The 4th International Symposium for Sustainable Humanosphere (ISSH)

a Forum of the Humanosphere Science School (HSS)

PROCEEDINGS

ISSN 2088-9127

''The Advanced Science and Technology in Humanosphere"

Auditorium LAPAN
Jl. Dr. Djundjunan No.133 Bandung
West Java, Indonesia
December 22-23, 2014

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ISSN 2088-9127

ASSESSMENT OF SOIL QUALITY BASED ON ORGANIC CARBON, MICROAGGREGATE, AND THE PRESENCE OF SOIL FAUNA

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Abstract

The impact of degraded soil has affected the habitat of soil fauna and soil microorganisms. The objective of this study was to determine the quality of degraded soil based on microaggregate, organic carbon and the presence of soil fauna. The research was conducted at Forest Education Gunung Geulis, in Sumedang, West Java. Sampling was done at 5 different land use types: 1) Agroforestry (= AF) dominated by pine trees; 2) Agrosystem–banana (= AS1) 3) Agrosystem–cereals (= AS2); 4) Agrosystem–banana–cereal (= AS3); 5) Protected forest (= FS). Soil sampling was conducted by grid method, core sampling and composite sampling. Collection of soil fauna was conducted by pit fall trap, square method, and extracted by hand sorting, followed by Berlese-Tullgren and Bearman methods. Identification was done up to morphospecies level. The results showed that the size of microaggregate varied among different land use types. AS1 had the highest microaggregate (21.35%), followed by AS2 (19.98%), AS3 (19.44 %), FS (16.24%) and AF (16.21%). The accumulation of stable C organic (iPOM) at FS was the highest (6.03%), followed by AF (4.19%), AS2 (3.02%), AS3 (2.67%), AS1 (1.62%). There was a significant difference in number of species of soil fauna at each location. There were four order : Hymenoptera: (Formicidae : *Anoplolepis Gracillipes*, *Diacamma sp., Pheidole sp., and Camponotus sp. 1*). Entomobryomorpha (Entomobryidae). Orthoptera (Gryllidae: *Gryllus mitratus*), and Isoptera (Mastotermitidae*: Procornitermes sp.*). Hymenoptera was dominated in all location. The highest number of soil fauna was found at FS (25), followed by AS1 (18), AS2 and AS3 (14), and AF (11). The results of soil quality assessment of Inceptisol order using soil quality index showed that Eutrudepts group had poor soil quality at FS (0.523), AF (0.413), and AS1 (0.415), and very poor soil quality at AS2 (0.346) and, AS3 (0.362).

Keywords : *microaggregates; organic carbo; soil fauna; soil quality.*

Introduction

Damage to agricultural land tends to become widespread along with the intensification practices that have been applied without any concerns to conservation rules or without accompanied by soil recovery techniques. The indication of damage to agricultural land is shown by the declining productivity of the land, soil crusting, hardened and solid, low water holding capacity, decreasing of soil aggregate stability, depletion of population and species composition of soil fauna, and the interrupted of nutrient cycle [1].

The interaction of organic matter and soil fauna has strongly influenced the formation of micro-aggregate, through the soil cementation, chelating and transformation processes of organic material into an organo-mineral form. Organic material acts as a supplementary source of energy for the growth and the development of soil fauna and improves water capacity and water preserving power in the connective tissue of macro and micro pore which is beneficial to organism and its environment. In macroaggregate, fauna changed organic material into finer particles sizes in the form of iPOM (internal particulate organic matter) and transform it into organo-mineral form through segmentation and attachment process until the micro-aggregate is formed. Organo-mineral bond in micro-aggregate becomes mutually synergistic bonds that can stabilize the soil and it is good to improve the soil quality. Moreover, micro-aggregate that has been formed not only protects the soil from the decomposition of organic material, but also affects the microbial community structure [2], limits the diffusion of oxygen [3], control of water flow, cation exchange capacity [4], and reduces run-off and erosion [5]. The objective of this research is to assess the quality of the soil based on organic carbon and size of the microaggregate and the presence of soil fauna in Education Forest of Gunung Geulis – Sumedang District - Indonesia.

Materials and Methods

Studi Area

The research was conducted at Education Forest at Gunung Geulis, Cimanggung Sub District Sumedang, West Java – Indonesia. The area is about 800 to 900m above sea level (06°55.443'S – 06°56.404'S, 107°48.045'E – 107°48.045'E – 107°48'904E). Based on the land use type, the study area was divided to five locations: 1) Agro-forestry (AF) was dominated by pine tree, with land slope of 40%, under the village of Lebak Kaso – Cikahuripan. 2) Agrosystem–banana (=AS1), this area was dominated by banana plants, with land slope 50% under the village of Ciandarusah, Desa Mangunarga. 3) Agrosystem–cereal (=AS2), dominated by peanut, corn and cassava. 4) Agrosystem banana-cereal (=AS3) very often called as a mix garden (banana, corn, peanut etc.), land slope is about 40%. This area is in the village of Kiarapayung, Desa Sawahdadap- Cimanggung; 5) Protected forest (=FS) : This area is a protected forest dominated by *Caliandra sp*, litter thicknes is about 0.50-1 cm and the soil more humid than other locations. Administratively this area is in Bukit Jarian - Tanjungsari.

Soil Sampling and identification

In each locations, for each land use types (FS, AF, AS1, AS2, AS3) soil sampling was conducted purposively using the grid method by taking 5-point samples (distance between point was 20 m) in each land use type. Five soil samples were taken by core and composite sampling. Soil identification was done by making soil profile [6]. In each soil horizon, soil sample was taken to determine the horizon identifier, depth, colour, aggregate. The soil type was determined based on key system in soil taxonomy [7]. Identification of the type of soil in the study area was determine by soil profile, moisture regime, soil colour, aquic conditions, soil minerals and physico-chemical analyses (soil depth, bulk density, waterholding capacity, pH, macro nutrient : N, P, K, base saturation, exchangeable sodium percentage) [7].

Soil Organic Carbon and Microaggregate

The analysis of microaggregate was done based on method of Six et. al [8] [9] with some modifications (**Figure 1**). Soil samples were dried, and sieved (2 mm in size). Sample of pure soil aggregates was analyzed by using wet and dry sieving methods [10] [11]. Dry sieving is used to determine the aggregate grain size. Five hundred grams of soil samples were air dried and sieved with 9 different size of sieving successively (8 mm, 4.76 mm, 2.83 mm, 2 mm, 1 mm, 0.5mm, 0.3mm 0.01mm and 0.025mm). Dry sieving resulted an isolate fractions of macroaggregate with grain size (3.0 mm, 2.0 mm, 1.0 mm, 0.3 mm) and microaggregate with the smaller size (0.250 mm, 0.100 mm, 0.045 mm).

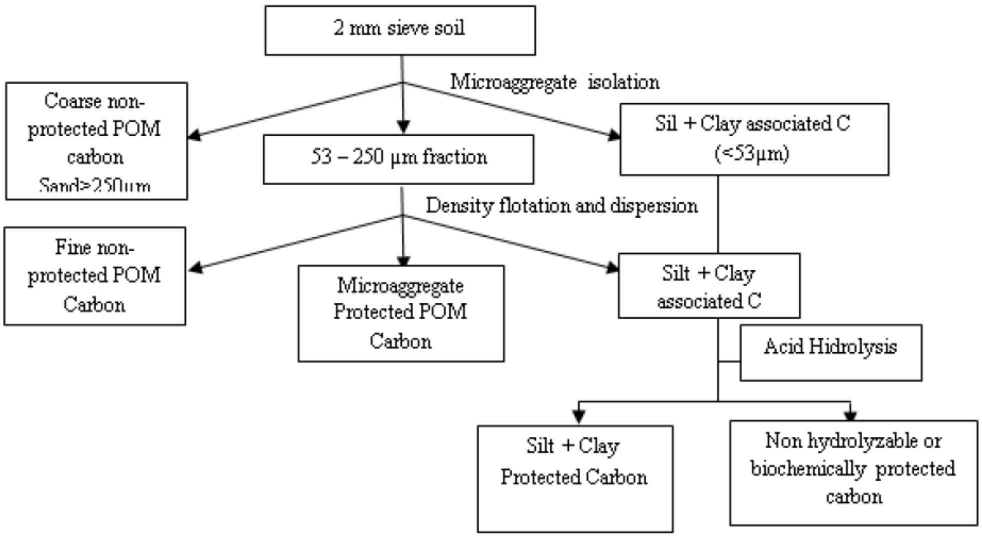

Figure 1. Fractionation of microaggregate and soil organic carbon following Six *et al.* (2002) [10] and some modifications

The organic carbon of soil microaggregate was measured using Loss Organic Ignition method (LOI) with the following mathematical formulation [12]:

Weight of organic material = $DW_{(105^{\circ}C)} - DW_{(700^{\circ}C)}$. (1)
Percentage of organic material = (1)/$DW_{(105^{\circ}C)}$. (2)

One hundred grams of soil microaggregate heated at 105° C for 12 to 24 hours to obtain a constant weight and put into the oven (temperature of 700° C) for 2 to 4 hours to get ash content. Percentage of organic materials was calculated by formula (1) and (2). The results of LOI in fine soil fractions are used to determine particle organic material (POM) which contain of three POM pools : unprotected, physically protected, and biochemically protected. Unprotected POM found in unstable aggregate, in wet condition and sieved (1mm) this aggregate will disintegrate. Protected POM physically found in rather stable aggregate, in wet condition with 5% NaOH and sieved (1mm) this aggregate rather stable. Biochemically protected POM contain a stable aggregate, it could not destroy by 5% NaOH and sieved (1 mm).

Soil Fauna Sampling

Sampling of fauna was conducted in five locations. In each locations, a transect of 30 meter was made contain 15 plot (distance of each plot was 1 m). In each plot, "pitfall traps" were set to collect ground level of soil faunas. For below ground fauna such as earhtworm and nematodes, soil collections were made differently. In each location earthworms sampling was done by soil removal (at 20 cm x 20 cm x 20 cm) and hand sorting method. Nematodes sampling was done by taking soil sample following star method [16] and extracted by Bearmenn method. Identification of soil fauna was done following "Soil Biology book with Guide" [17] up to morphospecies level.

Analysis of Soil Fauna Presence

The presence of soil fauna was analysed using Shannon-Wiener Index (H') for diversity and Margalef Abundant Index (R1).

$$H' = -\Sigma (Pi).(Log\ Pi) \quad (3)$$

$$Pi = Ni/N$$

Margalef Abundance Index (R1)

$$R1 = s-1/Ln\ N \quad (4)$$

S = number of taxa
N = population number

Assessment of Soil Quality Model

Three aspect were use in the valuation of soil quality, that were physical, chemical and biological properties. Physical and chemical indicators has been analyzed in the previous methods during soil identification, organic carbon analysis and microaggregate content [15]. Biological properties of the soil was determined by the presence of soil fauna (diversity and abundance). The value of soil quality was score by the three properties, and the composition was 40% physical, 30 chemicals and 30% biological. The results will represent by the index that will indicate the quality of the soil.

Results and Discussion

Soil Type

Based on mineral soil test using XRD (X-Ray Powder Diffraction) at Education Forest of Gunung Geulis showed that soil mineral was kaolinite type 1: 1 (Al2Si2O5 $(OH)_4$) about 31.1%. Quartz sand (SiO2) 6.15%, cristobalite (SiO2) 57.15% and hematite (Fe_2O_3) 5.60%. XRD analysis results showed this mineral has the peak number on theta was at 10.96 and 20.2 with the top rated of each was 480 and 708 with 7.20 A°angle by XRD could be determined that the type of clay minerals in the location was a kaolinit clay mineral.

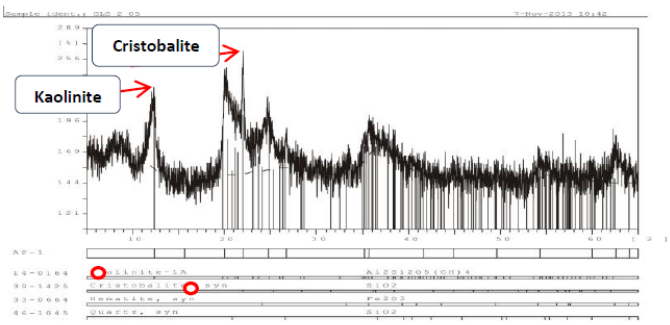

Figure 2. Kaolinite from Forest System analyzed using XRD method [7]

Soil profiling data that was taken showed that the parent material included lava crossing, breccia, tuff and off-lava deposits. The results of physical and chemical analysis from each layer profiles was inceptisol, with classification as in **Table 1**.

Table 1. Soil Types Classification

Classification		Soil Type
Ordo	:	Inceptisols
Sub Ordo	:	Udepts
Great group	:	Eutrudepts
Sub group	:	Humic Lithic Eutrudepts
Family	:	Humic Lithic Eutrudepts, smooth, mixed, isohipertermik
Serial	:	Tanjungsari

Source : field data and chemistry laboratory analysis, Soil Physics, 2014.

The soil texture (fraction of sand, silt, and clay) in Agrosystem (AS1 and AS2), agro-forestry (AF), and Forest System (FS) were differ significantly. The sand fraction in Forest System was the highest (FS = 14%), followed by Agrosystem (AS3 = 8.5 %, AS1 = 8 %, AS2 = 6 %) and the lowest was Agro-forestry (AF = 2.75 %). The clay fraction in Agro-forestry was the highest (AF = 69.25%), followed by AS1 = 58 %; AS3 = 46 %; AS2 = 38.5 %; and the lowest was FS = 33% (**Table 2**). This result indicates that Agrosystem has had erosion that reduceds the fraction of sand and dust. Although sand fraction was larger than the other fractions, it did not have strong adhesive power, and can be easily carried away by run off.

Table2. Soil texture at different five land use at Education Forest Gunung Geulis.

No	Parameter	AF	AS1	AS2	AS3	FS
1	Sand (%)	2.75[a]	8[b]	6[b]	8.5[b]	14[c]
2	Silt (%)	28[a]	34[b]	55.5[b]	45.5[b]	53[b]
3	Clay (%)	69.25[a]	58[b]	38.5[b]	46[b]	33[b]
4	Texture Class	Clay (Very Smooth)	Clay (Smooth)	Loam Silt Clay	Silt Loam	Loam Clay Silt
5	Solum Thickness	B – 40	Ap – 10	Ap – 50	Ap – 50	A – 28
6	Soil Color	Reddish Yellow 5 YR 3/4	Yellowish Red 5 YR 5/8	Reddish Yellow 5 YR 6/6	Reddish Yellow 5 YR 6/6	Dark Brown 7,5YR 3/2
7	Rocky Surface	5	15	10	10	0

AF = Agro-Forestry; AS1 = Agrosystem–banana; AS2 = Agrosystem–cereal, AS3 = Agrosystem banana-cereal FS = Forest-system.

Accumulation of clay fraction in the AF does not necessarily indicate good quality of soil, AF had already lost its A layer (there is only B layer at 40cm depth), so that the accumulated clay fraction was the result of sedimentation caused by erosion. Sediment in the form of sand particles and mud cannot form aggregates, because they do not have strength adhesion and cohesion. At FS, although the O layer had lost its organic, the soil horizon at FS was relatively complete and the depth of each layer was relatively thin. The rocky surface of Agrosystem (AS1, AS2, AS3) had already showed symptoms of degradation, even though the percentage of rocky surface was not exceeding a critical threshold of soil damage that was 40% [8].

Aggregate Grains Diameter

The weight fractions of grain aggregates (macro-aggregate and micro-aggregate) and the quantity of microaggregate at all location varied (**Table 3**). At Forest-system (FS) the grain fraction was the highest (0.25 mm in size and 33.44g) and (0.045 mm in size and 29.63g) with total aggregate weight 388.42 g.

Table 3. Weight Fractions of Macro and Micro-aggregates (g)

Types of Aggregates	AF	AS1	AS2	AS3	FS
Macro-aggregates, diameter 3 mm	50.12[a]	45.96[a]	102.25[a]	82.84[a]	-
Macro-aggregates, diameter 2 mm	75.30[a]	89.10[a]	117.49[a]	108.88[a]	241.66[b]
Macro-aggregates, diameter 1 mm	60.62[a]	75.08[b]	74.42[b]	72.98[b]	83.69[c]
Macro-aggregates, diameter 0.5 mm	49.45[a]	56.74[b]	51.53[a]	49.76[a]	-
Macro-aggregates, diameter 0.3 mm	11.40[a]	12.06[a]	12.07[a]	11.48[a]	-
Micro-aggregates, diameter 0.25 mm	18.25[a]	19.20[b]	19.60[b]	18.91[b]	33.44[c]
Micro-aggregates, diameter 0.10 mm	21.81[a]	41.28[b]	40.54[b]	37.09[b]	-
Macro-aggregates, diameter 0.045 mm	7.51[a]	20.86[b]	31.43[b]	25.42[b]	29.63[b]
Aggregate Total Weight (g)	294.19	380.94	459.66	418.89	388.42
Macro Aggregate Total Weight (g)	246.63	299.60	368.09	337.47	325.35
Micro Aggregate Total Weight(g)	47.56	81.34	91.57	81.42	63.07
Micro Aggregate (%)	16.21[a]	21.35[b]	19.98[b]	19.44[b]	16.24[a]
Macro Aggregate (%)	83.79[b]	78.65[a]	80.02[a]	80.56[a]	83.76[b]
Water Stable Aggregate (%)	61,27[a]	72,14[b]	64,72a	68,56[a]	92,41[c]

AF = Agro-Forestry; AS1 = Agrosystem–banana; AS2 = Agrosystem–cereal, AS3 = Agrosystem banana-cereal FS = Forest-system.

The microaggregate in different land use type showed by its weight fraction or its percentage was varied. The highest fraction of microaggregates (21.35 %) was found in AS1, followed by AS2, AS3, and FS were 19.98%, 19.44% and 16.24% respectively and the lowest was at FS (16.24 %). The microaggregate quantity in FS was higher than in AF. The micro-aggregates could protect the soil organic carbon from the soil processing disorder [9] [10]. Besides the content of organic carbon, the percentage of microaggregates is one of the indicators of soil quality. Based on organic content and microaggregate, the soil condition of FS could be used as an upper limit of soil quality. This condition was supported by lots of litter and no tillage.

Organic Carbon

Soil organic carbon in Education Forest of Gunung Geulis varied showed by the stable organic carbon in microaggregate (iPOM). The Forest-System (FS) produced the highest iPOM (6.03%) and this value was significantly differ from those of AF, AS1, AS2, AS3 (**Table 4**). In FS (without soil cultivation) the iPOM formed by fractionation process of fresh organic materials. On the contrary, in AS and AF, the tillage had interrupted the process of aggregate formation thus the iPOM was not formed. Soil cultivation could cause aggregate splitting (both macro and micro), and mechanical action could be the major cause of organic material depletion and it could decrease the stability of soil aggregates [10] [18]. Consequently, in FS the soil more stable and increased carbon absorption.

Table 4. Soil Organic Carbon in Education Forest of Gunung Geulis

C Organic Inside Aggregate	AF	AS1	AS2	AS3	FS
	---------------		%	------------	
C organic inside unprotected POM	5.62^b	6.31^c	5.45^b	4.74^a	5.96^b
C organic inside protected POM	6.81^b	7.16^b	7.06^b	6.38^b	5.72^a
C organic inside aggregate stable (iPOM)	4.19^a	1.62^a	3.02^a	2.67^a	6.03^b

AF = Agro-Forestry; AS1 = Agrosystem–banana; AS2 = Agrosystem–cereal, AS3 = Agrosystem banana-cereal FS = Forest-system.

Organic C in the soil could be a source of energy for the soil fauna [19] and also play a role in microaggregate formation. Fresh organic materials were fractionated by soil fauna resulted smaller particles organic material (POM) and stable macroaggregate. However, fractionation process by soil fauna between macroaggregate resulted on the labile organic carbon (fPOM). These materials were more sensitive to soil physical and biological process (tillage, decomposition) than fine organic carbon on microaggregate (iPOM). The accumulation of iPOM and formation of macroaggregate from stable microaggregate will increase the soil organic carbon [18], [20], [21]. By conversion of the percentage of microaggregate (g) to soil biomass (kg), the stable microaggregate in Education Forest of Gunung Geulis (Table 4) showed that the highest stable microaggregate was in FS (9.79 g/kg) followed by AS2 (6.02 g/kg), AS3 (5.18 g/kg) and AF (6.77 g/kg) successively and the lowest was AS1 (3.46 g/kg).

The Presence of Soil Fauna

During the period of research, the soil macrofauna on the soil surface of Education Forest found four order. There were Hymenoptera; Entomobryomorpha; Orthoptera and Isoptera. Hymenoptera was found in all locations. The dominant taxa were *Anoplolepis Gracillipes*, *Diacamma sp., Pheidole sp., and Camponotus sp.* Which belongs to the family of Formicidae. In Entomobryomorpha found only the family of Entomobryidae. The same tendency for Orthoptera which found only *Gryllus mitratus* from the family of Gryllidae and from Isoptera found only *Procornitermes sp.* from family of Mastotermitidae. Twenty five taxa was found at Forest System (FS), followed by Agriculture System (AS1 = 18 sp, AS2 = AS3 = 14 sp), and Agroforestry (AF = 11 sp). The highest number of individuals found in AS1 (920 individuals) followed by FS (828 individuals). Soil macrofauna diversity found in each type of land use (location) varied. This phenomenon showing by Shannon index of diversity. In Agrosystem (AS3) the diversity index was the highest (2.20) followed by Forest System (FS = 1.60). The presence of soil fauna in each type of land use correspond to POM content. Margalef index of abundance showed differently, at FS was 3.57 and 2.49 at AS1 (**Table 5**). Although the number of taxa and individuals of each group are not abundant, the compositions of the soil fauna showed different functional groups. There were transient (Hymenoptera – Formicidae), temporary (Coleoptera, Lymantridae), periodical (Hymenoptera - Formicidae), and permanent (Entomobryidae*, Acari,* Megascolecidae).

Table 5. Soil fauna diversity at Education Forest of Gunung Geulis

Taxa and Population	AF	AS1	AS2	AS3	FS
Taxa amount	11a	18b	14a	14a	25c
Number of individuals (N)	90a	920c	428a	223a	828b
Shannon Index (H')	1.08a	1.54b	0.85a	2.20c	1.60b
Margalef Abundance Index	2.22	2.49	2.15	2.40	3.57

AF = Agro-Forestry; AS1 = Agrosystem–banana; AS2 = Agrosystem–cereal, AS3 = Agrosystem banana-cereal FS = Forest-system.

Assesment of soil quality

The results of soil quality assessment in the study area of Education Forest of Gunung Geulis confirm that the type of the soil was order Inceptisol of Eutrudepts group. Soil quality was analyzed and determined based on the minimum data set of the soil parameters [13] [14] [15]. Based on physical, chemicals properties and the presence of soil fauna showed that different type of land use has different quality of soil showing by their soil quality index. At AS2, the soil quality index was 0.346, indicated that soil in AS2 was very poor. The same tendency in AS3 with the index was 0.362. The second group of soil quality was AF (0.413) and AS1 (0.415) was poor in soil quality, and at Forest-System the soil quality index was higher than other locations (FS = 0.523). This was due to its status as a protected area of Gunung Geulis.

Conclusions

The assessment of soil quality in order Inceptisol of Eutrudepts group resulted that the Forest System has a better index of soil quality than other location. Forest System (FS) produces the highest iPOM with 6.03% of stable C organic and it is significantly differ from those in Agro-Forestry and Agro-System. At Agro-System and Agro-Forestry area were classified as a low quality of soil. The clay fraction dominated at Agro-Forestry area unable to increase the formation of micro-aggregate although the organic carbon content was relatively high.

Acknowledgement

This research was funded by the funding from “Ikatan Alumni ITB” period of 2013-2014 through Tati Suryati Syamsudin, and from The Directorate of Higher Education of Indonesian Ministry of National Education through BPPS to Aep Supriyadi.

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