Soil Macrofauna Community Structure and Biodiversity on Organic and Conventional Vegetable Land in Bedugul, Bali Island

Authors:
Yulianto Setyo Wibowo[a],
Anak Agung Istri Kesumadewi*[a], Anak Agung Ngurah Gede Suwastika[a]

[a]Agriculture Faculty, University of Udayana,
Office Address Jalan P.B. Sudirman Nomor 1, Denpasar, Bali, Indonesia, 80225
*Corresponding Author : Anak Agung Istri Kesumadewi
Office Address : Lantai 2 Gedung Agrokomplek, Universitas Udayana, Jalan P.B. Sudirman, Denpasar, Provinsi Bali,
Indonesia, 80225.
E-mail : aai-kesumadewi@live.com, Telp. :+62 82144500674
Co-author :
E-mail : agungsuwastika@yahoo.co.id Telp. :+62 857-3941-8483
E-mail : yuliant833@gmail.com Telp. : +62 822-4723-2659

Abstract

The soil macrofauna diversity had studied worldwide, but least done on tropical vegetables under organic and conventional farming systems. A study was done to determine the structure and biodiversity of soil macrofauna communities between organic and conventional vegetable field in Bali Island. The Pitfall trap and soil pit methods were equally applied to collect soil macrofauna from the lands. The results indicated that the structure and diversity of soil macrofauna were not different between farming systems. Totally 3 phylum, 6 classes, 10 orders, 15 families and 16 species of soil macrofauna were found in both farming systems. Most of them are herbivore and predator. They present mostly accidental, construct medium sized biodiversity and developed by uniform and very similar species. To our knowledge, this is the first report on selective negative impact of conventional farming system on particular species of soil macrofauna that lead to nearly similar biodiversity.

Keywords: biodiversity, community structure, farming system, herbivore, pitfall trap, predator, soil macrofauna, vegetable field.

1. Introduction

Soil ecosystems have a specific function by providing ecosystem services for life. The function of soil ecosystems is closely related to the activities and interactions between communities of soil organisms and their environment and is influenced by soil management (Ferrarini et al., 2017; Rui et al., 2018). Intensive soil management is known to reduce soil microbial diversity (Soho et al., 2010; Soho et al., 2019). However, there are limited reviews on the effect of agricultural land management on soil macrofauna (Ruiz et al., 2008; Toana et al., 2014) especially in annual crop farming systems in the tropics. Soil management in tropical annual crops cultivation uses excessive amounts of agrochemicals compared to the amount used in parennial crops. High-dose agrochemical input reported reduces the number and diversity of soil biota (Vasconcellos et

al., 2013). Accordingly, Santos (2018) found more populations and types of macrofauna in organic coffee cultivation systems.

Soil macrofauna have bodies size > 2 mm which include orders Araneae, Opiliones, Scorpiones, Isopoda, Diplopoda, Chilopoda, Isoptera, Hymenoptera, and Lumbricidae (Richard John Hayne, 2014). They have the greatest potential to modify the soil environment through their activities (Jouquet et al., 2006) and influence soil properties (Lobry de Bruyn and Conacher 1990; Barrios 2007). Macrofauna specifically play get involved in formation of soil structure, decomposition of organic matter, and nutrient mineralization (Brown et al., 1996). Macrofauna is the key to soil fertility and a sensitive bioindicator for changes in an ecosystem (Prayogo et al., 2019; Sofo et al., 2020). The functional role of macrofauna is strongly supported by the diversity and structure of macrofauna community. Community structure describes the species composition and abundance in a community. In general, there are three approaches that commonly used to describe community structures, namely species diversity, species interactions and functional interactions (Schowalter, 1996). The genus/species diversity approach was used in this study to determine community structure and soil macrofauna diversity in organic and conventional vegetable fields.

2. Research Method

2.1. Description of research site

The research site located in a highland vegetable field in the Bedugul area, Tabanan Regency, laid down at 8°17′S 115°10′E and 8°17′S 115°10′E, at an altitude of 850 m above sea level. The area has an average daily temperature of 32^{o}C and an average rainfall of 1,100 -2,016 mm/year. The type of soil in the study area was classified as Andisol with loamy sand texture. The characteristics of the land in the research site generally representative of highland vegetable production areas in Indonesia, except variation in altitude.

Vegetable plants in the research area were cultivated conventionally or organically by implementing intensive farming system. Organic vegetable land was only fertilized with cow and chicken manure without pesticides application. In contrary, beside the use of cow and chicken manure, conventional lands received additional chemical fertilizers and pesticides.

2.2. Sampling Method

The sampling locations for soil macrofauna were determined purposively for the two types of land management. In each plot of the land, 15 sample plots were selected which were determined squarely with a minimum distance between sample plots of 10 m or adjusted to the contours. Furthermore, soil macrofauna sampling was carried out by following Swift and Bignell (2001), namely the Pitfall Trap and Soil Pit, while the macrofauna calculation was carried out by Hand Sorting. Pitfall Trap devices were installed at each sampling location at 10.00 WITA and taken 24 hours after installation.

The soil pit system was used for sampling of soil macrofauna that were less active on the soil surface. Soil taken from the soil pit was placed in a plastic container followed by hand sorting to collect soil macrofauna. Soil macrofauna obtained by both methods were then cleaned up with water and then preserved with 70% alcohol in tightly closed bottles before being identified in laboratory. Identification to the species level was carried out based on morphological characteristics and body size of macrofauna (Wallwork, 1970; Suin, 2006). Each number of species classified and tabulated then was used to describe community structure and soil macrofauna diversity for organic and conventional land, respectively. The formula used was as follows (Dindal, 1990; Suin, 2006; Ruiz and Lavelle, 2008).

a. Population Density (D)

$$D = \frac{\text{Number of individu}}{\text{(number x plot area in } m^2\text{)}}$$

b. Relative Density (RD)

$$RD = \frac{\text{Density of species}}{\text{Total density}}$$

c. Presence Frequency (PF)

$$PF = \frac{\text{Number of Occupied Plots}}{\text{Total Plot Number}}$$

Suin (2006) explains the AF value based on its constant as follows:

0-25% : Constancy Accidental (very rare),
25-50% : Accessory Consistency (rare),
50-75% : Constant (often),
>75% : Absolute Constancy (very often)

d. Diversity Index Shannon-Wienner (H')

$$H' = \sum_{i=1}^{S} (pi)(\ln pi)$$

where:

Pi = ∑ni/N,
H : Diversity Index Shannon-Wiener,
Pi : Total individuals number of a species divided by the total number of species
ni : Number of individuals of the-i species,
N : Total number of individu.

The criteria for the Shannon-Wiener (H') diversity index value are as follows:

H' < 1 : Low diversity,
1<H'≤3 : Medium diversity,
H'> 3 : High diversity

e. Equitability/Uniformity Index (E)

$$E = \frac{H}{Hmax}$$

where:

E = Index of equity/uniformity,
H'= Shannon-Wiener diversity index,
Hmax = Maximum species diversity, = ln S (S = number of species)
The value of uniformity (E) ranges from 0 – 1 (Odum, 1996):
If E is close to 0 : Uniformity is getting lower
If E is close to 1: Uniformity is getting higher

f. Similirity index of Sorensen (Q/S)

$$Q/S = \frac{2J}{(A+B)} \times 100\%$$

Where:

Q/S = Similarity Index between locations,
J = Number of the same species at two different locations,
A = Number of species on organic farmland,
B = Number of species on conventional agricultural land

Suin (2006) explains the Q/S value as follows:

Q/S value = < 25%: The similarity is very dissimilar,
Q/S value = 25% - 50% : Similarities are not similar,
Q/S value = 50% - 75% : The same type is similar,
Q/S value = > 75% : The similarity is very similar.

3. Result and Discussion

3.1. The Types of Soil Macrofauna

The types of soil macrofauna found in upland vegetable fields in Bedugul consisted of 3 phyla, 6 classes, 10 orders, 15 families, and 16 species. Conventional agricultural land inhabited by more phyla, classes and orders of macrofauna than organic land. Soil macrofauna found on organic land consisted of 2 phyla, 5 classes, 7 orders, 11 families, and 12 species, while on conventional agricultural land there were 3 phyla, 6 classes, 9 orders, 11 families and 12 species (Table 1). The most abundant phylum was Arthropoda which consists of 4 classes, 8 orders, 11 families, and 12 species. Phylum Annelida only found 1 class, 1 order, 2 families and 2 species, while Phylum Mollusca only found 1 class, 1 order, 2 families and 2 species. Based on the number of phyla found, the results of this study support the findings of Campbell & Reece (2010) which states that Arthropoda is the largest phylum with the largest number of members from the kingdom Animalia.

Some species were not found in conventional land, namely *Lumbricus terrestris*, *Gryllotalpa* sp., *Gryllus* sp., and *Argiope argentata* which are classified as sensitive orgnisms to chemical pesticides. The disappearance of some species of Annelida and Arthropoda indicates selective pressure due to the use of agrochemicals, especially sinthetic pesticides. This finding was in line with that published by Usman et al. (2016). Interestingly, the main polypagous plant pest groups from the Mollusca phylum, Gastropod class, Stylommatophora order (*Monacha* sp. and *Hempilia* sp) emerged in conventional land. In addition, endogeic earthworm species (*Pontoscolex corethrurus*) and *Tipula* sp. was only present in conventional land.

Table 1
Soil Macrofauna Found at the Research Site

Phylum & Class	Order	Family	Spesies	Common Name	Landuse	
					O	C
I. Annelida						
1. Citellata	1 Haplotaxida	1.Lumbricidae	1. *Lumbricus terrestris*	Epigeic Earthworm	+	-
		2.Glossoscolecidae	2. *Pontoscolex corethrurus*	Endogeic Earthworm	-	+
II. Artrhopoda						
2. Insecta	2. Hymnoptera	3. Formicidae	3. *Odontoponera denticulate*	Black Ant	+	+
			4. *Oecophylla smaradigna*	Red Ant	+	+
		4. Apidae	5. *Apis* sp.	Wasp	+	+
	3. Diptera	5. Tipuladae	6. *Tipula* sp.	Field Fly	-	+
	4. Lepidoptera	6. Noctuidae	7. *Agrotis ipsilon*	Field Caterpillar	+	+
	5. Orthoptera	7. Gryllotalpidae	8. *Gryllotalpa* sp.	Mole Cricket	+	-
		8. Gryllidae	9. *Gryllus* sp.	Cricket	+	-
	6. Blattodea	9. Blattidae	10. *Blatta orientalis*	Field Cockroach	+	+
3. Malacostraca	7. Isopoda	10. Asselloidea	11. *Asellota* sp.	Centipede Shrimp	+	+
4. Arachnida	8. Araneae	11. Araneidae	12. *Argiope argentata*	Spider	+	-
		12. Philodromidae	13. *Philodromus sp.*	Long Leg Spider	+	+
5. Chilopoda	9.Scolopendromorpha	13. Scolopendridae	14. *Scolopendra* sp.	Centipede	+	+
III. Mollusca						
6. Gastropoda	10. Stylommatophora	14. Hygromiidae	15. *Monacha* sp.	Nun	-	+
		15. Arionidae	16. *Hemphilia* sp.	Naked Slug	-	+
		Total Number			**12**	**12**

Description : O = Organic Farming Land, C = Conventional Agricultural Land, (+) = Present (-) = Absent

3.2 Density and Relative Density of Soil Macrofauna

The addition of 1 macrofauna phylum in conventional agricultural land was not accompanied by a higher macrofauna density. In contrast, organic farmland had relatively higher density and relative density of macrofauna. The total density of macrofauna on organic land was 463.771 Ind/m2, while that on conventional agricultural land was 343.213 Ind/m2 (Table 2). The type of macrofauna that had the highest relative density and density in organic land was *Odontoponera denticulate*, on the other hand *Pontoscolex corethrurus* had the highest relative density and density on conventional land. Both species known to be sensitive to be exposure to agrochemicals and their behavior tends to be evasive. However, *Odontoponera denticulate* which was an active macrofauna on the soil surface easily escape from surface soil, *while Pontoscolex corethrurus* was more protected from direct exposure to agrochemicals because its habitat was below sub soil.

Table 2
The Density and Relative Density Index of Soil Macrofauna

Nr.	Species	Organic		Conventional	
		D (Ind/m^2)	RD (%)	D (Ind/m^2)	RD (%)
1.	*Agrotis ipsilon*	28,94	5,56	18,17	5,30
2.	*Argiope argentata*	21,65	4,16	-	-
3.	*Apis* sp.	56, 28	10,82	21,65	6,31
4.	*Asellota* sp.	43,29	8,32	41,18	12,00
5.	*Blatta orientallis*	22,39	4,31	51,95	15,14
6.	*Gryllotalpa sp.*	10,14	1,95	-	-
7.	*Gryllus sp.*	28,94	5,56	-	-
8.	*Hemphillia sp.*	-	-	12,99	3,78
9.	*Lumbricus terrestris*	97,04	18,66	-	-
10.	*Monacha sp.*	-	-	8,66	2,52
11.	*Odontoponera denticulate*	119,29	22,94	56,28	16,40
12.	*Oecophylla smaradigna*	79,75	15,33	12,99	3,78
13.	*Philodromus sp.*	4,33	0,83	21,65	6,31
14	*Pontoscolex corethrurus*	-	-	76,70	22,35
15.	*Scolopendra sp.*	8,03	1,55	16,69	4,86
16.	*Tipula sp.*	-	-	4,33	1,26
Total Number		**463,77**	**100,000**	**343,21**	**100,000**

Description: D = Density, RD = Relative Density

3.3 Presence Frequency or Constancy of Soil Macrofauna

Soil macrofauna can be grouped based on the frequency of their presence and constants, namely accidental, accessory, constant, and absolute (Suin, 2002). These findings indicate that environmental disturbances due to intensive agriculture of both lands create pressure on most of the soil macrofauna. Soil macrofauna very sensitive to environmental disturbances (Soho et al., 2020; Souza et al., 2016).

Table 3
Presence Frequency and Constancy of Soil Macrofauna

Nr.	SPecies	Organic		Conventional	
		PF (%)	Konstansi	AF (%)	Konstansi
1.	*Agrotis ipsilon*	8,60	Accidental	11,11	Accidental
2.	*Argiope argentata*	5,38	Accidental	-	
3.	*Apis* sp.	7,53	Accidental	6,35	Accidental
4.	*Asellota* sp.	5,38	Accidental	12,70	Accidental
5.	*Blatta orientallis*	3,27	Accidental	9,52	Accidental
6.	*Gryllotalpa sp.*	4,30	Accidental	-	
7.	*Gryllus sp.*	5,38	Accidental	-	
8.	*Hemphillia sp.*	-	-	3,18	Accidental
9.	*Lumbricus terrestris*	16,13	Accidental	-	
10.	*Monacha sp.*	-	-	3,18	Accidental
11.	*Odontoponera denticulate*	23,66	Accidental	7,94	Accidental
12.	*Oecophylla smaradigna*	15,05	Accidental	3,18	Accidental
13.	*Philodromus sp.*	1,08	Accidental	3,18	Accidental
14	*Pontoscolex corethrurus*	-	-	28,57	Accessories
15.	*Scolopendra sp.*	4,30	Accidental	9,52	Accidental
16.	*Tipula sp.*	-	-	1,59	Accidental

Description: AF = Attendance Frequency

3.4. The Community Structure of Soil Macrofauna

Soil macrofauna community structure in agricultural land was dominated by herbivores (50%) and predators (31.25%) (Table 4). The dominance of herbivores indicates the abundance of plants as their sufficient food sources and the presence of various organisms will be followed by predators. Four of the five predators found were classified as biological controllers except *Scolopendra* sp. which in addition to prey on insects but also worms.

Soil ecosystems on vegetable land at the study site had limited numbers and types of both main decomposer and detrivore. The decomposers found were earthworms, namely *Lumbricus terrestris* and *Pontoscolex corethrurus*. In addition, only 1 species of detrivore was present. Thus, the decomposition of litter and organic matter potentially slower, especially on conventional land and lead to a great impact on nutrient mineralization.

Table 4
The Present Macrofauna Based on The Tropic Level

Nr	Species	Tropic Level
1.	*Agrotis ipsilon*	Herbivore
2.	*Argiope argentata*	Predator
3.	*Apis* sp.	Herbivore
4.	*Asellota* sp.	Herbivore
5.	*Blatta orientallis*	Detritivore
6.	*Gryllotalpa sp.*	Herbivore
7.	*Gryllus sp.*	Herbivore
8.	*Hemphillia sp.*	Herbivore
9.	*Lumbricus terrestris*	Decomposer
10.	*Monacha sp.*	Herbivore
11.	*Odontoponera denticulata*	Predator
12.	*Oecophylla smaragdina*	Predator
13.	*Philodromus sp.*	Predator
14	*Pontoscolex corethrurus*	Decomposer
15.	*Scolopendra sp.*	Predator
16.	*Tipula sp.*	Herbivore

3.5. Index of Diversity, Uniformity and Similarity

In general, it is known that soil biota is more diverse and abundant in organic soils than conventional ones. However, the diversity of soil macrofauna on agricultural land in Bedugul was relatively the same between organic and conventional land. The Shannon-Wiener index was classified as moderate with H' values of 1.727 and 1.677 for organic and conventional land, respectively. The macrofauna found in the two land uses were also classified as uniform with E values of 0.70 and 0.68 and had similar species (Table 5). The same diversity and similar types of soil macrofauna between organic and conventional agricultural land in Bedugul indicated that most of the soil macrofauna except *Lumbricus terrestris*, *Argiope argentata*, *Gryllotalpa* sp., and *Gryllus* sp. were suscceptible to the agrochemicals used. The similarity of climate between the two agricultural lands seems to be more dominant than the use of agrochemicals.

Table 5
Index Value of Diversity, Uniformity and Similarity of Soil Macrofauna

Landuse	Diversity	Uniformity	Similarity
Organic	1,73	0,70	67%
Conventional	1,68	0,68	

Conclusions

The different types of soil management between organic and conventional vegetable cultivation did not affect the diversity and structure of the soil macrofauna community. Soil macrofauna found on organic farms consisted of 2 phyla, 5 classes, 7 orders, 11 families, and 12 species, while on conventional agricultural lands there were 3 phyla, 6 classes, 9 orders, 11 families, and 12 species with additional phyla. molluscs of the gastropod class. The possible negative effect of agrochemicals on conventional land was selective for *Lumbricus terrestris*, *Argiope argentata*, *Gryllotalpa* sp., and *Gryllus* sp.

The value of the total density of soil macrofauna on organic and conventional agricultural land was 463.77 Ind/m2 and 343.21 Ind/m2, respectively. Macrofauna group mostly present incidentally on both agricultural lands. Soil macrofauna diversity on organic and conventional agricultural land was classified as moderate with Shannon Wiener index values of 1.73 and 1.68, respectively. The macrofauna was classified as uniform (the uniformity index value was 0.39 on organic farmland and 0.33 on conventional agricultural land). The soil macrofauna found on both lands were similar as indicated by similarity index of 67%.

Conflicts of Interest

The authors declare no conflict of interest

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