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The role of agroforestry system for microarthropods biodiversity at upstream area of Merawu watershed, Banjarnegara District, Indonesia

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Abstract. The role of agroforestry system is significant for the sustainability of land-use, soil, water, biodiversity, and environmental conservation. The soil microfauna and vegetation pattern are potential as ecosystem indicators to evaluate the quality of the environment. The research was conducted in the catchment area level, using 9 plots with difference stratification of up-stream, mid-stream, and downstream in the catchment. The nested quadrat divides into 6 layers of vegetation, and soil fauna sample is in the middle of the study plot. The soil microarthropods is observed by Berlese fauna method for 7 days and identify order by microscope and counting. The result indicates that the microarthropods in the agroforestry system shown in high abundance and biodiversity. Moreover, the vegetation pattern has a strong correlation with the microarthropods biodiversity. The research found that microarthropods biodiversity and vegetation pattern in the agroforestry system have a strong correlation and interaction. This relation will have a significant role to maintain the ecosystem balance on nutrient and water cycle in the catchment area. Farmers on agroforestry system provide both of environment and economics by following the natural role to support agroforestry system as an ecosystem service.

1. Introduction

Agroforestry system in the Leksana village, Banjarnegara district is a part of Merawu upstream area where links many components such as the biodiversity, hydrologic cycle, nutrient cycle, ecosystem, agriculture, soil and so on. Furthermore, it plays a significant and positive role in the balance of ecology at macro and micro levels and maintaining a higher level of biodiversity [1]. The biodiversity roles important for ecosystem and food web such as microarthropods community is “ecosystem engineering” or “litter transformers” which performs a vital function in soil. For example, degradation pollution, decomposition of organic matter, nutrient cycle, plant protection (suppression of pests, parasites, and disease), carbon sequestration and gas exchange, growth enhancement, maintenance of soil structure, regulation of soil hydrological processes (invertebrates and plant roots) [2]. To study the role of agroforestry system to support the microarthropods biodiversity and identify the microarthropods biodiversity in the catchment area. Does microarthropods diversity change across the



environmental gradient? In general, the higher the soil quality, the higher the microarthropods groups found [3] that well adapted to soil habitat [4]. Its community is balanced soil and decomposing as well as nutrients recycling vegetation [5]. In fact, the agroforestry system has an ecosystem, is a dynamic complex of plant, animal and microorganism communities and their non-living environment interacting [6]. Beside this, the hydrologic cycle is precipitation, evaporation, transpiration, soil water, groundwater, and streamflow [7] which is soil living process part and watershed output that water absorbs by soil to become groundwater [8]. Hence all components in the agroforestry system are a vital function to conservation and sustainable development.

2. Agroforestry system

Agroforestry system is dynamic, the ecologically based natural resources management system of trees on farms and landscape, diversified and sustained for increase social, economic and environmental benefit for land use at all levels [6][9]. Its environment services are the greatest relevance the watershed protection, biodiversity conservation, climate change mitigation and adaptation [10]. It includes all practices that deliberately combine trees, shrubs with agricultural crop and or livestock. It is a land use between forestry and agriculture which evolve with sustainable concerns; resiliency, diversity and avoiding negative side effects [11]. Moreover, it can reduce exploitation of nearby 1or distant protected areas, increase biodiversity in landscapes and farming system [10]. It was classified by main three:

- Agrisilvicultural system: annual crop shrub and trees
- Silvopastoral system: pasture or cut fodder with animals and trees.
- Agrosilvopastoral system: trees, crops, pasture, cut fodder and animals [9], it provides more benefit of ecosystem service than agrisilviculture, and silvopastoral system [12].

2.1. Role and ecosystem service of agroforestry system

Role of agroforestry system ensures the sustainable land-used [13]. Agroforestry system is a basic concept for land-use system management on agriculture production and wild biodiversity conservation [10]. Furthermore, it generates environmental benefits value to communities, national societies, and the global community. In addition, it provides the greatest relevance to watershed protection, biodiversity conservation, and climate change mitigation, habitat combination and adaptation [10]. Moreover, it has the potential for improving water use efficiency by reducing run-off, soil evaporation and drainage due to vegetation cover, structure, litter, and humus [9]. Beside of role, agroforestry system has ecosystem service. For instance,

Provisioning service: food, energy, fiber, fuel, medicine.

Regulating service : soil formation, carbon sequestration (carbon market) [10], waste detoxification, water quality maintenance, water treatment, water supply, ecological restoration, wildlife habitat, crop pollination, food source and habitat for beneficial insect, biological and natural control of pests, soil conservation, biodiversity conservation, climate change mitigation, climate regulation.

Supporting service: primary production, nutrient processing, soil formation.

Cultural service: intellectual, culture, spiritual inspiration, aesthetic, education, ecotourism, scientific discovery [12] [14].

2.2. Ecosystem cycle of catchment

In general, the upland of land use management provides benefit both upstream (reduce soil loss and surface runoff, increase productivity) and downstream (reduce flood dangers and restoration of downstream ecology) [15]. Downstream communities are dependent on upstream communities for the quality, quantity, and timing of delivery of their water [8]. There are three Watershed functions: regulating the water cycle; providing good water quality and quantity; controlling the soil movement and sedimentation;

Water cycle: high dry-season flow, low peak-flow, maximum and minimum discharge, groundwater recharge.

Good water quality and quantity: suitable as drinking water, adequate for fish and another biota, low organic pollution, low nutrient load.

Soil movement: erosion control in the upstream, low sediment load of streams, control the potential landslides [16].

Watershed management perspective, agroforestry can provide both on-site and off-site downstream benefit [11]. For example, erosion reduces the overall productivity of terrestrial ecosystems such as increased water runoff, decrease water infiltration, water-storage capacity in the soil, reduce biodiversity in soil [17]. Furthermore, poor management on upland cause soil erosion and sedimentation. For example, nutrient loss, reduce productivity, groundwater depletion, water pollution, high surface runoff, the death of human and livestock, decline soil quality [15]. In addition, movement of water through soil decreases, stream falls more quickly after rainfall, it will make downstream flooding. The water has less overland flow since present more litter in vegetation area which less compacted, less sediment (decrease soil erosion) and take the longer movement of water on soil surface [8]. The vegetative species and cover cropping system, hedgerow planting (plant along contour line) and multipurpose planting (plant along the road as fence system) are soil erosion control [9] [18].

2.3 Microarthropods in the soil

A generalized, soil functioning is determined by spatial and temporal scales, of majority important in the ecosystem, soil development and maintenance are called “ecosystem engineering” (ant, termites, and earthworm) [2]. Soil fauna on decomposition processes is greatest in the humid tropics, where plant litter decomposition occurs most rapidly [19] due to interaction between microbial population [20] and live component of soil organic matter consists: plant root 5 to 15%, soil organisms is 85 to 95%, macrofauna and mesofauna are 15-30% and microorganisms is 60-80 [2].

Table 1. Abundance of Microarthropods in soil [20]

Ecosystem	Microarthropods (10^3 per m^2)	Reference
Fallow crop field, Nigeria	40-60	Adejuyigbe, 1990
Corn tillage plot, Guelph, Canada	16-17	Winter and Voroney, 1990
No-tillage plots, North Carolina	1-30	House and Worsham, 1987
Cedar Plantation, Nagoya, Japan	48-149	Hijii, 1987
Deciduous forest, Tennessee	36.9	Reichle, 1975
Deciduous forest, North Carolina	88	Lamoncha and Crossley, 1998
Burned tallgrass prairie, Kansas	35-50	Seastedt, 1984
Unburned tallgrass prairie, Kansas	63-77	Seastedt, 1985
Mediterranean desert, Negev	1-2	Sterinberger and Wallwork, 1985
North and southwest America desert	1-8	Sterinberger and Wallwork, 1986

In fact, the body size of soil fauna divide into three type as the body size is microfauna (0.02 to 0.16 mm), mesofauna (0.16-10.6 mm) and macrofauna (10.4-83.2 mm) [20]. Despite, microfauna is small but it's abundant is the second trophic level or middle links of soil food webs [19-20]. In the case of, acari is a high number compared with other arthropods. In addition, acari, collembolan, and isopoda are the most abundant and diverse [19] which role significant of all organic matter [5] compare with protura, dipluran, and pauropoda [19] Acari and collembolan are found most of the type of soil. By the way, Acari tolerant than collembolan even warm and climate change and they have a strong correlation with plant cover as well as high abundance in warmer soil temperature [21]. Collembola always present at 5-10 cm depth or deeper [22], it's density increased in presence of both

litter and plants where nitrogen and carbon concentrations [23]. Moreover, the diet of Collembola is bacteria, fungal hyphae and spores, algae, protozoans, pollen, decaying plant materials, and humus, the majority of species are primarily or largely fungivorous [19]. On another hand, Acari feed is dead plant materials and microflora (bacteria, fungi etc.) [19]. Nonetheless, it is also the prey of coleopteran [20]. The Diplopoda and symphylan are important on feeding on dead plant matter, leaf litter and wood, fungal mycelia, fecal matter, nutrients recycling and decompose [19]. The soil has protective litter layer and soil structure forming soil biota [16].

Table 2. Trophic of microarthropods [24]

Trophic guilds	Predator	Detritivore	Herbivores	Phytophagous
Order	Araneae	Collembola	Protura	Diptera
	Chilopoda	Isopoda	Psocoptera	Isoptera
	Pseudoscorpionida	Diplura	Symphyla	
	Diplura	Diplopoda	Thysanoptera	
	Hymenoptera		Hemiptera	
			Coleoptera	
			Orthoptera	

The consequence, the microarthropods is player of the nutrient cycle on the litter layer of soil where reduce runoff, increase water stock capacity, soil erosion by rainfall and wind, avoid soil compaction that has a negative impact to absorb water for groundwater, well watershed, biology natural pest control. Soil erosion is a complex process that involves ground slope, vegetation cover, rainfall intensity, and land management system [15]. Furthermore, erosion increases water runoff, thereby decreasing water infiltration and the water-storage capacity of the soil [17]. In addition, soil compaction reduces the capacity of the soil to hold water, the rate of water movement through soil and storage capacity of the soil. It increases runoff and vulnerability to erosion by wind and water and lost productivity [2]. Nevertheless, soil with abundant vegetation cover and high presence of roots, the organisms concentrate in the upper part of the ground which, being rich and decomposing organic matter, and maintain a numerous population of their prey [4].

3. Methodology

3.1. Study area

The research was conducted at Taman sari sub-village, Leksana village, Banjarnegara district which has applied agroforestry system over 30 years ago. This catchment divides into 9 plots but ranks into 3 classes by sea lever: 1220 to 1237 m, 1175 to 1200 and 1150 to 1175m.

Table 3. Description of the plot in the catchment

Plot	Height (m)	Canopy covering
A	1225-1237	Tree, pole, corn, cabbage, cassava, long bean, sweet potato, shrub, and grass.
B	1200-1212	Tree, pole, coffee, taro, and grass.
C	1212-1225	Tree, pole, banana, cassava, chili and grass.
D	1175-1187	Pole, coffee, banana, cassava, and grass.
E	1175-1187	Tree, vegetable(harvested) and grass.
F	1200-1212	Tree, pole, cassava and grass.
G	1162-1175	Tree, banana, chili, onion and grass.
H	1175-1187	Tree, pole, tea, coffee, banana, taro and grass.
I	1150-1162	Tree, coffee, banana, citrus, chili, cabbage

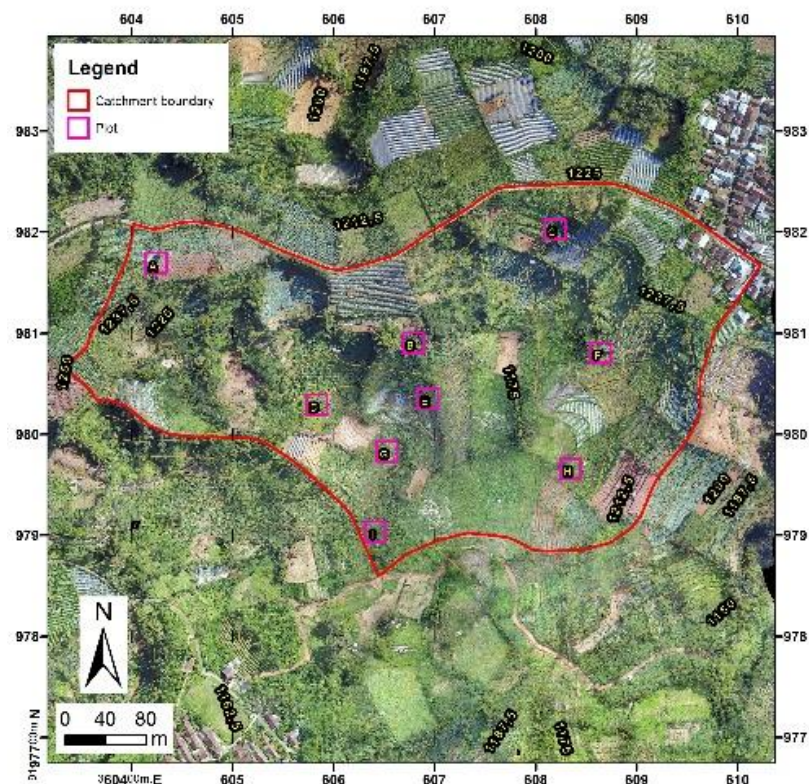


Figure 1. Catchment and Plot

3.2. Site description

They are two seasons; raining season (November-April) and dry season (May to October). As the map of catchment; the lowest sea level is from 1160 m to 1237 m. The average temperature is between 20.41 °C to 22.39 °C (logger recorder from April 2017 to April 2018). The cultivation area is 16.4 hectares and the perimeter is 1800 m. For the crop which plant by a border or random mix: coffee, potato, bean, cassava (border or random), tea, banana (border or random), peanut. The vegetable which farmers plants are cabbage, corn, chilli, tomato, lettuce, carrot, green onion, eggplant, Chinese cabbage, taro (eating and cow feed).

3.3. Soil fauna sampling

Soil sampling is from three replicates were taken randomly [3]. by the high of sea level. The most soil fauna is from the top layer to 30 cm depth but they concentrate on 10 cm depth [2] [25]. Thus, soil sample size is 20 × 20 × 20 cm [25] and the soil fauna was extracted by hand-sorting [26]. For the composition of the soil sample for soil fauna is from 5 g to 73g that depend on the kind of communities and condition; 5 g for the annual crop, 20g for the forest, 32g for savannas, 38g for tree plantation and 73 g for pasture [2]. Berlese funnel method applies for soil microarthropods the sieve fitting inside the funnel (mesh size 2 mm), the container fills by 30 ml and 70% of alcohol with the appropriate killing-preserving liquid (usually 70% ethanol). Soil sample experiment 10g is carefully placed inside the funnel, the collecting container is placed below and the top covering the sieve. Microarthropods die quickly because of drying, the sample will dry under the environmental conditions [3]. The catchment area is sandy loam so it dries quickly; the duration of the experiment is just conducted one week for Berlese funnel. The microarthropods stocks in alcohol 70% is counted by microscope and identify their order. Sampling in the lab, there are 3 replications sample per each plot, each sample divides 3 slides (200µl) for counting and then total 3 slides for one replication.

3.4. Nested quadrat

The standardized measure method of plant biodiversity; nested quadrat, Whittaker Plot, Long-Thin plot, Modified-Whittaker plot [27]. There are choices to observe squares study in the border or in inside [28]. Plot size study is 20 m X 20 m, 2 m tall or >10cm dbh (diameter at breast height) of the stem is recorded as a tree [29]. 10 m X 10 m <10 cm dbh is pole plot. 5 m X 5 m is crop plot, 2 m X 2 m is vegetable and shrub. 1 m X 1 m is a grass plot [30]. For the World Agroforestry Center, the sample size is 100 m² for tree [31]. Vegetation of plants are counted and recorded, the grass just identifies on family only.

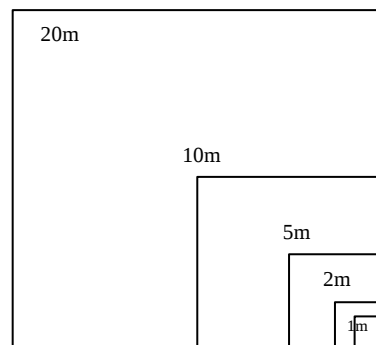


Figure 2. Nested quadrat

3.5. Data analysis

All data is analyzed by R program on the richness index, cor.test, biplot, and PCA. Cor.test shows the correlation, PCA (Principle Component Analysis) to observe variables of co-effect and the biplot show the location with effect by variables.

3.5.1. Shannon Diversity Index

$$Diversity H' = \sum_{i=1}^s p_i \ln p_i$$

S= the number of order

P_i=the proportion of individuals or abundance of the ith order expressed as a proportion of total cover

ln=log baseⁿ [32]

3.5.2. Evenness Index

$$Evenness(E) = \sum_{i=1}^s p_i \ln p_i / \ln s$$

P_i = the proportion of individuals of the ith order or abundance of the ith order expressed as a proportion of total cover

ln = log baseⁿ [32]

3.5.3. SExI-FS

The tree canopy uses the Spatially Explicit Individual-based Forest Simulator(SExI-FS) program to build the 3-D Visualization which needs the X position, Y position, species, DBH (Diameter at breast height), the height of the tree, crown depth, crown curve to set up 3-D project [33].

4. Result and discussion

4.1. Microarthropods

Microarthropods of all plots are non-significant by P-value 0.2881^{ns} of richness with Shannon index and P-value 0.5891^{ns} between richness vs Evenness (Table 4). It indicates that the agroforestry system of the ecosystem on the catchment area provides same condition environment for microarthropods habitat(soil). In addition, the height of catchment is not effected to microarthropods habitat. We use the biplot of Principal Components Analysis (PCA) in R program to indicate a correlation between microarthropods and microarthropods. As Table 2 and the distribution on biplot shows that even the ecosystem of the catchment is the same environment, on another hand, a difference of vegetation distribution and plant function so that arrow of Acari (predator) and Hemiptera, Diptera Orthoptera (herbivores and prey) have strong relation since preys are eaten by a predator. Moreover, the detritivores, predator and herbivore group of microarthropods contribute all area in biplot which they have own function in soil that indicates good quality of ecosystem and soil quality. Generally, soil fauna associates with stable soil conditions, such as pauropods, symphylans, proturans, and diplurans [4]. The interaction between all these components can play an important role in successional changes in the ecosystem [4].

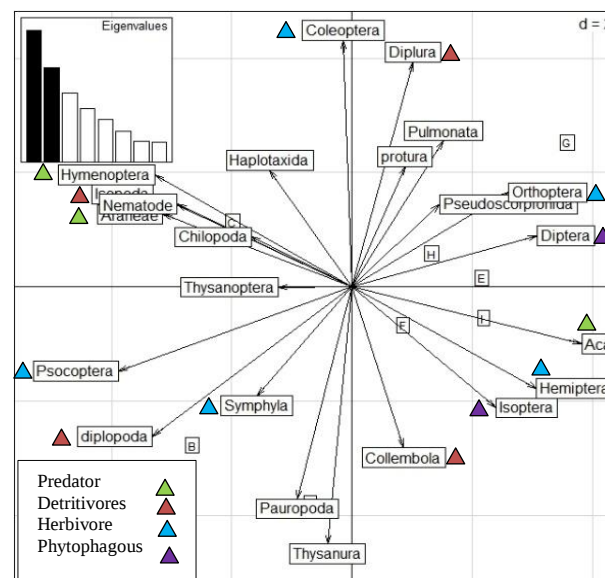


Figure 3. Biplot (PCA) of micro arthropods

4.2. Vegetation

The vegetation (nested) of 6 layers has strong correlation 97% and signification with p-value 0.001^{**}. Consequently, the canopy of the layer by layer have affection on cultivation and growing. For Constance, the plot I cover by the tree, pole, and grass so the crop and vegetable cannot grow well under the shade. However, the grass can grow up even under tree and canopy. For plot H and C cover more by crop and less of tree and grass which is a contrast with Plot I. For plot A cover by grass, vegetable, and crop but less tree. According to Table 4 and Figure 4 plot, A of Shannon index 2.77 and evenness 0.9786 value indicate that this plot A is more diversity and high abundance compare with another plot. In Figure 4 of grass and tree, vectors are closely and longer so that they have a strong correlation, in contrast, vegetation and crop vectors are shorter than tree and grass vectors so that they cannot compete on photosynthesis and nutrient with grass and tree. In summary, if the tree, pole and grass increase so the vegetable and crop decline, but the tree go down that means the vegetable, crop and grass go up, by the way, the grass is resistant both canopy.

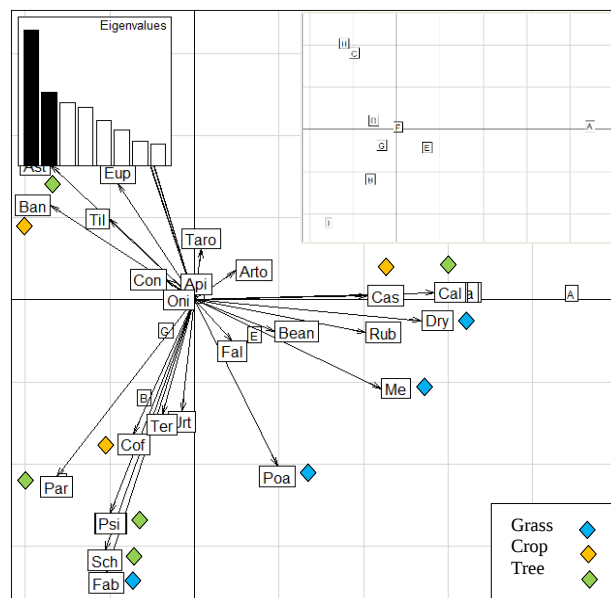


Figure 4. Biplot (PCA) of vegetation

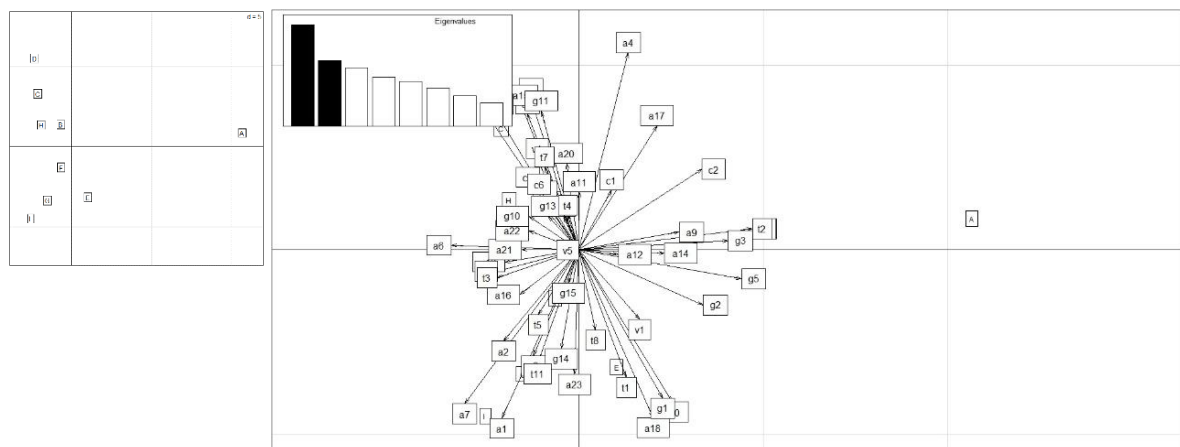


Figure 5. Microarthropods and vegetation (a=arthropods, g=grass, c=crop, v=vegetable, t=tree)

4.3. Microarthropods and vegetation

The microarthropods of each plot catchment show non-significant (Figure 3). Which one of vegetation does provide the high benefit from agroforestry and ecosystem conservation? According to Table 4 of P-value 0.01214* is significant and strong correlation 78%. Moreover, in the biplot (Figure 5) shows vegetation has relation with microarthropods and the best top three plot is A (Shannon index 2.5624), H (Shannon index 2.4454) and I (Shannon index 2.3856). In addition, by the (Figure 6) also indicate plot A of tree canopy is less than plot H and I, Plot A of tree (*Artocarpus heterophyllu*, *Calliandra calothyrsus*) plant along the border of vegetable and crop that allows other layer growing together. There are the reasons high both profit from agroforestry system and ecosystem conservation; First, low photosynthesis competition for vegetable and crop with tree canopy. Second, more vegetation layers (grass, vegetable, crop, and tree) is more biodiversity habitats and feed. Third, the more of biodiversity and vegetation are more diet for microarthropods community play balanced soil and decomposing as well as nutrients recycling vegetation [5], the high abundance of microarthropods is

higher soil quality [3]. For example, Acari and Collembola are extremely abundant in soil and leaf litter, their feed is microflora and play second trophic level on soil food web [4] [19-20]. The contribute of microarthropods spread whole biplot and vector is also far from 0 points of X and Y. In addition, the grass and tree vector and microarthropods vector are strong relationships. In an instance, Coleoptera and Diptera (Herbivores) are strong effects to crop (coffee and tea) and vegetable(chili) for feed and then grass is well habitat for them as the pasture is resulted increase the population of soil fauna [2]. Acari (predator) and Collembola (detrivores) vector with Diptera (Herbivores) vector are very close so they are strongly related, it means that high quality of ecosystem should have multi-function microarthropods in the soil to ensure a balance of prey and predator population which is a diver for pest and disease control in nature. The natural biological control agent can protect crop and reduce chemical control by activities of predators and parasites to control the population of pest and disease [6].

4.4. Correlation of catchment

Table 4. Correlation of biodiversity in the catchment

Plot	Microarthropods		Vegetation		Vegetation and microarthropods	
	Shannon index	Evenness	Shannon index	Evenness	Shannon index	Evenness
A	1.9803	0.6851	2.7726	0.9786	2.5624	0.7207
B	1.9230	0.6316	2.3026	0.9603	2.3596	0.6808
C	1.9439	0.6602	2.0794	0.9464	2.3733	0.7122
D	2.0904	0.6866	1.6094	0.8982	2.3481	0.7125
E	1.9510	0.6513	2.3026	0.9603	2.2579	0.6575
F	1.9213	0.6525	1.3863	0.8614	2.1401	0.6734
G	1.8857	0.6404	1.9459	0.9358	2.2437	0.6808
H	1.9465	0.6611	2.3026	0.9603	2.4454	0.7190
I	1.9331	0.6565	2.4849	0.9688	2.3856	0.6883
Correlation	0.398522	-0.2092	0.974922	0.881595	0.785369	0.213318
P-value	0.2881 ^{ns}	0.5891 ^{ns}	8.02E-06**	0.001672**	0.01214*	0.5816 ^{ns}

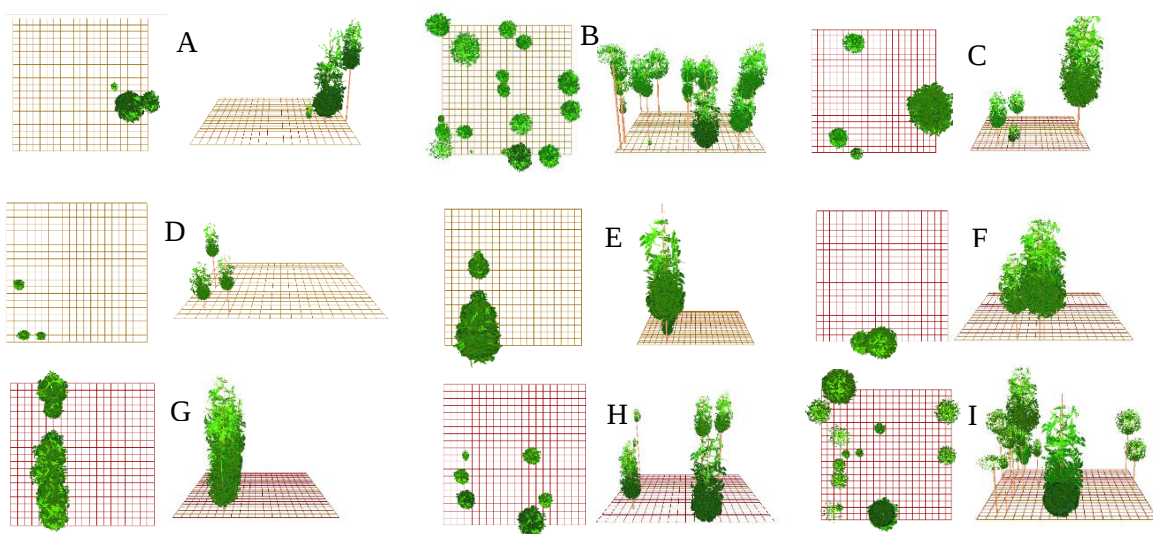


Figure 6. The tree canopy by SExi-FS

According to Figure 6 and Table 4, there are two type of agroforestry system is tree along border (plot A, G, E, F) and random mix (Plot H, I, C, B, D), the best intensive agriculture is plot A compare with plot H and I where are more of tree, crop, and grass. Trees cultivate along border allows more intensive agriculture activity that why it high abundance because of more vegetation layer and enough photosynthesis for crop and vegetable which is main income for farmers. Plot H and I of the random mix are less intensive agriculture on short-term crop but instead of long-term crops such as tea and coffee. By the way, the less cultivation action like plot B seems the forest but it indicates slow nutrient cycle and low abundance since no artificial to return and mix the soil, organic fertilizer, nutrient and soil fauna feed. As result, plot B is less abundance than plot A, H, and I. In addition, As the Table 1 showed the microarthropods abundance of plantation>forest>grass>desert. It means that canopy, artificial intensive agriculture, soil fauna, agroforestry system land use design, environment, hydrologic cycle, vegetation, and soil are strong interaction together to build sustainable of the ecosystem. As result, all the inputs in this system must be suitable and limited to link the high profit and low negative impact.

5. Conclusion

Agroforestry system of Taman-sari catchment has a good ecosystem by the strong correlation between vegetation composition and microarthropods biodiversity. Plot A (trees are along the border) has the highest biodiversity abundance with less of the canopy of the tree but refill by other vegetation which is farmers profit from this system. In contrast, there are two more plots H and I (trees are a random mix) are also show the high abundance with more of the tree but less crop and vegetable. The environmental gradients of agroforestry system role vital on the soil, water, biodiversity conservation which toward maintenance ecosystem.

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