p*i: the proportion of individuals belonging to the *i*th species to total sample

We calculated species evenness to evaluate variation in communities among sampling areas which represented by Pielou's evenness index (J') (Mulder et al. 2004).

$$J' = \frac{H'}{H'_{\max}}$$

Where, H'_{max} is the number derived from previously calculated by Shannon diversity index.

$$H'_{\max} = -\sum_{i=1}^{S} \frac{1}{S} \ln \frac{1}{S} = \ln S.$$

Where, S is total number of species in the community.

Species evenness index, then, was supplemented with Simpson's dominance index (Morris et al. 2014) in order to find possibility of dominance of some species at sampling areas.

$$D = \sum_{i=1}^{S} p_i^2.$$

Where, *p*i: the proportion of individuals belonging to the *i*th species to total sample.

All species abundance data was subjected to statistical analysis of variance. First test was normality test by Shapiro-Wilk test with alpha level $P < 0.05$. Our test obtained P value of Shapiro-Wilk test with 0.01483 indicating non normal distribution of sample. Thus, Kruskal Wallis test was applied to evaluate differences between separate means. This test followed by Mann-Whitney pair wise test to establish the significance of differences among study areas. Differences obtained at levels of $P < 0.05$ were considered significant. All statistical analysis was carried out with Past 3.12

Multivariate statistic method of CCA, calculated with CANOCO software (Microcomputer, Ithaca, N.Y.) , was used to explore the variability of taxa related to environmental variables (soil humidity, soil temperature, soil pH, nitrogen, carbon, phosphat).

RESULTS AND DISCUSSION

We collected 7,379 individuals during sampling period. Among all study areas, coffee plantation (C) had the highest abundance of individuals (3,486 individuals, 47%), followed by coffee-pine agroforestry (2,519 individuals, 34%), and pine forest (1,374 individuals, 19%) (Figure 2.A). The similar pattern also showed on the number of morphospecies and number of soil invertebrate family (Figure 2.B). Further, statistical test showed that mean abundance of soil invertebrates at coffee plantation was significantly higher than other sampling areas (Table 3). Normality test indicated non normal data distribution of sampling area as soil invertebrate population at each sampling area dominated by some taxa, like Formicidae and Scarabaeidae. This finding was also supported by low evenness value and high dominance value of all sampling area (Table 4).

This study showed benefit of agroforestry management for soil invertebrates, even though its abundance and richness was higher at coffee plantation. Diversity index of both coffee plantation and coffee-pine agroforestry indicated more diverse and equally distributed soil invertebrates compare to pine forest. Studies showed that plantation management practices that promote the maintenance of plant residues on soil provide more favorable environment for soil invertebrates (Moco et al. 2005). This study showed increasing litter quantity in mixed stands which was agree with most studies (Scheu et al. 2003; Albers et al. 2004; Gartner and Cardon 2004). Thicker litter was found on coffee plantation and coffee-pine agroforestry providing more habitats for soil invertebrates while maintaining soil temperature and humidity which was important for many soil invertebrates.

Differences on soil invertebrate abundance and diversity could be explained by litter quality. Litter quality was considered as important resources for soil invertebrates and could shape soil communities (Kaneko and Salamanca 1999; Salamon et al. 2004). Coffee litter which was much easier to decompose seemed to provide better environmental condition to encourage and maintain higher number and more diverse soil invertebrates compared to other area. Furthermore, coffee litters having lower tannin and polyphenol content could offset the unfavorable condition for decomposition and improve environmental condition for soil invertebrates (Hattenschwiler et al. 2005; Korboulewsky et al. 2016). Higher tannin and polyphenol content of pine needle might lead to slower decomposition process which lowered the abundance and activities of soil invertebrates and it explained low population and diversity on pine forest (Hattenschwiler et al. 2005; Vivanco and Austin 2008; Cesco et al. 2012).

Both litter quantity and quality may influence the soil invertebrate community as they create specific microclimate on soil surface. Highly specific litter and microclimate in pine forest made it favorable only for some specific species with ability to decompose, feed on microorganism life on pine litter, or live on the humus of pine forest which creates unique spatial distribution of soil invertebrates. This specialization of soil invertebrates created by differences in humus characteristic was also reported to be occurred on other agroforestry in East Java (Peritika et al. 2012). With possibility of higher rate of nitrogen lost from nitrification (soil of pine forest had lowest N) (Krave et al. 2002) made this area considered as barren area compared to other area and it lowered soil invertebrate population and diversity. Our result showed that only scavenger like Blattidae and Formicidae thrived well in this area (Table 4). Coffee-pine agroforestry system provided various litter types which allow different decomposer species to coexist and share the resources (Wardle et al. 2006), and it is showed by an increasing population and diversity of soil invertebrates in our study. Our study also showed that humus condition of coffee plantation provides best condition for many soil invertebrate. Furthermore, coffee plantation area where coffee trees were planted with specific distance had more patches (where litters were physically separated) than coffee-pine area (where different litters were thoroughly mixed) and it provided more microhabitat for soil invertebrates (Sulkava and Huhta 1998).

In some studies, soil invertebrate is negatively correlated with soil pH (Wu et al. 2011; Peritika et al. 2012) which may explain higher abundance on coffee plantation. CCA analysis showed long term application of agroforestry system already created specific habitat for some taxa at both coffee-pine and coffee plantation, i.e. Anisolabididae and Apidae which were only found at coffee-pine area while Berytidae, Calliphoridae, Dolichopodidae, Dytiscidae, and Histeridae which were only found at coffee plantation (Table 4, Figure 3).

Based on CCA, it could be concluded that distribution of most soil taxa was influenced by amount of carbon at humus, while high nitrogen content of coffee plantation creating specific niche for specific taxa were found at that area (Figure 3). Furthermore, this result also showed high mobility of taxa to move on all area as pit fall trap designed for trapping active surface soil invertebrates.

This study showed benefit of agroforestry to improve soil invertebrate population and diversity especially for forest which produced low quality litter. Abundance and diversity of soil invertebrates could be increased through creation of additional nutrition and microhabitats. The possibility of similar pattern found in agroforestry and located in rich natural forest should be observed in order to find best management practice for agroforestry in tropical regions like Indonesia.

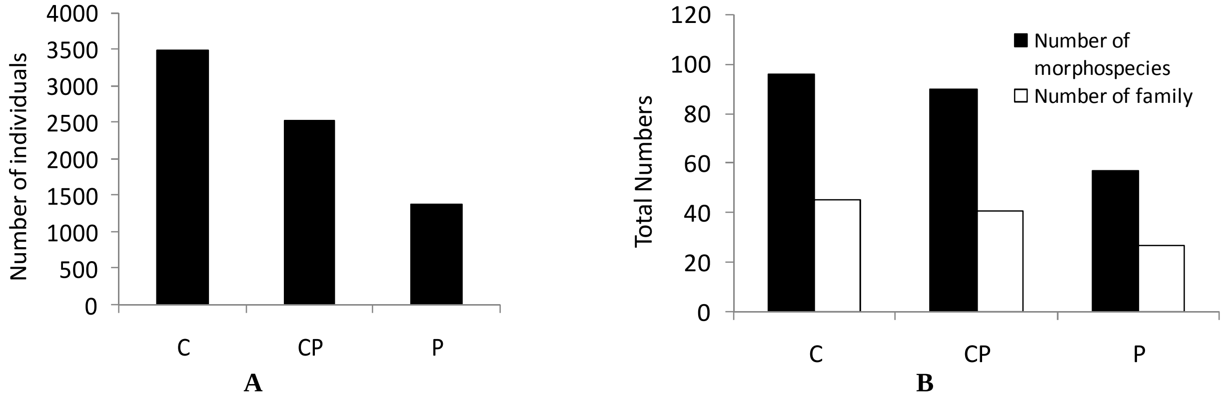

Figure 2. Abundance and diversity of soil invertebrates per sampling area

Table 3. Mean of Soil Invertebrate Abundance among sampling area

Site	Mean abundance (mean ± SD)
Coffee plantation	348.6 ± 118.57a
Coffee-pine agroforestry	251.9 ± 109.3b
Pine forest	137.4 ± 61.17c

Note: Different letter indicates significant difference with P < 0.05

Table 4 Number of individual, families and diversity index at each site

Families	C	CP	P
Acrididae	8	13	1
Anisolabididae		1	
Apidae		3	
Berytidae	8		
Blattellidae	9	43	8
Blattidae	674	453	161
Calliphoridae	1		
Carabidae	5	18	1
Cecidomyiidae	8	3	5
Cerambycidae	1	1	
Cheliferidae	5	7	
Chrysomelidae	1		1
Coccinellidae	3	2	
Cossidae (larvae)	7	2	3
Curculionidae	21	13	
Deinopidae	2	2	1
Dermestidae	1	1	
Dipluridae	93	85	44
Dolichopodidae	3		
Drassidae	5	1	3
Drosophilidae	149	93	28
Dysderidae	2	1	
Dytiscidae	4		
Forficulidae	227	101	33
Formicidae	753	980	981
Gryllidae	28	41	6
Hepialidae	47	39	12
Histeridae	1		
Hypodermatidae	11	8	
Ichneumonidae	3	5	
Lepidoptera	2	5	2
Lithobiidae	2	5	1
Lymantriidae	16	13	1
Mantidae	1	2	
Noctuidae (larvae)	2	2	
Nymphalidae	29	34	1
Phalangiidae	111	245	33
Phasmatidae	2	1	
Pompilidae	7	11	4
Scarabaeidae	1162	230	7
Scytodidae	23	20	11
Sparassidae	13	10	10
Sphecidae	4	2	4
Staphylinidae	24	17	10
Tenthredinidae	1	1	2
Thelyphonidae	4	4	
Therevidae	3	1	
Number of individual	3486	2519	1374
Diversity index (H')	2.24	2.64	1.85
Pielou’s evenness index	0.30	0.49	0.39
Simpson's dominance	0.79	0.86	0.74

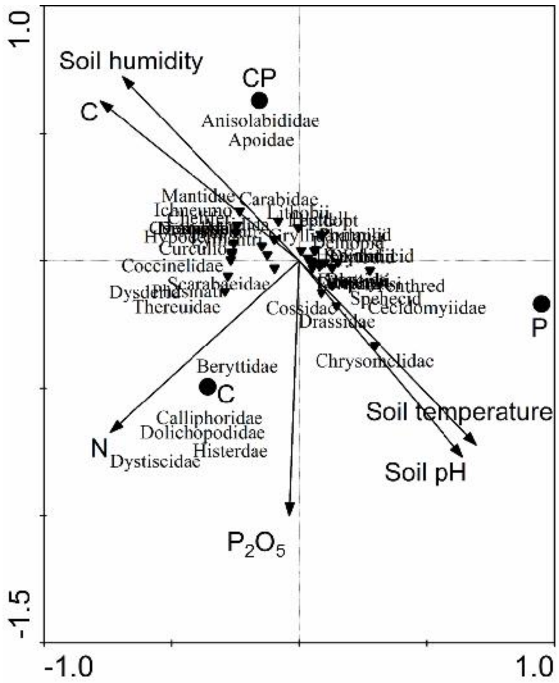

Figure 3. Ordination plots of CCA results for taxa distribution related with sampling area and soil characteristics. The direction of an arrow indicates the steepest increase in the variable and the length indicates the strength relative to other variables.

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