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Optimizing degraded steep upland paddy field under no tillage practice using leaf mulching and earth-worms

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A field experiment project was conducted in Karawang District, Indonesia from April to October, 2016 in the search of efforts to optimize degraded steep upland paddy field and paddy yield. The experiment was designed under no tillage practices and statistical randomized block were applied with two factors, that is, banana leaf mulch, and worms where each factor is varied into four levels of treatments with three times-replication, respectively. Results showed that both banana leaf mulch and worms significantly improved the soil physic properties of degraded land such as reduced soil bulk density by 28%; increased soil water capacity by 144%; increased total porosity by 24.5% ; and soil permeability from 1.12 to 29.34 cm/h. While, the regression/corelation of this improvement to the paddy (dry-land paddy rice) tiller and yield is strong at R^2 = 0.54 and R^2 = 0.72, respectively.

Key words: Banana leaf, mulching, degraded upland paddy field, earth-worms, paddy.

INTRODUCTION

Degraded land may occur due to erosion exerted by raindrop and/or surface run-off and become critical problem in a marginal land. The loss of soil from land surfaces by erosion is widespread and reduces the productivity of all natural ecosystems as well as agricultural, forest and pasture ecosystems (Troeh et al., 2004). Top soil loss due to run-off is more intensive in sloping land. Despite its poor condition for retaining water, the land practice for long has served as a field for cultivating crops with so-called upland paddy rice field which relies on rainfall for its growth. Moreover, the land may be critical for agriculture if managed not in compliance with the standard procedures of soil conservation.

In general, sloping dry lands in Indonesia are critical since it lost their fertile top soil owing to erosion. Damages left by erosion are mostly disturbances either in biological, chemical and/or physical properties of the soil such as the loss or even the absence of nutrients and organic substances (Cruse et al., 2010) and the increase in soil compaction (Horn and Peth, 2011) and reduced water holding capacity (Berndes, 2008). These undermined properties will in turn reduce the soil's benefit for agriculture (Blum and Nortcliff, 2013). Organic matter, phosphorous, nitrogen, clay, dust, field capacity, wilting point and available water capacity were higher in

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afforested areas which was 15 years than un-afforested areas, while it was opposite for pH, sand, lime and volume weight values (Yazici and Turan, 2016).

In light of the phenomenon described above, land exploitation for agriculture should refer to proper land conservation techniques in order to be continuous. This implies some proper and accountable planning as well as management for farms are necessary to prevent them from being possibly degraded. Sloping dry lands where the upland paddy is commonly cultivated should be made as rainwater catchment areas to control flood and prevent surface erosion. When well-managed, sloping dry lands can keep ecological stability, maintain bio-diversity and absorb greenhouse gases. The paddy mostly relying on rainfall for growth often cultivated in such condition. Unfortunately, it has never been massively cultivated, as compared to wet land paddy, so far owing to its low productivity.

Proper and proportional fertilizing is one effort to improve the soil's fertility. Other efforts such as the implementation of organic fertilizers to replace inorganic, are now being exercised. Organic fertilizers that have been used to improve soil quality and productivity are manure and compost. However, farmers reluctant use the latter owing to its relative amount in every hectare of land cultivated, that is, 10 to 20 tons, in order to meet a specified need of soil nutrition. Large tonnages of compost are difficult to provide fertile soils typically containing 100 tons of organic matter per hectare (4 to 5% of total topsoil weight) (Pimentel et al., 2005; Sundquist, 2010). Many vehicles are needed to transport them to the sites, and fertilization process is laborious. Due to this, production cost of an agriculture program becomes high owing to high cost of fertilization process using compost. In fact, Indonesia has still a great number of natural resources other than compost to be beneficially exploited in relatively short time.

Agriculture results have wasted other materials besides grain. Leave waste of the banana leaf is abundant as being adaptive to any environment. However, not much effort is applied to scientifically observe it or adopt it as something useful. The use of banana leaf as mulching will give a good prospect because the farmers can reduce the use of the relatively expensive and harmful inorganic fertilizer. This type of leaf mulching can supply chain-food to the population growth of earthworm species.

The importance of macro-organisms (e.g., earthworms and termites) for restoring soil quality has been widely recognized for centuries (Darwin, 1881). Earthworms in soil enriches the availability of nutritive elements of nitrogen (N), phosphorus (P) and potassium (K) and soil structure changes (Castellanos-Navarrete et al., 2012). Observation on barren lands used to be mining areas in Ohio, USA, shows that *Lumbricus rubellus* is able to increase the availability of potassium and phosphorus in soil as much as 19 and 16,5%, successively (Curry and Good, 1992). Earthworm not only fertilize soil, but leave as well in them tracks in the form of burrows or holes, serves as aeration and drainage paths that make the soil become more friable. It assists also the transportation of organic substances-bearing layers and changed soil structure. The presence of burrows in soil enhances infiltration and percolation so as to reduce the suface runoff.

Muys and Granval (1997) showed that worms consumes organic substances, such as leafs, in an equivalent weight to its body in 24 h. It can decompose organic waste 2 to 3 times faster than the decomposing microorganism, and the organic waste that has been decomposed by earth-worms generally loses its weight to 40 to 60%. Moreover, it can live as long as 1 to 10 years and serves much improvement in the soil's physical properties.

Based on the facts described above, observation in search for the benefit as well as role of the bio-agents of bananas leaf and earthworm in optimizing of soil physic of the degraded lands and their effect to the paddy yield is necessary.

MATERIALS AND METHODS

A field observation was done from April to November 2016 in a steep and degraded upland paddy field in Karawang District, Indonesia. Duo bio-agents such as banana leaf mulch (code M) (with-out; 0.5; 1.0; and 1.5 kg/m^2 land) and earth-worms (code W) (0, 36, 72, and 108 worms population per meter square of land) were applied aiming to optimize its potential energy. Statistical methods were designed by randomized complete block design and repeated three times.

Analysis of variance followed by the F test with 5% level of significance is used to test the overall data. The Duncan's multiple range test 5% and correlation-regression analysis was also obtained following the analysis of variance.

Response variables to observe in this research are as follows: (1). The soil physic, that is, bulk density, soil water content, soil total porosity and permeability. A *core ring sampler* technique as an undisturbed soil was tested in Soil Laboratory of Faculty of Agriculture, University of Singaperbangsa; and; Upland paddy tiller and yield.

RESULTS AND DISCUSSION

The improvement of soil physical properties of degraded land

The absence of difference between physical properties of degraded land in Table 1 proves that there is an improvement in soil's physical properties due to the collaboration of mulching and worms used in the land.

Worms with 108 populations gave the best bulk density and reduced by 28%. It plays an important role in improving physical properties of degraded land by

Table 1. Improvement of bulk density of degraded paddy field upland by mulch and earthworms.

Treatment	Bulk density (gr/cm^3)
Worms	
W_0 = none	1.27^d
W_1 = 36 worms/m^2	1.17^c
W_2 = 72 worms/m^2	1.10^b
W_3 = 108 worms/m^2	0.99^a
Mulch	
M_0 = none	1.18^b
M_0 = 0.5 kg/m^2	1.15^a
M_0 = 1.0 kg/m^2	1.13^a
M_0 = 1.5 kg/m^2	1.0^{8a}

Means in the same rows followed by same letters are not significantly different at p<0.05.

Table 2. Improvement of soil water capacity of degraded paddy field upland by mulch and earthworms.

Interaction	Water content (%)			
	M_0	**M_1**	**M_2**	**M_3**
W_0	19.20^{Aa}	28.02^{Ba}	32.36^{Ca}	33.56^{Ca}
W_1	35.00^{Ab}	36.82^{Bb}	39.39^{Cb}	41.05^{Db}
W_2	42.43^{Ac}	43.65^{Ac}	43.99^{Ac}	43.75^{Ab}
W_3	44.76^{Ac}	45.62^{AC}	45.11^{Ac}	46.91^{Ac}

Means in the same rows followed by same small letters are not significantly different at p<0.05; Means in the same column followed by same capital letters are not significantly different at p<0.05.

Table 3. Improvement of soil total porosity of degraded land due to interaction of mulch and earthworms.

Interaction	Total porosity (%)			
	W_0	**W_1**	**W_2**	**W_3**
M_0	50.76^{Aa}	52.08^{Aa}	52.27^{Aa}	54.53^{Ba}
M_1	55.09^{Ab}	55.66^{Ab}	56.23^{Ab}	56.61^{Ab}
M_2	58.12^{Ac}	59.44^{Ac}	59.24^{Ac}	58.49^{Ab}
M_3	58.11^{AC}	58.68^{AC}	61.89^{Bd}	63.20^{Bc}

Means in the same rows followed by same small letters are not significantly different at p<0.05; means in the same column followed by same capital letters are not significantly different at p<0.05.

decomposing organic materials and mix them with soil so as to form soil aggregates, and restore land structure.

The improvement of soil's physical properties of the degraded land is sharply marked by the soil's total pore space. The absence of difference between soil's water capacity in Table 2 proves that the both agents are able to increase the number the pore spaces in degraded land as shown in Table 3. Also, soil permeability as shown in Table 4. Worms improves aeration system in earth due to the development of cavities and improvement of soil porosity following the restoration of land structure (Spurgeon et al., 2013). The movement of worms is very aggressive and random depending on temperature of its living environment and the need for food such as mulch. Owing to its aggressive movement, the soil became more porous. Once the soil temperatures increases, it moves

Table 4. Improvement of soil permeability of degraded paddy field upland by mulch and earth-worms.

Interaction	Permeability (cm/hour)			
	W_0	**W_1**	**W_2**	**W_3**
M_0	1.12^{Aa}	1.15^{Aa}	1.51^{Aa}	1.65^{Aa}
M_1	2.18^{Aa}	2.82^{Aa}	3.35^{Aa}	3.87^{Ab}
M_2	4.92^{Ab}	7.59^{Bb}	10.80^{Cb}	13.39^{Dc}
M_3	15.28^{Ac}	18.10^{Bc}	20.05^{Bc}	29.34^{CD}

Means in the same rows followed by same small letters are not significantly different at p<0.05; means in the same column followed by same capital letters are not significantly different at p<0.05.

to underground places of better aeration to recover oxygen from free air for breathing through skin. Worms are fond of organic materials derived from dung and plant remains. That is why they are referred to as decomposing agent that are able to service the soil function and ecosystem (Blouin, 2013) due to its ability to change organic materials into compost (Muys and Granval, 1997).

Relationship between soil physical improvement to the paddy's tiller and yield

The influence of the improved soil's physical properties on the productive tillers is shown by the following regression-correlation equation:

$Y = 2.52 + 4.55_{BD} + 0.54_{TP} + 0.01_{PER} + 0.60_{WC}$ ($r = 0.73$ and $R^2 = 0.54$)

This statistics shows that the improved soil's physical properties have significantly influenced the tiller production in the degraded land. The 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 improvement of soil's physical properties by reclaiming the degraded land using bio-agents of banana leaf such as mulch and earth-worms leads to an increase of paddy yield as depicted by the following equation:

$Y = 27.79 + 1.20_{BD} + 0.20_{TP} - 0.04_{PER} + 0.03_{WC}$ ($r = 0.85$ and $R^2 = 0.72$)

Earth-worms make burrows or cavities in the earth by pushing earth masses or eating them (Abbot, 1989). The burrows or cavities developed are used not only to nullify earth pressure on its body during motion, but to store food and digest it as well (Edwards and Bater, 1992). Viert (1989) showed that burrow in soil of 0.80 cm in diameter developed by *Lumbricus* can join the A and subsoil horizons. Having been digested, foods are partly secreted as solid waste. Edwards and Bater (1992) showed that most of the minerals digested by *Lumbricus* are returned into the soil as useful waste with high nutrients. Production of solid waste depends much on species and monsoon. Healthy population of earth-worms can produce 100 tons/ha/year. Edwards and Bater (1992) cited that *Lumbricus* can perforate soil body vertically downward and upward as deep as one meter so as to allow water to permeate in greater volume, reduce the velocity of surface runoff and in turn prevent surface erosion. *Lumbricus* improves aeration system in earth due to the development of cavities and improvement of soil porosity following the restoration of land structure (Alaoui et al., 2011). Earth-worms can present a better aeration system for the growth of crops roots, particularly when soil moisture is high enough. Total earthworm density and biomass were strongly correlated with each other and positively associated with soil moisture (Crusmey et al., 2014). In the presence of high moisture, the absorption of nutrients by parts of the plants will run easily. The optimal moisture for *Lumbricus* to grow well is 15 to 30%. Earth-worms will die when exposed directly to sun light or living in a hot environment (Mele and Carter, 1999). When its living environment gets hot, it always moves to moister environment in order to survive. Sawdust is so far of great use to maintain the optimal moisture of the soil, intensify the action of earth-worms in improving physical properties of the soil, restore the fertility of soil and maintain the presence of the groundwater (Beven and Germann, 2013). Sawdust can be served as well as food resource for earth-worms.

Lee (1985) showed that *Lumbricus* has an ability of perforating the soil body to a depth of 1 m to make water permeate easily in greater volume, reduce the velocity of surface runoff, lessen the possibility of land erosion and increase underground water content. The sowing of 0.5 g of live *L. terrestis* and *L. rubellus* on 1 kg soil significantly increase 25% dry weight of crops and harvest.

Conclusion

Banana leaf mulching and earth-worms restore the degraded land by improving some of its physical properties such as bulk density, total porosity, permeability and water capacity. The improvement of soil's physical properties by the two bio-agents has significantly improved both tiller and yield of the degraded paddy field.

Having healthy soil fauna populations is beneficial to the soil. Developing a restoration project requires analysis of the resource to determine the level of degradation and amounts of site preparation necessary for reclamation. The literature examined did not have extensive information on pre-degradation site conditions, including the species of invertebrates present and ground cover. Having this information could give planners an indication of abundance and diversity of species adjacent to the site. These species have the potential of dispersing the site.

Restoration projects require follow up evaluations to determine the success of colonization. Documentation of successes and failures can help future restoration projects succeed.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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