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Full Length Research Paper

The effect of *Lumbricus rubellus* and *Crotalaria retusa* in the enhancement of soil physical properties of eroded land and rice yield in Karawang, West Java, Indonesia

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Erosion has been one of the extreme conditions threatening crop production which may become more serious under tropical rain forest country such as Indonesia. This study is to address the potential of using *Lumbricus rubellus (L.* rubellus) and *Crotalaria retusa (C. retusa)* as bio-agents in the enhancement of soil physical properties (bulk density, soil water content, total porosity, and permeability) to ameliorate unproductive land due to erosion and their relationship to the rice yield. The experiment was executed for six months in 27% eroded slope land of Karawang soil in West Java using randomized factorial approach. The data gathered were analyzed by using Anova and regression-correlation test. Result of analysis showed that with 1,080,000 *L. rubellus* ha^{-1} and 15 tons ha^{-1}. *C. retusa* has improved soil bulk density by 28% and 9% respectively; the soil water content in the interaction of the two bio-agents has improved by 144%; the soil total porosity has improved by 24% and; the soil permeability has improved by 2,520%. There was a significant relationship between the soil physical properties and tiller with r of 0.73 and R^2 of 0.54; and rice yield with r of 0.85 and R^2 of 0.72. Therefore, the study concludes that *L.* rubellus and *C.* retusa improve soil physical properties which lead to increase in the rice yield.

Keywords: Erosion, bio-agents, physical soil properties, rice yield.

INTRODUCTION

Foliar (leaf) waste of the legumminocea family such as *Crotalaria* is abundant as being adaptive to any environment. However, not much scientific effort is made in observing or adopting it as something useful. The use of *Crotalaria retusa* (*C. retusa*) as green manure shall give a great prospect because the farmers can reduce the use of expensive and harmful inorganic fertilizer. Also, *C. retusa* can be applied as mulch to reduce clash of rain against the top soil and as a food-stocks for earth-worms. Besides *C.retusa*, other macro-fauna agent that can be used to enrich nutrients in soil is earthworm of *Lumbricus rubellus (L. rubellus)*.

The “underground” activity of *L. rubellus* enriches the availability of nutritive elements of nitrogen (N), phosphorus (P) and potassium (K) in soil (Sudjana, 2011). Research on barren lands that used to be mining areas shows that *L. rubellus* is able to increase the availability of potassium and phosphorus in soil as much as 19% and 16,5%, successively (Muys and Granval, 1997). *L. rubellus* not only fertile the soil, but also forms burrows or holes serving as aeration and drainage paths that make the soil become more friable and porous which enhance infiltration and percolation so as to decrease the suface run-off (Sudjana, 2011). Moreover, *L. rubellus* assists the transportation of organic substances-bearing layers and changes the soil structure (Peres *et al*., 1998).

Muys and Granval (1997) stated that *L. rubellus* consumes organic substances in an equivalent weight to its body in 24 hours. *L. rubellus* is able to decompose organic waste 2-3 times faster than the decomposing microorganism (Edwards, 1998), and the organic waste that has been decomposed by *L. rubellus* generally loses its weight up to 40% to 60%. Moreover, *L. rubellus* can live for decade and serves much in the improvement of soil's physical properties (Schrader, 1994).

Based on the facts described above, *L. rubellus* and *C. retusa* become the chosen bio-agents for this study. An experiment in search for the benefit as well as the role of *L. rubellus* and *C. retusa* in the improvement of the soil physical properties on-the eroded slope land and their relationship to the rice yield is necessary.

MATERIALS AND METHODS

Experiment site

The field experiment site is located in Telaga Desa at Karawang International Industrial City, Karawang District, West Java Province, Indonesia. The site experiment was executed from April to September 2012 in 27% of eroded slope land. Based on the data of 10 years rainfall, the annual precipitation average was 1,582 mm per year with 8 raining months which classified as a type C which is considered as slightly wet. The soil was acid (pH= 4.8), poor in organic carbon (C= 1.48%) and soil nutrients, moderately compacted despite a high carbon exchange capacity of 21.09. The above phenomenon had produced erosion and was recorded as clay content of 68%. The condition lead to the higher value of bulk density of 1.32 $gr.cm^{-3}$ and lower permeability flow of 0.02 $cm.hr^{-1}$. As a local conventional cropping system, cultivation of rainy season upland rice, horticultural leaf in the dry season had been applied manageably well and was barren since years before the experiment was conducted.

Lumbricus rubellus (L) and Crotalaria retusa (C) solution used

The worms of *L. rubellus* species used for the field experiment was dug from the river-bank of Citarum River in Karawang District. In order to get the needed amount, the worms were intentionally produce, grown, and fed. The worms were applied to the soil and buried 5 cm below the topsoil and covered with *C. retusa*.

The *C. retusa* was gathered from the nearby area of the field experiment. Normally it grows as bushes and or used as house fences. The leaves were sun-dried and used as mulch. In the application for the experiment, mulched *C. retusa* was applied to cover the barren land and functioned not only to lessen rain-drops but also as a food-material for the worms.

Experiment design

In this study, an abandoned *C. retusa* was used for field experiment. A plot of 4 meter square (2 m x 2 m; which then being converted into 1 hectare for the need of statistical calculation) was treated with *L. rubellus;* and each amendment was applied at three levels of treatment as shown below:

The first factor is the use of *C. retusa:*

1. *Crotalaria* (Co) = without *C. retusa.*
2. *Crotalaria* (C_1) = 5 tons per hectare of *C. retusa.*
3. *Crotalaria* (C_2) = 10 tons per hectare of *C. retusa.*
4. *Crotalaria* (C_3) = 15 tons per hectare of *C. retusa.*

The second factor is the *L. rubellus*:

1. *Lumbricus* (Lo) = without *L. rubellus.*
2. *Lumbricus* (L_1) = 360,000 *L. rubellus* per hectare.
3. *Lumbricus* (L_2) = 720,000 *L. rubellus* per hectare.
4. *Lumbricus* (L_3) = 1,080,000 *L. rubellus* per hectare.

Following the local conventional fertilization, basal fertilizers of urea, calcium super-phosphate and potassium chloride was applied at 200 kg N ha^{-1}, 100 kg P2O5 ha $^{-1}$ and 50 kg K2O5 ha^{-1}, respectively. Seeds of Situ Bagendit, (a region-typical up-land rice cultivar), were directly sowed into the soil.

For comparison, a plot of un-reclaimed (un-eroded land) was used as background control without *L. rubellus* and *C. retusa* (CoLo), which was similarly fertilized. The rice cultivar and use of chemical fertilizers under CoLo were the same as the other treatment. As conventional in the region, 3 weeks before sowing seeds the *C. retusa* leaves

Table 1. Bulk density after land reclamation.

Factors	Bulk density (gr/cm^3)
L. rubellus	
L_0	1.27 d
L_1	1.17 c
L_2	1.10 b
L_3	0.99 a
C. retusa	
C_0	1.18 b
C_1	1.15 a
C_2	1.13 a
C_3	1.08 a

Different letters in the same column indicate significant differences (p<0,05)

was decomposed by an Effective Micro-organism (EM 4 that consists of *Rhizobium, Azotobacter, Azospirilium*, *Pseudomonas*, and *lactobacillus*) after cutting it into a smaller size.

The experiment was repeated in triplicates with a complete randomized block design (Sudjana, 1996) of the individual plots in an area of 4 m^2. The crop growth management was consistent across the treated and untreated plots. No irrigation was performed during rice production.

Soil sampling and analysis

For soil fertility assessment, topsoil sampling was done at the eroded land. A composite sample at depth 0-20 cm was obtained of 5 subsamples collected using core-ring sampler from each treatment plot. Samples were sealed in plastic bags and shipped to the laboratory within 24 hours. Basic soil properties were determined following the laboratory protocols. Soil pH (H^2O) was measured by Metter-Toledo pH meter with soil/water ratio of 1:2.5. Cation Exchange Capacity (CEC) was measured with ammonium acetate (1 mol L^{-1}, pH 8.7) leaching method; total soil water contents was measured with water extraction and weighed after completely oven-dried. Soil Bulk Density (BD) was measured using a cylinder of 100 cm^3 in volume with 5 random replicates collected in a plot.

Soil physical properties (bulk density, water contents, total porosity, and permeability)

For soil physical assessment, a un-disturbance techniques soil sample using core-ring sampler from the topsoil was obtained of 5 subsamples from each treatment plot. Samples were analyzed in the laboratory. Soil bulk density, water content, total porosity, and permeability was analyzed.

Rice yield measurement

Rice was harvested and grains were threshed using a thresher and weighed to obtain a yield separately for each experiment plot.

Statistical analysis

All analytical data were expressed as mean plus/minus one standard deviation. Data processing was performed with Microsoft Excel 2003 Statistical analysis was done with SPSS. Version 16.0 (SPSS Institute, USA, 2001). Significance for differences between the treatment means was examined by one-way analysis of variance (ANOVA), with a probability defined at 0.05.

RESULTS AND DISCUSSIONS

Soil physical properties

In Table 1, the data of bulk density parameters under different treatments are presented. There was significantly lower soil compaction either treated by *L. rubellus* or by *C.retusa.* It showed that the more *L. rubellus* or *C. retusa* was applied, the bulk density become lower. At *L. rubellus* of 1,080,000 has given the best to bulk density and reduces 28%. The soil compaction of 1.27 gram.cm^{-3} (bulk density of eroded topsoil) had become more friable (0.99 gram.cm^{-3}); while with *C.retusa* of 15 tons.ha^{-1} had reduced by 9% (from 1.18 gram.cm^{-3} to 1.08 gram.cm^{-3}). *L. rubellus* plays an important role in enhancing physical properties of eroded soils by decomposing organic materials of *C. retusa* and mixing them with soil to form soil aggregates (Buck *et al.* 1999), and restores land structure.

The interaction of both bio-agents in performing the soil water content has significantly increased by 144% as shown in table 2 below. Under control scheme, the soil water content was only 19.20% and was gradually increase to 46.91% after *L. rubellus* and *C. retusa* were applied. The organic carbon of *C. retusa* was primary a food-material for the *L.rubellus* and were brought to enrich the soil

Table 2. Soil water content after land reclamation

Interaction	Soil Water Content (%)			
	C_0	C_1	C_2	C_3
L_0	19.20 A c	28.02 B b	32.36 C a	33.56 C a
L_1	35.00 A b	36.82 B b	39.39 B a	41.05 B a
L_2	42.43 A c	43.65 A b	43.99 B a	43.75 B a
L_3	44.76 A b	45.62 A B	45.11 A B	46.91 A A

Different letters in a same row (sub-letter) and column (capital letter) indicate Significant differences (p<0,05)

organic content as it enable to increase the soil water holding capacity (Buckman and Brady, 1969).

The enhancement of soil's physical properties of the eroded land is sharply marked by the soil's total porosity (Mele and Carter, 1999). In Table 3, the increment of total soil porosity from 50.76% to 63.20 % was due to the presence of *L. rubellus* of 1,080,000 and *C.retusa* of 15 ton.ha^{-1}. The absence of the difference between soil's water content of the eroded land is a proof that *C. retusa* and *L. rubellus* was able to increase the number of porosity of the eroded land.

structure and land use (Lee, 1985) as shown in table 4 below. The movement of *L. rubellus* is very aggressive and random depending on the temperature of its living environment and the need for food such as *C. retusa* (Atiyeh *et al.* 2000). Owing to its aggressive movement, the soil becomes more porous. Once the soil temperatures increases, it moves to underground places of better aeration to recover oxygen. *L. rubellus* is fond of organic materials derived from dung and plant remains. That explains why *L. rubellus* is referred to as a decomposing agent due to its ability to change the organic materials into compost.

Table 3. Soil total porosity.

Interaction	Total Porosity (%)			
	L_0	L_1	L_2	L_3
C_0	50.76 B a	52.08 B a	52.27 B a	54.53 B a
C_1	55.09 A a	55.66 A a	56.23 A a	56.61 A a
C_2	58.12 A a	59.44 A a	59.24 A a	58.49 A a
C_3	58.11 A B	58.68 A B	61.89 A a	63.20 A a

Different letters in a same row (sub-letter) and column (capital letter) indicate Significant differences (p<0,05)

Aside from the soil pores, *L. rubellus* also improves the aeration system in the earth due to the development of cavities and the improvement of soil porosity following the restoration of the land

Relationship between the enhancement of soil physical properties and rice grain yield

The influence of the improved soil's physical

Table 4. Soil permeability.

Interaction	Permeability (cm/hour)			
	L_0	L_1	L_2	L_3
C_0	1.12 B a	1.15 C a	1.51 C a	1.65 C a
C_1	2.18 B b	2.82 C b	3.35 C a	3.87 C a
C_2	4.92 B b	7.59 B b	10.80 B a	13.39 B a
C_3	15.28 A b	18.10 A B	20.05 A b	29.34 A a

Different letters in a same row (sub-letter) and column (capital letter) indicate Significant differences (p<0,05)

properties on the production of rice tiller (Y_1) is unveiled by the following regression-correlation equation:

$$Y_1 = 2.52 + 4.55_{BD} + 0.54_{TP} + 0.01_{PER} + 0.60_{WC}$$

(r = 0.73 and R^2 = 0.54)

Statistics shows that the improved soil's physical properties have significantly influenced the rice tiller production in the eroded land. The rice tiller production is due to the significant increase in proportion of the needed soil's components such as water, air, minerals and organic materials.

The enhancement of soil's physical properties by reclaiming the eroded land using bio-agents of *L. rubellus* and *C. retusa* leads to an increase of rice yield (Y_2) as depicted by the following equation:

$$Y_2 = 27.79 + 1.20_{BD} + 0.20_{TP} - 0.04_{PER} + 0.03_{WC}$$

(r = 0.85 and R^2 = 0.72)

CONCLUSION

Combined amendment of *L. rubellus* and *C. retusa* significantly enhanced the soil physical properties of the eroded land and thus increasing rice production through a decline in soil bulk density that gave the increase of water content, total porosity, and permeability. The enhancement of the soil physical properties by the two bio-agents had significantly affects the rice tiller and rice yield of an eroded land. This could be accounted for by the multiple benefits on the vertical and horizontal movement of the earth-worms in a time, taking *C. retusa* as food-stocks from the topsoil which leads to the declined of the soil bulk density. This experiment suggested a great potential to economic efficiency using chemical fertilizers due to the soil enrichment from the worm-cast secretion. However, the mechanism behind deserves further research.

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