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Increasing Physical Soil Quality by Using Rice Straw Biomass

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ABSTRACT

Paddy straw as an agricultural waste can be returned to the soil to increase the organic matter content. This study aims to determine the optimum inoculant treatment of rice paddy straw on soil quality. The straw handling was carried out by spreading the straw on paddy fields and sprayed with four inoculant treatments (0, 3, 6, 9, and 12 L/ha). The incubation process was carried out for 21 days and incorporated in the soil through plowing. Each treatment was repeated three times so that the total treatment was 15 units. The variables observed in each treatment were soil quality. The soil quality parameters observed were particle density, bulk density, porosity, field capacity and pH. ANOVA statistical analysis which was continued by the Tukey HSD Post Hoc Test to determine the effect of treatment on soil quality. The results showed that the inoculant treatments showed a significant difference (p-value=0.05) in soil volume, density, and porosity. P4 gave the optimum results which are statistically not significantly different from P3. P4 shows the physical properties of the soil which consist of the soil bulk density of 0.61 g/cm^3; particle density 1.74 g/cm^3; porosity was 64.91%, and pH 6.68. The utilization of straw biomass as source of organic material contributes to zero waste rice cultivation.

1. INTRODUCTION

The continuous application of chemical fertilizers on land used for crop cultivation can cause changes in soil acidity, alter soil structure, and kill microorganisms that play a role in soil decomposition, potentially altering the paddy field ecosystem. Based on these issues, it is necessary to apply efficient and environmentally friendly technology. LEISA (Low External Input for Sustainable Agriculture) emphasizes the management of organic materials to improve the quality of the soil ecosystem. The application of organic fertilizers can improve the physical properties of the soil in potato cultivation (Setiyo *et al*., 2017) and increase farmers' income through the integration of rice, catfish, and laying duck farming (Mustikarini & Santi, 2020).

To maintain agricultural sustainability, dependence on external inputs such as pesticides and chemical fertilizers must be limited (Omwenga *et al*., 2014; Sanjaya *et al*., 2014; Pita *et al*., 2016) . The implementation of LEISA is based on concerns about the sustainability of environmental carrying capacity, the limited resources of farmers, and the various benefits of utilizing local resources to increase agricultural productivity (Mustikarini & Santi, 2020). LEISA uses ecological principles to maintain agricultural sustainability. The basic ecological principles of LEISA are: (1) ensuring soil conditions that support plant growth, particularly in the management of organic materials and the utilization of soil microorganisms, (2) optimizing the availability, balance, and recycling of nutrients while minimizing external inputs as supplements, (3) managing the flow of solar radiation, water, and air related to microclimate, water, and erosion management, (4) minimizing losses due to pests and plant diseases through safe protection systems, and (5) utilizing the integration and synergy of genetic resources, including the development of integrated farming systems with high functional diversity to achieve synergistic plant interactions (Asandhi *et al*., 2005). The realization of the first ecological principle by several studies has been achieved through the provision of organic materials as agricultural inputs (Setiawati *et al*., 2019; Setiyo *et al*., 2017; Liebman, & Davis, 2000; Tripp, 2005; 2006; Gbenou *et al*., 2016). LEISA cannot solve all agricultural and environmental problems, but it can significantly contribute to addressing these issues.

Soil quality is defined as the ability of a land unit (soil) to provide functions required by humans or natural ecosystems over a long period (Cahyadewi *et al*., 2016). High-quality soil helps forests or agricultural lands remain healthy, produce good crops, and maintain attractive landscapes (Plaster, 2003). Soil quality is a combination of physical, chemical, and biological soil properties. Soil quality assessment focuses more on physical and chemical properties because simple methods to measure these parameters are relatively available and ideally, changes in these indicators can be detected in a short time (Seybold *et al*., 2018).

Straw is a biomass residue from rice harvests with a large potential. Preliminary research at the study site showed that straw potential reaches 17.5 tons per hectare. The application of straw compost can improve soil quality during the vegetative phase (from weeks 0 to 6 after planting) (Anwar *et al*., 2006). However, farmers generally do not use straw as compost material due to difficulties in handling straw into compost. Therefore, alternative handling methods are needed to return straw biomass to the land as a source of organic material for the soil.

Straw is a biomass with a high lignin content, requiring a considerable amount of time for decomposition. Inoculants can be used in the composting process to accelerate the decomposition rate (Manuputty, 2012). The optimal dosage of inoculants required for straw decomposition is still unknown. This study aims to determine the optimal inoculant treatment for using straw to improve soil quality.

2. MATERIALS AND METHODS

The research was conducted in Subak Sigaran, Jegu Village, Penebel District, Tabanan Regency, Bali. The equipment used included a ring soil sample, measuring tape, hoe, fork, bucket, sprayer, wheelbarrow, plow, and other cultivation tools. Equipment for the analysis stage included an oven, pH meter, crucibles, and a digital scale. The materials used included agricultural waste in the form of straw, inoculants, and water.

This study used effective microorganisms called EM4 inoculant applied in the following 5 treatments, namely P0: control (without inoculant), P1: spraying EM4 3 L/ha, P2: spraying EM4 6 L/ha, P3: spraying EM4 9 L/ha, P4: spraying EM4 12 L/ha. Each treatment was repeated 3 times, resulting in 15 experimental units. The research stages included the preparation of tools and materials to handle straw waste.

2.1. Straw Spreading

The rice harvest residual straw, with a potential of 17.5 tons per hectare at a moisture content of 70%, was uniformly spread back on the experimental plots, each measuring 2 ares (200 m²). Thus, 350 kg of straw was spread on each experimental plot unit. Spreading was done manually from 08:00 to 10:00 WITA.

2.2. Inoculant Spraying

The EM4 inoculant was diluted before spraying. For every 10 ml of EM4, 1 liter of water was mixed. Inoculant spraying according to the treatment was carried out after the straw was evenly spread on each experimental plot unit. Spraying was done using a sprayer directly above the straw to minimize evaporation. After inoculant spraying, the straw waste was incubated for 21 days. Land preparation for rice planting was carried out after the incubation period. Irrigation was provided as needed for land preparation.

2.3. Soil Sample Collection

Sampling points were randomly selected and not adjacent to each other. Three samples were taken from each experimental unit, resulting in a total of 45 samples for analysis.

2.4. Soil Characteristic Testing

The parameters observed in this study included soil bulk density or soil volumetric weight, specific gravity, soil porosity, field capacity, and soil pH.

2.4.1. Volumetric Weight or Soil Bulk Density (BV)

The soil was removed from the soil sample ring until clean and placed in a tray, and the soil sample ring was cleaned from the remaining soil. The soil sample was dried in an oven at a temperature of 105 °C for 24 h and its dry weight was recorded as Ms. The height (p) and inner diameter of the soil sample ring (d) were measured to obtain the total soil volume (Vt). The soil bulk density (BV) was calculated using the following equation:

$$BV = \frac{Ms}{Vt} \tag{1}$$

2.4.2. Soil Specific Gravity

The clean and dry pycnometer was weighed with its lid (W_1). The pycnometer was filled with distilled water of known temperature, then weighed together with its lid (W_4). If the water temperature in the pycnometer is not 25 °C, then a correction (k) was made from the weight of the pycnometer and the water used, so that $W_4 = k \times W_{25}$. Absolutely dry soil samples were inserted into the pycnometer and then the weight of the pycnometer + soil sample was weighed (W_2). Furthermore, the pycnometer was filled with distilled water up to 2/3 and the pycnometer containing the soil sample and water was heated to boiling for about 10 minutes to remove air from the soil pores. Furthermore, the pycnometer containing water and soil was cooled to room temperature. After cooling, distilled water was added until full and the lid is installed and then weighed (W_3). Soil specific gravity was calculated using the following equation:

$$BJ = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)} \tag{2}$$

2.4.3. Soil Porosity (N)

Soil porosity (N) was calculated according to the following equation:

$$N = \left(1 - \left(\frac{BV}{BJ}\right)\right) \times 100\% \tag{3}$$

2.4.4. Field Capacity

Determination of water content at a field capacity condition was done by giving water to the soil in the soil sample ring little by little until it reached field capacity (± 20 min), then draining it for ± 5 min until it stops dripping and weighing it (M_{kl}). After that, the soil sample was dried in an oven at a temperature of 105 °C for 24 h. The dry soil sample was then weighed and its dry weight (M_s) was recorded. The ring soil sample was weighed as M_r. The water content at field capacity (KA_{kl}) of the soil was calculated using the following formula:

$$KA_{kl} = \frac{[(Mkl - Mr) - (Ms - Mr)]}{(Mkl - Mr)}\ x100\ \% \tag{4}$$

2.4.5. Soil pH

As much as 10.00 g of soil sample was weighed twice, each was put into a shaker bottle, then 50 ml of distilled water was added to one bottle (pH H_2O) and 50 ml of 1 M KCl to the other bottle (pH KCl). Shake with a shaker for 30 min. The soil suspension was measured with a pH meter that has been calibrated using pH 7.0 and pH 4.0 buffer solutions. The pH value was recorded with one decimal place. This procedure used a ratio of 1:5.

2.5. Data Analysis

Data analysis was conducted using One Way ANOVA followed by Tukey HSD Post Hoc Test with Rstudio Software.

3. RESULTS AND DISCUSSION

3.1. Soil Bulk Density (BV)

ANOVA analysis results showed significant differences in average bulk density among the five treatments (p-value = 0.05). Post Hoc Tukey Test results indicated that EM4 inoculant spraying significantly differed from the control (P0). P1 and P2 significantly differed from P4, as shown by different notation letters, while P3 and P4 did not significantly differ. Figure 1 demonstrates that the application of 9 and 12 L/ha inoculant dose was most effective in reducing soil bulk density compared to other treatments. This is due to the faster decomposition process of organic matter from the straw with higher inoculant doses. Buckman & Harry (1982) also suggested that soil loosening and the addition of soil amendments (such as organic materials) and organic fertilizers (manure and/or compost) could reduce soil bulk density. Low bulk density indicates low soil compaction (loose soil). P3 and P4 were looser than P0, P1, and P2. Loose soil has a low unit volume weight, and its mass density is determined by the solid soil particle grains (Buckman & Harry, 1982). Soil with high total pore space, like clay, tends to have low bulk density (Bintoro *et al*., 2017).

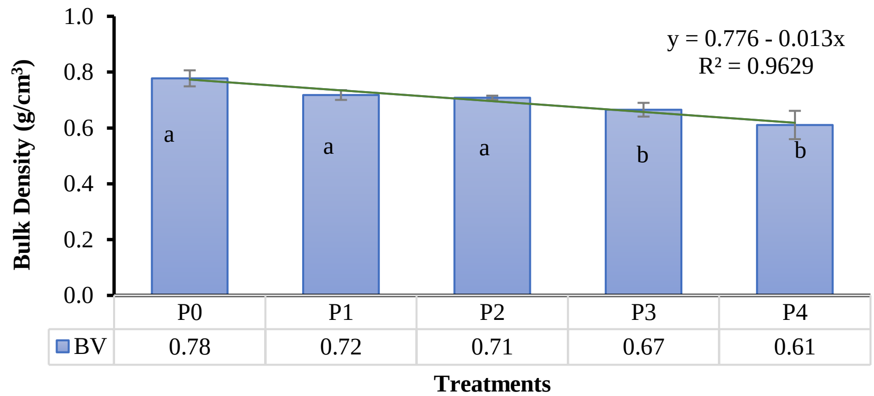

Figure 1. Effect of treatment on soil bulk density. (Note: error bars are standard deviation of 3 measurements)

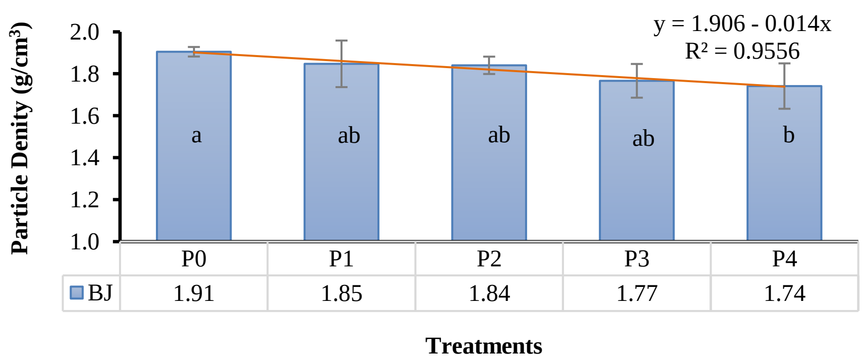

Figure 2. Effect of treatment on soil specific gravity. (Note: error bars are standard deviation of 3 measurements)

3.2. Soil Specific Gravity (BJ)

ANOVA analysis results showed significant differences in average specific gravity among the five treatments (p-value = 0.05). Post Hoc Tukey Test showed that P0 and P4 had significant differences in specific gravity compared to P1, P2, and P3, indicated by different notation letters. Figure 2 shows that P4 had the lowest specific gravity compared to other treatments. Although other treatments had lower specific gravity values than P0, these differences were not statistically significant with a 95% confidence interval. Higher inoculant doses applied to straw spread on the field resulted in decreased soil specific gravity due to faster organic matter decomposition from the straw. Clay soil, rich in minerals, stores nutrients beneficial for plants and the environment. According to Pairunan *et al*. (1985), smaller pore sizes mean more and wider surface area per unit weight of soil. Soil cultivation activities using organic fertilizers in paddy fields increase solid soil density, approaching the density of quartz at 2.6 g/cm³, with high soil mineral and silicate mineral content (Hillel, 1980).

3.3. Soil Porosity

ANOVA analysis results showed significant differences in average porosity among the five treatments (p-value = 0.05). Post Hoc Tukey Test results indicated that the application of a 12 L/ha inoculant (P4) significantly increased soil porosity by 5.74% (compared to P0). P4 had the highest porosity among all treatments. P4 did not significantly differ from P2 and P3, as shown by the same notation letters. Figure 3 demonstrates that higher inoculant doses applied to straw spread on the field increased soil porosity. This is due to the faster decomposition process of organic matter from the straw. Hardjowigeno (1986) also stated that clay-textured soil predominantly contains micro pores, making it easy to retain and bind water. Porous soil has adequate free pore space for water and air movement in and out of the soil. Increased porosity indicates a higher clay content, resulting in finer soil texture. Compared to sandy and fine-grained soil, fine-grained soil is better at preventing large-scale runoff to reduce erosion (Rahim, 2000). Good management systems yield good soil porosity, while poorly managed soil will have worsened porosity, leading to soil compaction and disrupted soil aeration.

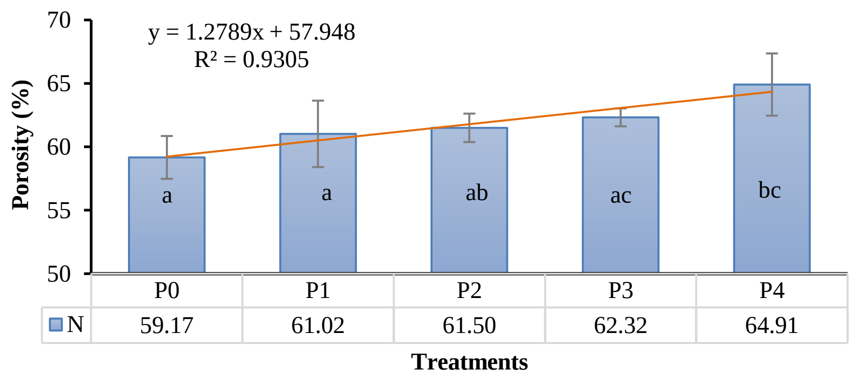

Figure 3. Effect of treatment on soil porosity. (Note: error bars are standard deviation of 3 measurements)

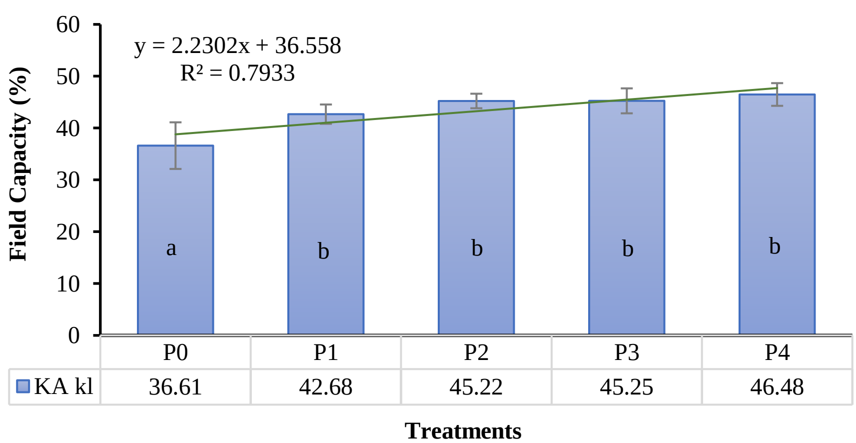

Figure 4. Effect of treatment on soil field capacity. (Note: error bars are standard deviation of 3 measurements)

3.4. Field Capacity

ANOVA analysis results showed significant differences in average field capacity among the five treatments (p-value = 0.05). Post Hoc Tukey Test results indicated that the use of inoculants significantly affected soil field capacity. However, the addition of inoculants (P1, P2, P3, and P4) did not significantly differ in their effect on soil field capacity. Figure 4 shows that the addition of inoculants increased soil field capacity values, but the dosage did not significantly affect the results. The highest field capacity value was obtained from P4. The more organic matter in the soil, the less water available, and the larger the pore size, the easier it is to decompose (Tamara *et al*., 2020).

3.5. Soil pH

ANOVA analysis results showed that the five treatments did not cause significant differences in pH (p-value = 0.05). Generally, paddy soil tends to be near neutral pH. The data from the study indicated that the soil pH in all treatments was close to neutral as shown in Figure 5. The control treatment had a slightly lower pH compared to the other treatments. Soil pH not only indicates the acidity or alkalinity of the soil but is also related to other soil chemical properties, such as the availability of phosphorus nutrients, base cations, and others (Hanudin, 2000).

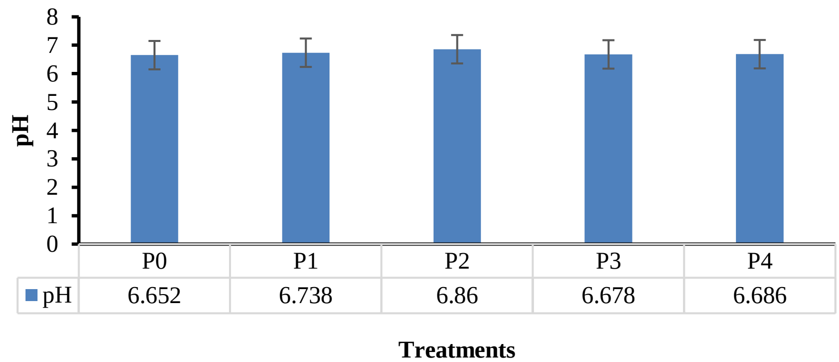

Figure 5. Effect of treatment on soil pH. (Note: error bars are standard deviation of 3 measurements)

4. CONCLUSION

Based on the statistical analysis, the treatment of inoculants on straw spread on the field showed significant differences (p-value = 0.05) in soil bulk density, specific gravity, and porosity. Treatment P4 provided optimal results, which were not statistically significantly different from P3. Treatment P4 exhibited the following soil physical properties: bulk density of 0.61 g/cm³, specific gravity of 1.74 g/cm³, soil porosity of 64.91%, and pH of 6.68.

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