



Organic Matter in the Topsoil of Soybean Field Alters Arthropod Diversity and Their Covariation

Akhmad Rizali^{*)}, Julia Putri Pramudita, Eva Febriyanti, Yolla Frinsiska Rama and Tita Widjayanti

Department of Plant Pests and Diseases, Faculty of Agriculture, Universitas Brawijaya, East Java, Indonesia

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*) Corresponding author:
 E-mail: arizali@ub.ac.id

ABSTRACT

The presence of organisms in soil play a pivotal role in the health of a ground ecosystem. Diversity and abundance of soil organisms are mainly influenced by soil characteristics and condition of above-ground habitat. This research aimed to study the diversity of arthropods in topsoil of soybean field and investigate factors that affect the abundance and interaction of dominant arthropods. Field research was conducted in three different locations in Malang District, Indonesia. A sampling of arthropods was focused in the topsoil of soybean fields in the soil surface and below-ground. Results found that three dominant taxa of arthropods in the topsoil of soybean field i.e. collembolan, ants, and mites. Different location of soybean field did not affect the species richness and abundance of the dominant arthropods, except the ant abundance. In contrast, soil strata was altered the abundance of collembolan and mites, but not ants. Based on the GLM (generalized linear model), organic matter had a positive relationship with the abundance of collembolan and ants. The abundance of collembolan and ants also had a relationship with mites, yet not vice versa. In conclusion, organic matter in the soybean field supports not only the abundance of arthropod but also their covariation.

INTRODUCTION

The presence of organisms in the soil play an important role for the health of the ground ecosystem and also contribute to the growth of plants (Coleman, Crossley Jr., & Hendrix, 2004). Soil organism can support plant growth through their involvement in soil formation and nutrient cycling (Decaëns, Jiménez, Gioia, Measey, & Lavelle, 2006). In agroecosystem, soil organisms are a very crucial component to achieve sustainable crop production through decomposing crop plant biomass which provides valuable nutrients for crop growth as well as contribution in protection of plants against pests (Lavelle et al., 2006).

Diversity and abundance of soil organisms especially in the topsoil are mainly influenced by soil characteristic and habitat conditions of the above-ground. The above-ground habitat consisting of decayed wood, litter, and animal waste support the presence of soil organisms

which have a positive impact on soil fertility and provide stability of ecosystem (Eggleton et al., 2005). The diversity of organisms in soils makes an important contribution in maintaining ecosystem balance, both as a decomposer and as a biological controller (Coleman, Crossley Jr., & Hendrix, 2004). An organism in the soil also affects the above-ground plant-insect interactions in an agroecosystem (De Deyn & Van der Putten, 2005). For instance, arbuscular mycorrhizal fungi that has positive effects on herbivores although for soil arthropods there are no clear patterns yet (Heinen, Biere, Harvey, & Bezemer, 2018).

The most dominant arthropod in the soil is insects (e.g. collembolan and ants) and arachnids (e.g. mites) that act a pivotal role as soil or litter dwellers (Decaëns, Jiménez, Gioia, Measey, & Lavelle, 2006). Collembolan and mites can influence the decomposition rate in agroecosystem and their presence is sensitive to the removal of

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Akhmad Rizali *et al.*: *Arthropod Diversity in the Topsoil of Soybean Field*.....

organic matter (Eaton, Barbercheck, Buford, & Smith, 2004). While ants have an important role as material flow in soils (Wagner, Jones, & Gordon, 2004) and contribute to improving soil aggregation and aeration (Lafleur, Hooper-Bùi, Mumma, & Geaghan, 2005). However, soil management practices in agroecosystem altered the densities of collembolan (Coulibaly *et al.*, 2017), mites (Bedano, Cantú, & Doucet, 2006) and ants (Sanabria, Lavelle, & Fonte, 2014). Therefore, understanding the importance of arthropod diversity and their role in agroecosystem is important to achieve sustainable agriculture.

Research about arthropod diversity and their interaction in the topsoil of soybean field are still less reported. The previous research in the soybean field was conducted for other organisms such as microbial community (Vargas Gil *et al.*, 2011), earthworm (Abail & Whalen, 2018) and nematode (Neher, Nishanthan, Grabau, & Chen, 2019). This research would gain basic information about arthropod diversity in the topsoil of soybean field. Diversity of arthropods was mainly influenced

by soil characteristics as well as condition of above-ground habitat. In the end, ground habitat has a pivotal role in the health of a ground ecosystem. Therefore, this research aimed to study the diversity of arthropods in the topsoil of soybean field and investigate the factors that affect the abundance and interaction of dominant arthropods.

MATERIALS AND METHODS

Research Location and Plot Determination

The field research was conducted in three different locations in Malang District, East Java, Indonesia from November 2018 to February 2019. The crop fields are usually planted with soybean once per year *i.e.* Singosari, Sidorejo, and Sumberblimbing (Table 1). A soybean field in Singosari was planted by monoculture system, while in Sidorejo and Sumberblimbing was planted together with maize. Each research location was selected four plots for observation of soil arthropods with minimum distance between plots is 25 m and each plot consisted of 1,000 soybean plants (10 m x 10 m).

Table 1. Characteristic of research location located in three different soybean fields in Malang

Location	Plot	Latitude (S)	Longitude (E)	Altitude (m asl)	Soil characteristics		
					pH	C organic (%)	N total (%)
Singosari (SS)	1	7°57'21.1"	112°36'34.9"	502	5.8	1.51	0.14
	2	7°52'09.2"	112°40'56.8"				
	3	7°52'10.5"	112°40'57.1"				
	4	7°52'12.2"	112°40'58.7"				
Sidorejo (SR)	1	8°19'06.1"	112°23'37.5"	278	6.3	1.19	0.13
	2	8°19'06.3"	112°23'36.8"				
	3	8°19'04.0"	112°23'39.2"				
	4	8°19'03.4"	112°23'37.3"				
Sumberblimbing (SB)	1	8°21'02.1"	112°23'26.9"	154	5.5	1.01	0.10
	2	8°21'03.5"	112°23'26.8"				
	3	8°21'05.2"	112°23'26.8"				
	4	8°21'02.4"	112°23'28.0"				

Sampling and Identification of Arthropods

A sampling of arthropods was focused in the topsoil of soybean fields include of soil surface (above-ground) and below-ground (depth 15 cm). To cover both soil strata, arthropods were sampled in each plot by using three different methods i.e. soil sampling, pitfall trap, and visual observation. Soil sampling was done using a pipe (d = 10 cm, h = 15 cm) in three random points per plot with minimum distance between points is 2 m. Sample of soils was then put in the Berlese funnel to collect the arthropods. The Berlese funnel was modified from plastic funnel (d = 28 cm, h = 30cm) with mesh size 2 mm and installed with 15-watt lamp. At the bottom of the funnel was placed a plastic bottle that has been filled with 70% alcohol. Soil samples were placed in the Berlese funnel for three days.

Pitfall traps were set up in three random points per plot with minimum distance between traps is 2 m. Pitfall trap was made from plastic cups (d = 7 cm, h = 15 cm). Pitfall traps were installed for 1 day and the killed arthropods were then placed in plastic vial contains 70% alcohol.

Visual observation was carried out by taking a soil sampling using a pipe (d=10 cm, h=15cm) in three random points per plot with minimum distance between points is 2 m. The soil was sampled near the roots of soybean plants and placed into a tray for arthropods observation. Arthropods were visually observed and collected using forceps and a small brush for 30 minutes per sample. Collected arthropods were then stored in a plastic vial that filled with 70% alcohol. Samplings of arthropods were conducted on different plant age 2, 6, 10, and 14 weeks after planting. All the killed arthropods from soil sampling, pitfall traps, and visual observation were then being sorted and identified in the laboratory. Arthropods were initially sorted to order the levels using Borror, Triplehorn, & Johnson (1989). For identification, ants were based on Bolton (1994), collembolan using Suhardjono, Deharveng,

& Bedos (2012) and mites using Zhang (2003).

Data Analysis

The difference of dominant arthropod abundance between research location, plant age and soil strata were analyzed using Kruskal-Wallis test and if significant were continued with Bonferroni test at $\alpha = 0.05$. Effect of environmental factors on arthropod abundance was analyzed by fitting a generalized linear model (GLM) without interactions (Zuur, Ieno, Walker, Saveliev, & Smith, 2009) and using a quasipoisson distribution to account for overdispersion. Explanatory variables included an abundance of collembolan, ants and mites, pH, C organic and plant age. This research excluded altitude (Pearson's $r = 0.999$, $P < 0.001$) and N total (Pearson's $r = 0.904$, $P < 0.001$) due to has a strong correlation with C organic. All analyses were performed using R statistical software (R Core Team, 2019).

RESULTS AND DISCUSSION

Arthropod Diversity in the Topsoil of Soybean Field

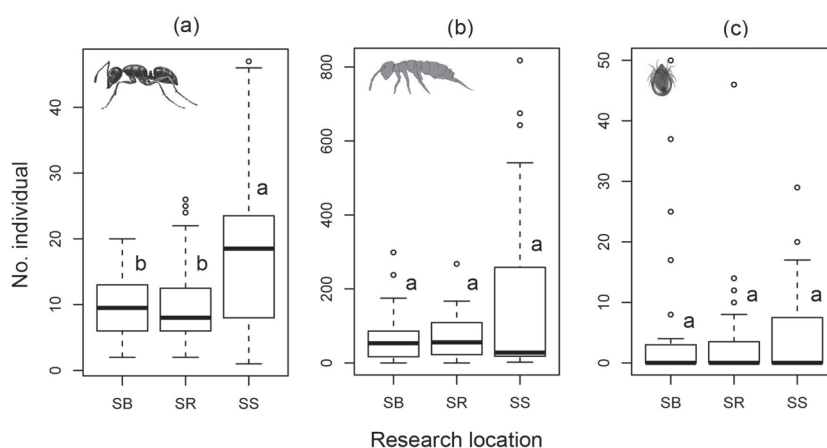
This research found three dominant taxa of arthropods with high abundant in the topsoil of soybean field i.e. collembolan, ants and mites (Table 2). The most abundant arthropod is collembolan with 9,765 individuals from 12 species and *Ceratophysella* sp (Fig. 1a) is recorded as the most abundant collembolan that recognized as cosmopolite species (Suhardjono, Deharveng, & Bedos, 2012). Ants are recorded to have the highest species richness (40 species) from 1,245 individuals with *Iridomyrmex* sp (Fig. 1b) as the most abundant species which is distinguished as common species in Southeast Asia (McGlynn, 1999). The most abundant species of mites is *Lohmanniidae* sp (Fig. 1c) from oribatid group that is known as a dominant below-ground animal in acidic forests (Maraun & Scheu, 2000).

Table 2. Species richness (S) and abundance (N) of the most dominant arthropod that collected from different soybean field

Location	Collembolan		Ants		Mites	
	S	N	S	N	S	N
Singosari	11	5,287	31	606	10	138
Sidorejo	11	2,277	31	316	11	113
Sumber blimbing	8	2,201	34	323	8	159
Total	12	9,765	40	1,245	15	410

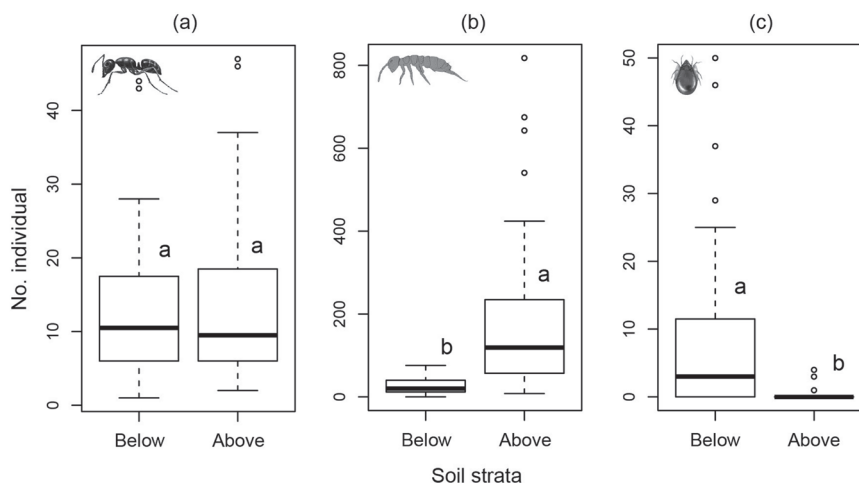


Fig. 1. The most abundant arthropods that recorded from the topsoil of soybean field in Malang: (a) collembolan (*Ceratophysella* sp), (b) ants (*Iridomyrmex* sp), and (c) mites (*Lohmanniidae* sp)



Remarks: SB = Sumber blimbing, SR = Sidorejo, SS = Singosari; Box with different letters are significantly different at $P < 0.05$ according to the Bonferroni test

Fig. 2. The different abundance of (a) ants, (b) collembolan, and (c) mites between research locations



Remarks: Box with different letters are significantly different at $P < 0.05$ according to the Bonferroni test

Fig. 3. The different abundance of (a) ants, (b) collembolan, and (c) mites between soil strata i.e. below-ground vs above-ground (soil surface)

The different location of soybean field did not affect the species richness of dominant arthropods ($P > 0.05$), but significantly affected the abundance of ants ($X^2 = 11.342, P = 0.003$) and did not affect on collembolan ($X^2 = 0.357, P = 0.837$) and mites ($X^2 = 0.062, P = 0.969$). Ants are found highly abundant in Singosari than Sidorejo and Sumberblimbing (Fig. 2). In contrast, soil strata significantly influenced the abundance of collembolan ($X^2 = 48.577, P < 0.001$) and mites ($X^2 = 38.207, P < 0.001$), but did not influence on ant abundance ($X^2 = 0.008, P = 0.927$). Collembolan are found highly abundant in above-ground, while mites are highly abundant in below-ground (Fig. 3).

In the topsoil of soybean field, the difference of arthropod abundance was influenced by the different location of the soybean field and soil strata. A different location is related to different soil characteristic, soil management practices as well as habitat conditions of above-ground in the soybean field. Habitat consisting of leaf litter and other crop biomass support the presence of soil organisms (Eggleton et al., 2005). In Singosari, the crop field has usually planted the soybean and has higher organic matter than other locations (Table 1). This arguably causes a higher abundance of arthropods especially collembolan and ants. As a legume, soybean has a symbiosis with rhizobium and contributes to soil fertility. The presence of rhizobium in agricultural land, besides supports the

growth and community structure of plant (Van Der Heijden et al., 2006) also affects the diversity of soil fauna (Karanja, Kimenju, Esilaba, Jefwa, & Ayuke, 2011). However, the presence of rhizobium is related to soil management (Grossman, Schipanski, Sooksanguan, Seehaver, & Drinkwater, 2011) which might differ between research locations. Besides, soil management practices in the soybean field also directly affected the densities of arthropods, that previously had been shown affect collembolan (Coulibaly et al., 2017), mites (Bedano, Cantú, & Doucet, 2006) and ants (Sanabria, Lavelle, & Fonte, 2014).

Effect of Soil Characteristic on the Abundance and Covariation of Dominant Arthropods

Based on the GLM showed that organic matter (C organic and N total) had a positive relationship with collembolan ($P = 0.012$) and ant abundance ($P < 0.001$), but had no relationship with mites abundance ($P = 0.991$) (Table 3). The age of soybean plants, as well as soil pH, did not affect the abundance of arthropods. Collembolan had a negative relationship with mites ($P = 0.004$) and ants had a positive relationship with mites ($P = 0.048$). Yet the abundance of mites had no relationship with collembolan and ants. It is arguably due to the abundance of mites were not affected by organic matter and as consequence it had no covariation with collembolan and ants.

Table 3. Generalized linear models relating abundance of collembolan, ants and mites to abundance of collembolan/ant/mite, pH, C organic and plant age as predictors

Variable	Collembolan			Ants			Mites		
	Estimate	SE	P	Estimate	SE	P	Estimate	SE	P
(Intercept)	3.494	2.96	0.241	2.428	1.35	0.075	6.450	310.49	0.983
Collembolan				0.001	0.00	0.115	-0.047	1.12	0.966
Ant	0.018	0.01	0.165				0.028	1.80	0.988
Mite	-0.173	0.06	0.004	0.013	0.01	0.048			
pH	-0.289	0.50	0.564	-0.298	0.23	0.196	-0.610	56.03	0.991
C organic	1.862	0.73	0.012	1.332	0.32	<0.001	-1.129	103.13	0.991
Plant age	0.057	0.03	0.062	0.007	0.02	0.640	0.121	4.47	0.978

Akhmad Rizali et al.: *Arthropod Diversity in the Topsoil of Soybean Field*.....

The interaction between dominant arthropods in the soybean field may shape ecosystem balance as well as provide ecosystem services. Based on Coleman, Crossley Jr., & Hendrix (2004), the diversity of organisms in soil made an important contribution in maintaining ecosystem balance such as a decomposer and as a biological controller. However, the covariation between collembolan as well as ant abundance with mites in this research is still uncertain. The previous research in Europe also found a similar pattern that mites had a relationship with collembolan communities and soil microbial activity in different land-use types (Dirilgen et al., 2016). This uncertainty is because collembolan, ants and mites have different life-history strategies. The relationship between those groups may be affected by similar ways to use organic matter and microbial tissue as food sources. Research by Potapov et al. (2017) showed that the distribution of collembolan and mites depended on C-org content, although collembolan was also related to root biomass, while mites to microbial biomass.

Another factor that may shape the interaction between mites and collembolan with ants is the complexity of below- and above-ground interactions. An organism in the soil can affect the above-ground plant-insect interactions in an agroecosystem (De Deyn & Van der Putten, 2005). The population of collembolan was also affected by the indirect effect of above-ground herbivory (Sinka, Jones, & Hartley, 2007; Winck, Rigotti, & Saccol de Sá, 2019). For instance, honeydew as herbivory result by aphids has an important role as a carbon source for soil organisms and increase microbial biomass. Although the production of honeydew by aphids was disturbed by the complex interaction between ants and natural enemies of aphids (Seeger & Filser, 2008).

Soil management practices also expected to influence the interaction between collembolan, ants and mites. Previous research in the soybean field showed that no-tillage system had a stronger influence on the below-ground than the above-ground fauna by increasing the soil food web structure and complexity (Leslie, Wang, Meyer, Marahatta, & Hooks, 2017). Understanding those factors is important for soil organism conservation as an integral component of ecosystems for agricultural management strategies. The changes and the loss of soil fauna diversity negatively impacted ecosystem multi-functionality (Wagg, Bender,

Widmer, & van der Heijden, 2014). Therefore, the concept of ecological intensification to soils and strategies to conserve soil organism is important to enhance agricultural sustainability and to minimize the environmental impacts (Bender, Wagg, & van der Heijden, 2016).

CONCLUSION AND SUGGESTION

Collembolan, ants, and mites were the most abundant arthropods in the topsoil of soybean field in Malang. Arthropod abundance was more affected by soil strata than the location of soybean field. The organic matter in the soybean field supports arthropod abundance and their covariation, especially for collembolan and ants. Collembolan and ants had a relationship with mites that supported by organic matter in the soybean field and the mechanism is uncertainty. Understanding the management of organic matter in the soybean field is an important aspect of a sustainable agriculture.

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