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Soil Amendments on Permanent Raised-Beds To Improve Aggregate Stability, Bed Stability, and Yield of Rice on Rainfed Vertisols in Central Lombok, Indonesia

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Abstract: *In Lombok, eastern Indonesia, vertisols is one of the potential soil types for production of food crops, especially rice, and off season cash crops on raised beds. However, it has some physical limitations, such as unstable soil structure which results in slumping beds. Previous research has proven that if vertisols could perform a permanent Raised Bed (PRB), then this PRB system was a favorable media for crop production, as well as the best technique in alleviating impact of water scarcity in the areas. This research aimed to examine potential use of soil amendments i.e. application of 20% sand mixed with cattle manure at various rates in improving bed stability and rice yield, by conducting a field experiment in 2012, arranged according to Randomized Complete Block Design with three replications. Results indicated that application of 20% sand along with 15 tons/ha manure could significantly reduce COLE value, increase soil organic C content, improve stability of the raised beds, and increase rice yield to 5.78 tons/ha compared with 4.01 tons/ha on the raised beds without soil amendment. The rate of 35 tons manure/ha was too high to gain 6.24 tons/ha of rice. It seems that lifting rates of cattle manure along with 20% sand did not significantly increase rice yield in the short term.*

Keywords: *Soil amendment, permanent raised bed, rice, rainfed vertisol, bed stability*

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I. Introduction

In Lombok vertisols is one of the potential soil types for growing agricultural crops, including rice, secondary food crops, and high economic valued horticultural crops (Ma'shum et al., 2005). The soil type spreads out on an area of semi arid tropic with the climate type of D3 and D4 (Oldeman, 1980). The main problems in this particular area is not only water scarsity (Mahrup et al., 2005), but also the swelling-shrinking properties of the soil with a very low soil C-organic content which results in slumping soil and unstable soil structure (Kusnarta et al., 2011). Success story of rice production on the vertisol areas was recorded in the 1980s due to the successful application of the "gogo-rancah" or "gora" technique of growing rice in dramatically increasing rice production in central Lombok (in "gora" technique, rice is dry direct-seeded then flooded at the end of vegetative stage during the rainy season) (Widyantoro et al., 2007). It was believed as an appropriate technique of growing rice in such an erratic climate region. However, this technique is no longer applied by farmers due to massive labors and some economic considerations. In 1990's, maximum tillage switched to a minimum tillage for "gogorancah". Rice response to minimum tillage on Vertisols was good, however weed problem had risen. Therefore, farmers were no longer afford to practice the minimum tillage.

There was a growing concern on the issues of climate change in early 2000. To respond the issues, a collaborative field research between the Australian Center for International Agriculture Research (ACIAR) and the University of Mataram in Lombok was established in 2001- 2003 to investigate crop production on permanent raised beds (PRB) on the Vertisols. Yield response of rice and secondary food crops was promising, where rice yield on raised beds with either no tillage or maximum tillage was not significantly different from that on an ordinary system of growing rice on flat land. Borrell et al. (1998), and Borrell and VanCooten (2000) reported that yield of rice grown under saturated soil conditions in semi-arid tropical regions was not significantly different from that of the flooded rice system. Permanent raised beds on the vertisols have many advantages over flat system in that particular agroecosystem in Lombok. Mahrup et al. (2005) also reported that the PRB could improve water use efficiency by 44 to 50% compared to an ordinary flooded system with maximum tillage and direct seeding or "gora" system. Ma'shum et al. (2005) also reported that rice yield under PRB was not significantly different from that of gora system. Potential benefit from PRB was crop diversification in rainy season because non rice crops can grow well on raised beds in rainy season. At this stage, however, the PRB on vertisols has performed unstable or slumping beds. Based on this slumping phenomenon, this research was focused to find a better solution to improve soil physical properties under PRB system by applying soil amendments. This study aimed to assess the rate of soil amendments (i.e. sand and cattle manure) to improve characteristics of vertisols under PRB technology, as well as to examine its effect on rice yield.

II. Materials And Methods

Site and Time

This research was conducted at a famer's field in Batujai village of Central Lombok, Indonesia, started in the rainy season in early February and finished in July 2012. The soil type is vertisols with 46% of clay content and 0.72% of soil organic carbon. The soil has a shrink-swell characteristic with a very high value of COLE (coefficient of linear extensibility), i.e. 0.12 (Kusnarta et al., 2011). Soil analysis were conducted at the soil physics Laboratory of the Faculty of Agriculture, University of Mataram.

Beds dimension

Beds have 1.2 m wide, 0.25 m high, and 10 m long. There were 3 beds in each plot, and between each two beds was seperated by furrow with the width of 0.3 m. The depth of the furrow was the same as the bed height of 0.25 m.

Experimental design and Treatments

Field experiment was arranged as a Randomized Complete Block Design with three replications. Data were analysed using analysis of variance (ANOVA) and Duncan's Multiple Range Test (DMRT) at 5% level of significance. There were 2 types of soil amendments applied i.e. sand at a rate of 20% of the top 20 cm of the soil, and catle manure at various rates depending on the treatments. Sand was obtained from the Jangkok river in Lombok, while cattle manure, with a C/N ratio of 19, was collected from cowshed cage close to the experiment site. The treatments were as follows:

P0 = without soil amendment
Ps = addition of 20% by weight of sand
Ps+Pk15 = addition of 20% by weight of sand and 15 ton/ha manure
Ps+Pk25 = addition of 20% by weight of sand and 25 ton/ha manure
Ps+Pk35 = addition of 20% by weight of sand and 35 ton/ha manure
Ps+Pk45 = addition of 20% by weight of sand and 45 ton/ha manure
Each treatments was replicated 3 times, therefore there were a total of 54 raised beds.

The variables observed were aggregate stability, COLE value, bed stability and crop yield components, including straw dry weight, number of tillers, and grain yield. Stability of soil aggregate was determined using wet and dry sieving method introdused by De Leenheer and De Boodt (1959). The value of COLE was determined by measuring length differences between wet and dry conditions of a cylindrical shape of 6 to 10 cm soil peds (aggregates) as what was recommended by Schafer and Singer (1976) in Vaught et al. (2006). Bed stability was determined by measuring dimension of the bed i.e. its width and height differences between before and after experiment (Dulur et al., 2011).Oven dry weight of shoot (SDW) was measured by weighing above ground rice plants at flowering stage after drying at 70^{o}C until it got constant weight. Crop samples determined puposively at 10% population of 1 m^2 quadrant. Number of tillers was counted per clump at flowering stage using the same samples as for SDW. Yield of rice was converted from weight of rice seeds, callected from 1 m^2 of quadrant, with 14% moisture content.

III. Results And Discussions

Soil aggregate stability

Aggregate stability of Vertisols was significantly affected by amendment of the soil with sand and combination of sand and manure (Figure 1). Sand application at a rate of 20% by weight was able to increase the aggregate stability of Vertisols by 19% (from 37.14% to 44.36%). Furthermore, combination of sand (20%) and manure at rate of 15 (Ps + Pk15), 25 (Ps + pk25), and 35 ton/ha (Ps + pk35) respectively showed no different from the treatment with 20% of sand only (Ps). Effect of mixture of sand and manure was significant at manure rate of 45 tons/ha (Ps+Pk45).

An efficient way to improve aggregate stability of rainfed Vertisols in Lombok was an application of sand at a rate of 20% plus manure at a rate of 15 tons/ha. Application of 35 ton/ha of manure showed no difference from that of application of 20% sand alone. Although, the treatment of 20% sand and 45 tons/ha manure (Ps + Pk45) resulted in the highest soil aggregate stability, this treatment was considered to be inefficient. There was no difference between treatments of manure at rate less than 45 tons/ha. It is allegedly caused by a relative long path of organic matter decomposition process, and rapid decomposition of organic matter can occur on permanent raised beds (PRB) where soil is under aerobic condition during a period of crop growth. An aerobic soil condition can acelerate the process of decomposition of organic matter (Delanue et al., 1981), so that the role of organic matter as an agent of aggregation is time dependence (Wuddivira and Camps-Roach, 2007).

Improvement of the aggregate stability was not only due to the effect of organic matter (manure) alone, but combination of both sand and manure. Sand can significantly reduce the value of COLE of Vertisols (Dulur et al., 2011) by reducing proportion of clay minerals, e.g. montmorillonite that causes swelling and shrinking properties of the Vertisols.

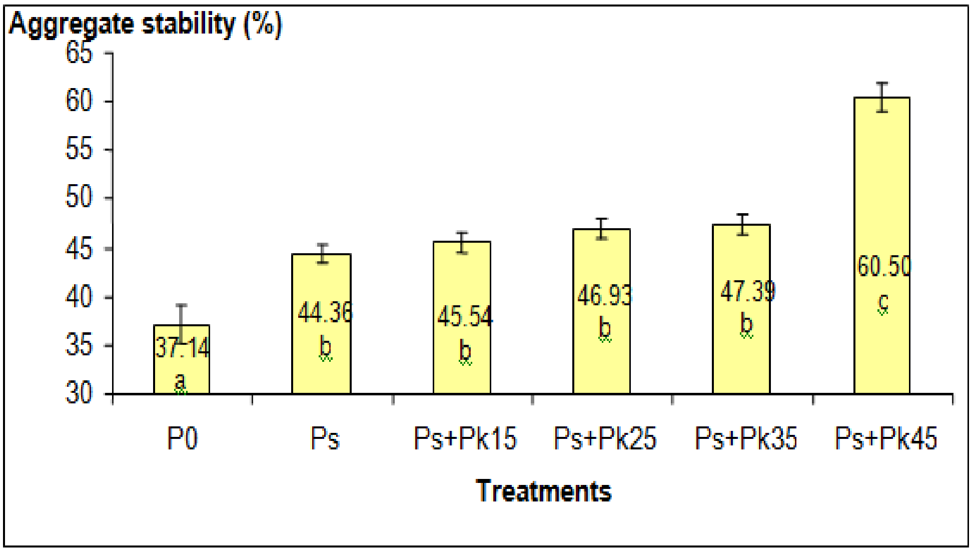

Figure 1: Soil aggregate stability of Vertisols under various tretaments.

COLE value of Vertisols

Application of 20% sand and sand mixed with a various rate of manure had a significant effect on reduction of shrink-swell characteristic of vertisols. Sand at rate of 20% (Ps) substantially reduced the COLE value about 29%, from 0.14 to 0.10 (Figure 3). According to the USDA-NRCS (2006) in Vaught et al. (2006), COLE value of >0.09 is categorized as high capacity of srinking and swelling soils. In addition, combination of sand and manure resulted in higher reduction of COLE value compared to without soil amendment (P0).

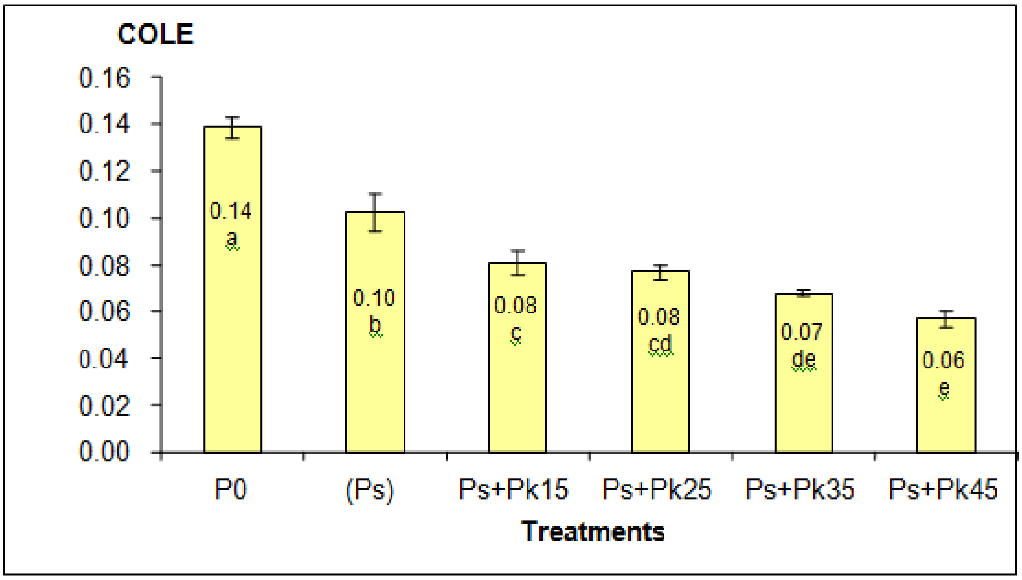

Figure 2: COLE value of vertisols under various treatments with soil ammandements

Swell-shrink property of Vertisols is a critical process called pedoturbation, where some materials at an upper layer (organic matter, water and others) can move down into deeper soil layers, through cracking that occurred during dry season (Dinka et al., 2013). Thus, swelling and shrinking property of Vertisols should not be totally eliminated, but it should be controlled to an allowable level. Simon et al. (1987) in Vaught et al. (2006) reported that reduction in COLE of up to ≤ 0.07 can be categorized as a safe level. Under this condition it can improve the vertisols stability as well as reduce the adverse effects on root growth.

Stability of beds

Bed stability can be represented by its changes on height and width after draining. It can be seen from Table 1 that application of sand (Ps) as well as sand and manure (Ps + Pk) improved bed stability. Sand at a rate of 20% (Ps) kept bed height of 23.33 cm, while at 0% the bed height was 19.08 cm (control). Furthermore, sand and its combination with cattle manure at all rates shows a significant firm bed shape with small reduction on bed height and width compared to that of control (P0). There was no difference in bed stability found among the manure applications. Thus, for economic reason, raised beds can be stabilized by application of 20% sand and 15 tons/ha manure.

Table 1. Beds width and heigth reduction under various treatments

Treatments	Bed width change (cm)		Bed height change (cm)	
T0= no soil amendment	23.33	a *)	13.67	a *)
T1= Sand only (20%)	19.08	b	11.23	b
T2= Sand+manure 15 t/ha	15.80	c	9.90	bc
T3= Sand+manure 25 t/ha	15.42	c	9.43	c
T4= Sand+manure 35 t/ha	15.27	c	9.39	c
T5= Sand+manure 45 t/ha	15.08	c	8.29	c

*) Figures in each column followed by the same letters are not significantly different based on DMRT at 5% level of significance.

Shoot dry weight at flowering stage and yield components of rice

Shoot dry weight (SDW) of rice plants indicates the amount of accumulated photosyntate produced in plant physiological processes. The higher the dry weight, the higher crop yield is expected. Application of 20% sand and its combination with manure at various rates gave higher dry weights compared to control (Table 2). Persistence of raised bed shape under sand treatment seemed to increase the straw dry weight by 43%, from 41.6 g/clump in control treatment (P0) to 59.4 g/clump. If sand was combined with manure, it gave greater improvement, and resulted in the highest straw dry weight at 20% sand plus manure of 35 tons/ha (Ps + Pk35) with dry weight of 89.3 g/clump. Further increment of manure up to 45 tons/ha (Ps + Pk45), shoot dry weight decreased to 75.1 g/clump. Thus, the output of this research can be considered as a guideline for application of sand and manure as a management measure of vertisols under PRB system.

Number of tillers per clump was not significantly affected by proposed treatments. Number of tillers in this experiment ranged from 14.6 to 17.2 tillers per clump. Apparently, this parameter probably influenced by other factors. e.g. nutrient availability, instead of physical factors. Rice yield under non slumping beds (PRB system) was higher than slumping beds (or unstable bed). Sand seems to play a significant role as a physical buffer of soils (Dafalla, 2013). Sand and manure (Ps + Pk) play role as a main agent of soil aggregation. Mixing sand and manure seems to be the best combination in term of soil physical improvement of vertisols. Under permanent beds a root zone is maintained at constant depth within a growing period. In contrast, on slumping bed, depth of root zone decreases and top soil is eroded along with a slow soluble fertilizer in the soil, e.g. phosphate. Application of 20% sand increased rice yield from 4.01 tons/ha to 5.72 tons/ha (Table 2). There was a tendency that the higher the rate of manure added together with 20% sand the higher the yield of rice. The recommended combination was 20% sand and 35 tons/ha manure. At the rate of 45 tons manure per ha, yield declined.

Table 2.Plant dry weight (DW) at flowering, tiller number, and dry grain yield of rice under various treatments of soil amendments

Treatments	Plant DW at flowering (g/clump)		Tiller number per clump		Rice grain yield (ton/ha)	
T0= no soil amendment	41.6	e*)	14.6	a*)	4.01	a*)
T1= Sand only (20%)	59.4	d	15.4	a	5.72	b
T2= Sand+manure 15 t/ha	72.9	c	16.4	a	5.78	b
T3= Sand+manure 25 t/ha	80.9	b	16.0	a	6.05	b
T4= Sand+manure 35 t/ha	89.3	a	17.2	a	6.24	b
T5= Sand+manure 45 t/ha	75.1	bc	15.6	a	5.62	b

*) Figures in each column followed by the same letters are not significantly different based on DMRT at 5% level of significance.

IV. Conclusion

Based on the results and discussion above, it can be concluded that:

1. Sole application of sand at a rate of 20% by weight on vertisols was able to increase aggregate stability by 19%, while its combination with manure at a rate of 45 tons/ha significantly increased aggregate stability by 60.5%.
2. The treatment with 20% sand improved bed stability, which was indicated by small reduction in bed dimension; width by 18.22% and height by 17.85%. Combination of 20% sand and 15 tons/ha of manure resulted in reduction of bed width by 15.80 cm and bed height by 9.9 cm.
3. Application of 20% sand could significantly increase rice yield to 5.72 tons /ha, while on control it was only 4.01 tons/ha. A potentially high yield of 6.24 t/ha was achieved on combination of 35 tons/ha manure and 20% sand.

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