**TITLE**

The Ameliorant Application in the Form of Rice Biomass and Rice Hull Ash Improved Nutrient Uptake and Soybean Yield in Tidal Swamps Under Saturated Soil Culture

**ABSTRACT**

Saturated soil culture (SSC) is a promising technology to cultivate soybean in the acid soil tidal swamp soil restrictions. However, improvement of this technology was obligatory. This study aimed to evaluate the effect of ameliorant addition in the form of rice biomass and rice hull on soybean production. The second purpose was to assay nutrient uptake to the plant and soybean growth under a saturated soil culture technique. The experiment was arranged in a split plot factorial design with two factors, i.e., rice biomass and rice hull ash. Four levels in the main factor were: without biomass immersion (T0), one immersion of short (3 cm above the root) rice stubble (T1), one immersion of usual (panicle harvested only) rice straw (T2), and two immersions of regular rice straw cut to the soil (T3). The four levels in the subfactor were 0 t ha-1 (A0), 0.25 t ha-1 (A1), 0.50 t ha-1 (A2), and 0.75 t ha-1 (A3) of rice hull ash dosage. The results showed that the ameliorant in the form of rice biomass and rice hull ash improved the soil chemical characteristics, i.e., the increase in pH to be neutral and more suitable for plant growth due to the high nutrient availability for soybean. There was a significant correlation between nutrient uptake (nitrogen, phosphorus, potassium and calcium) and soybean production. The results of the experiment showed no interaction between rice biomass application and rice hull ash addition on the yield. The best treatment on the first factor was one immersion of biomass with a usual cut of rice straw (T2) and 0.5 t ha-1 ash rice hull ash addition to the tidal swamp soil.

**KEYWORDS**

nitrogen; phosphorus; potassium; rice stubble; soybean production

**INTRODUCTION**

Soybean (*Glycine max* (L.) Merr) is one of the staple food crops in Indonesia in addition to rice and corn (BPS, 2018). Soybean has a unique chemical composition, and it is one of the most valuable sources of plant foods that provide 60% world vegetable protein that considered good as subtituent animal protein (Wijewardana et al., 2019). Isoflavone content in soybean has various benefits for humans because it is an anticancer compound, prevent degenerative diseases, such as coronary heart disease and hypertension (M. Akram, 2011; Muchlish Adie & Krisnawati, 2014). In Indonesia, the level of soybean consumption reached 2.2 million tons, and 53.32% of it was fulfilled by import (Surahman et al., 2018). The extensification program by tidal swamp utilization is beneficial to increasing soybean production (Firdaus, 2015; Toyip et al., 2019).

Cultivation problems in tidal swamp areas are related to the quality of the soil. The characteristics of soil on tidal swamps are high acidity, high aluminum content, and pyrite concentration (Fanning et al., 2017). Additionally, the low availability of essential nutrients thus becomes a limiting factor for soybean plant growth (Mukhlis et al., 2021). Saturated soil culture (SSC) has proven to become a new technology to maintain soil restriction for plant growth in tidal swamp areas. This technology concept was to maintain soil quality through water level regulation several centimeters below ground level. Sufficient nutrient availability is essential for soybean growth and production (Calabi-Floody et al., 2018).

Ameliorants could increase the availability of nutrients in the soil to maintain the sustainability of crop production in the tidal swamp area (Xiu et al., 2019). Ameliorant utilization increases soil pH and nutrients availability in tidal swamp land (Maftu’Ah et al., 2021). Biomass from agricultural waste products is utilizable as an ameliorant directly or through advanced processing (Bhowmick et al., 2018). Various studies using ameliorants, mainly rice hull ash or combined with other forms, have been carried out and have been proven to increase the productivity of food crops in acid soil tidal swamp, including soybeans (Sagala et al., 2021), maize (Ghulamahdi et al., 2023), and paddy (Saputra & Sari, 2021; Yartiwi et al., 2023). This research aimed to obtain technology for biomass utilization and obtain optimum rates of rice hull ash as an ameliorant to improve soil quality in tidal swamps, especially in increasing nutrient content and soybean crop production.

**MATERIALS AND METHODS** (Times New Roman 12)

The experiment was conducted in Simpang Village -1.270796S, 104.113425E, Berbak District, Tanjung Jabung East Regency, Jambi Province, Indonesia, from May to November 2018. Nitrogen, phosphorus, potassium, and calcium in plant tissue were analyzed in the Post Harvest Laboratory, Faculty of Agriculture, IPB University. Soil chemical and physical properties from the site were examined in the Soil Laboratory, Soil Research Institute, Ministry of Agriculture, Republic of Indonesia.

The plant materials in this experiment were soybean seeds, namely, Grobogan (large seed variety), Anjasmoro, Tanggamus, and Malika. Ameliorant treatments were rice hull ash and rice biomass, N fertilizer, inoculant *Rhizobium sp*. were also supporting materials. This experiment was arranged in a split plot factorial design with three replications. The main factor was the rice biomass application, which consisted of four levels: T0=without biomass application, T1=one immersion of short rice stubble (3 cm cut above the root), T2=one immersion of usual cut rice straw, and T3=two immersion of ordinary rice straw to the soil. The short rice stubble was prepared by harvesting rice straw and left 3 cm above the ground. The regular cut rice straw was composed of the usual harvest that only cut away the rice panicle. The subfactor was the rice hull ash dosage, which also consisted of four levels; A0=0, 0.25, A1=0.50, and A3=0.75 t ha-1. Each combination treatment was repeated four times, so there were 64 experimental units. The main plot was biomass application, while the subplot was rice hull ash.

Land preparation was carried out after the rice harvesting season so that rice stubble remained. The rice biomass was immersed entirely in the soil layer in all treatments except the control (T0). The rice straw was directly mixed in the soil (one way) using a hand tractor and then submerged for ten days. The inundation water was then reduced to make the soil muddy. The trench in the SSC treatment was digged by using *singkal* funnel maker (SPS BJA IPB). Treatment in the second immersion was two immersion periods, followed by two inundations before digging the SSC trench. The rice stubble was cleared in the control treatment before the land was submerged for ten days and then equipped with an SSC trench. All plots were treated with 1 t ha-1 agricultural lime (CaCO3 + MgCO3 80%), 27 kg ha-1 phosphorus fertilizer, and 40 kg ha-1 potassium fertilizer before incubation for five days.

The rice hull for the ash form was collected from rice milling shelters. Rice hull was then burned on the open area, followed by air cooling, and then incubated for one week. The rice hull ash resulting from the rice hull was 17.26% w/w. The application of ash was as a seed cover on the planting hole. The experimental plot was made with a size of 2 m x 5 m x 0.25 m. The distance between plots and between replications was made as wide as 30 cm and 50 cm, respectively. The plant spacing was 40 cm x 12.5 cm with two seeds for each planting hole so that in total, there were 400 000 plants per ha. The planting furrow was made by using a hand tractor. Before planting, the seeds were mixed with *Rhizobium sp*. inoculant as much as 5 g per kg of seed and *carbosulfan* 25.53% with a 20 g kg-1 seed concentration. Replanting was performed one week after planting. Nitrogen fertilizer was sprayed at 2, 3, and 4 weeks after planting with a 4.6 g l-1 water concentration. Pests and diseases were prevented by spraying an insecticide *(cypermethrin)* at a dose of 0.5 l ha-1. Weed control was carried out manually at 3 and 6 weeks after planting. The variables observed were the number of pods (pods per plant), grain weight on square 2.5 m-2 (g), production per ha and nutrient uptake level (nitrogen, phosphorus, potassium, calcium) of the soybean crop.

Statistical Analysis Software (SAS) version 9.4. was used for the analysis of variance (ANOVA). The Duncan Multiple Range Test (DMRT) evaluated any significant differences between treatments at a level of confidence of 5%.

**RESULTS AND DISCUSSION** (Times New Roman 12)

*Ameliorant effect on tidal swamp soil physical and chemical characteristics*

The chemical analysis of rice biomass showed that the ash, silicate, nitrogen, phosphorus, potassium, and calcium contents were 12.08%, 7.92%, 1.3%, 0.09%, 0.52%, and 0.19%, respectively. Rice hull ash contains 1.25% humic acid. Applying biomass and rice hull ash increased the physical and chemical quality in the tidal swamp soil.

The soil texture was altered after the application of rice biomass and rice hull ash. The effect of the ameliorant was also indicated by the increase in pH, N, P, K, S, cations, cation exchange capacity (CEC), humic acid, and base saturation of the tidal swamp (Table 1). This positive effect improved the suitability of soil conditions for soybean plant growth. In addition, the application of biomass and rice hull ash could also reduce the content of toxic compounds (Table 1). This finding was in agreement with previous studies reporting that the use of ameliorants reduced the toxicity of Fe and Al ions, increased the soil CEC, increased the availability of C-organic and several nutrients, such as phosphorus, potassium, calcium, and silicate (Contin et al., 2007; Mini & Lekshmi, 2018), increased the pH through the release of anion OH- (Saputra & Sari, 2021), improved soil structure by increasing soil aeration and porosity, improved soil microbial activity and reduced the need for potassium fertilizer since it can be an alternative source of potassium (Luo et al., 2018).

*Ameliorants affect soybean nutrient uptake*

There was an improvement in soil pH in all treated plots compared to its initial condition. The actual pH (pH H2O) before biomass immersion was very acidic (pH 3.9), while the soil pH in ameliorant application treatments in the form of one immersion of short rice stubble, one immersion of usual cut rice straw and two immersions of ordinary cut straw could enhance the pH to 4.2 (light acidic), 6.2 (neutral), and 5.7 (very light acidic), respectively. The increase in soil pH was more suitable for plant growth due to the high nutrient availability for soybean. The nitrogen content of the soybean crop varied every week of observation. There was an improvement in nitrogen uptake over time. The nitrogen content in all treatments at 8 WAP (weeks after planting) was the highest compared to that in the treatment at 6 WAP and 4 WAP, while the nitrogen content at 4 WAP showed the opposite trend (Figure 1). In general, the treatment of two immersions of usual cut rice straw combined with 0.5 t ha-1 rice hull ash showed the best phosphorus, potassium and calcium absorption compared with the other treatments (Figure 2-4).

The greater nutrient uptake as an effect of ameliorant addition that was proven in this study was supported by the results of previous studies. Pane et al., (2014) showed that rice hull ash and rice straw compost usage in the soil could increase nitrogen and phosphorus uptake in the maize plant. Application of rice hull ash could increase the uptake of phosphorus in rice plant. Rice hull ash contains high levels of silicon, which can improve the availability of P in the soil for plant uptake (Thind et al., 2017). The increase in nutrient availability in soil was the reason behind the rise in plant nutrient uptake or even nutrient status in plant tissue. This argument was supported by Mini & Lekshmi (2018), who applied rice hull to increase soil nitrogen and phosphorus availability in lowland soil, leading to increased nitrogen and phosphorus status in rice tissue. Moreover, the application of rice straw compost and rice hull ash improved the chemical characteristics of ultisol-type soil, as indicated by the increase in pH, organic carbon, phosphorus availability, and total nitrogen (Pane et al., 2014).

In addition to the increase in nitrogen and phosphorus content in the soybean tissue, the present experiment also showed an increase in potassium and calcium uptake as an ameliorant immersion (Figure 3-4). A previous study by Sasli (2011) reported that rice hull application could increase potassium availability in peat soil and increase plant productivity. A similar result was reported by Melati dan Asiah (2008) in soybean treated with rice hull ash. The increase in calcium uptake as a result of ameliorant addition might be related to the calcium content in rice hull ash, ranging from 0.44% to 0.46% and 0.48% (Tamtomo et al., 2015).

Nitrogen, phosphorus, potassium, and calcium are four essential macronutrients required by plants in large enough quantities for their crucial role in the growth and metabolism of plants (Marschner, 1986; Mitra, 2015). Nitrogen is the constituent element of amino acids, amides, proteins, nucleic acids, nucleotides, coenzymes, hexane amines, etc. Phosphorus served as a constituent element of sugar-phosphate nucleic acids, nucleotides, coenzymes, phospholipids, phytate acid, etc. Phosphorus elements play a role in reactions involving ATP. Plants need potassium as a cofactor for more than 40 enzymes, and potassium plays a significant role in maintaining cell turgidity and cells under average conditions. Calcium served as a constituent element of the cell wall lamella, cofactors for enzymes involved in the hydrolysis of ATP and phospholipids. In addition, Ca elements also act as second messengers in the regulation of metabolism (Marschner, 1986).

*Ameliorant effect on soybean production*

There was no interaction between rice biomass application and rice hull ash on the soybean production component, represented by three variables: number of pods per plant, seed weight (measured in a square sample size of 2.5 x 2.5 m2) and productivity (tha-1). The best result on the first factor as a single factor was found in soybean treated with one immersion of usual cut rice straw; however, it was not significantly different from twice the same cut straw (Table 2). The best treatment generated significant production improvement, as indicated by the increase in the number of pods per plant, seed weight and productivity by approximately 34.5%, 36.1%, and 26.4% compared to the control, respectively.

The second-factor result shows that 0.5 t ha-1 rice hull ash application was determined to be the best treatment, indicated by the highest number of pods per plant, seed weight, and productivity (Table 2). Compared to the control, the best treatment showed significant improvements of 62.9%, 66.8%, and 62.7% in pod number per plant, seed weight and productivity, respectively. Previous studies confirmed an increase in productivity as the effect of rice hull ash addition on soybean (Melati & Asiah, 2008) and rice hull combined composted straw on sweet potato (Tamtomo et al., 2015) and sweet corn (Seipin et al., 2016). In addition, the regression approach revealed the relation between soybean yield and rice hull ash dosage with a mathematical equation, y = 1.1494x + 1.9971, with y as soybean yield and x as ash dosage, regression coefficient = 0.785, and the coefficient of determination (R2) = 0617. Based on that regression equation, the potential production of soybean under saturated soil culture in the tidal swamp was approximately 2.93 t ha-1 as the effect of rice hull ash addition as much as 0.5 t ha-1.

Similar to the regression results, the correlation approach also reveals a relationship between soybean yield and nutrient uptake, as shown in Table 3. The increase in soybean nutrient uptake under saturated soil culture in the tidal swamp led to an increase in soybean productivity. All observed macronutrients, such as nitrogen, phosphorus, potassium and calcium, had a positive and significant correlation with soybean yield (α 1%). All mentioned nutrients were thought to be needed in large quantities to support plant growth. Ameliorant addition could improve the soil chemical and biological characteristics in the tidal swamp and increase nutrient availability to the plant could absorb at the optimal quantity level. Similar results regarding the relationship of macronutrients and crop productivity as the effect of ameliorant application on growth media have been reported before (Harahap, 2014; Melati & Asiah, 2008; Prasetyo et al., 2010).

**CONCLUSION**

The supplemental rice biomass and rice hull ash ameliorants in tidal swamps led to the improvement of soil chemical characteristics, an increase in pH value to be neutral and high nutrient availability for soybean. The correlation of nutrient uptake (nitrogen, phosphorus, potassium and calcium) and soybean production was positive and high. However, there was no interaction between rice biomass and hull ash applications on the yield variable. The best treatment of biomass ameliorant application for increasing soybean production in tidal swamp soil was one immersion of usual cut rice straw. The best treatment of supplemental rice hull ash addition was 0.5 t ha-1.

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**Table and Figures**

**Table 1. Soil characteristics under saturated soil culture in the tidal swamp before and after application of rice biomass**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Soil characteristics | Initial condition | Once immersion of short rice stubble | Once immersion of usual rice straw | Twice immersion of usual rice straw |
| Texture (%) |  |  |  |  |
| Sand | 29.00 | 35.00 | 1.00 | 1.00 |
| Dust | 29.00 | 32.00 | 72.00 | 78.00 |
| Clay | 42.00 | 33.00 | 27.00 | 21.00 |
| PH | 3.90 | 4.20 | 6.20 | 5.70 |
| C (%) | 4.01 | 3.69 | 10.83 | 11.08 |
| N (%) | 0.21 | 0.20 | 0.42 | 0.43 |
| C/N | 19.00 | 18.00 | 26.00 | 26.00 |
| P2O5 Olsen | - | - | 51.00 | 37.00 |
| P2O5 Bray | 68.80 | 166.30 | - | - |
| K2O | 83.00 | 71.00 | 608.00 | 200.00 |
| Ca (cmol(+) kg-1) | 0.70 | 1.10 | 10.50 | 5.83 |
| Mg (cmol(+) kg-1) | 0.71 | 0.56 | 0.67 | 0.62 |
| K (cmol(+) kg-1) | 0.08 | 0.07 | 0.64 | 0.25 |
| Na (cmol(+) kg-1) | 0.15 | 0.12 | 0.16 | 0.22 |
| CEC (cmol(+) kg-1) | 8.39 | 7.91 | 17.65 | 15.31 |
| Base saturation (%) | 20.00 | 23.00 | 67.00 | 45.00 |
| Al (cmol(+) kg-1) | 6.09 | 5.63 | 0.00 | 0.00 |
| Fe (%) | 2.80 | 2.77 | 1.98 | 1.47 |
| S (%) | 0.07 | 0.01 | 0.20 | 0.20 |
| Pyrite (%) | 0.38 | 0.38 | 0.13 | 0.03 |
| Humic acid (%) | 7.29 | 7.27 | 12.42 | 16.45 |

**Table 2. The effect of rice biomass and rice hull ash ameliorants on soybean production in tidal swamps**

|  |  |  |  |
| --- | --- | --- | --- |
| Treatment | Number of pods (pods per plant) | Seed weight\* (g) | Productivity  (t ha-1) |
| 1. First factor = rice biomass application | |  |  |
| Without biomass | 36.37c | 515.42c | 2.06c |
| Once immersion of short rice stubble | 37.13bc | 530.01bc | 2.12bc |
| Once immersion of usual cut rice straw | 48.95a | 701.62a | 2.81a |
| Twice immersion of usual cut rice straw | 47.67ab | 680.83ab | 2.72ab |
| 1. Second factor = rice hull ash dosage (tha-1) | |  |  |
| 0 | 31.53c | 449.46c | 1.8c |
| 0.25 | 42.05b | 594.45b | 2.4b |
| 0.5 | 51.38a | 749.97a | 2.93a |
| 0.75 | 45.15b | 634.01b | 2.58b |

\*Measured in a land sample size of 2.5 x 2.5 m2. Means in the same column within the same factor followed by different letters are significantly different based on DMRT at α 5%

**Table 3. Pearson correlation coefficients between nutrient uptake and soybean yield**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | N | P | K | Ca | SY |
| N | 1.000 | 0.311 | 0.123 | 0.067 | 0.532\* |
| P |  | 1.000 | 0.864\*\* | 0.849\*\* | 0.876\*\* |
| K |  |  | 1.000 | 0.885\*\* | 0.733\*\* |
| Ca |  |  |  | 1.000 | 0.746\*\* |

N = nitrogen, P = phosphorus, K = potassium, Ca = calcium, SY = soybean yield. \* = significant at α 5%; mark \*\*: significant at α 1%

**Figure**

**Figure 1.** The effect of rice biomass (left) and rice hull ash (right) ameliorants on the soil nitrogen level of soybean tissue under saturated soil culture in the tidal swamp. T0 = without rice biomass; T1 = once immersion of short rice stubble; T2 = once immersion of normal cut rice straw; T3 = twice immersion of normal cut rice stubble; A0 = 0 ton ha-1 of rice hull ash; A1 = 0.25 ton ha-1 of rice hull ash; A2 = 0.50 ton ha-1 of rice hull ash; A3 = 0.75 = ton ha-1 of rice hull ash; WAP = weeks after planting. The broken line was made based on the minimum nitrogen requirement in soybean, i.e 4.25% (Hellal et al. 2013)

**Figure 2.** The effect of rice biomass (left) and rice hull ash (right) ameliorant addition on the phosphorus level of soybean tissue under saturated soil culture in the tidal swamp. T0 = without rice biomass; T1 = once immersion of short rice stubble; T2 = once immersion of normal rice straw; T3 = twice immersion of normal rice straw; A0 = 0 ton ha-1 of rice hull ash; A1 = 0.25 ton ha-1 of rice hull ash; A2 = 0.50 ton ha-1 of rice hull ash; A3 = 0.75 = ton ha-1 of rice hull ash; WAP = weeks after planting. A broken line was made based on the minimum phosphorus requirement in soybean, i.e. 0.25% (Hellal et al. 2013)

**Figure 3.** The effect of the ameliorants rice biomass (left) and rice hull ash (right) on the potassium level of soybean under saturated soil culture in the tidal swamp. T0 = without rice biomass; T1 = once immersion of short cut rice stubble; T2 = once immersion of normal rice straw; T3 = twice immersion of normal cut rice straw; A0 = 0 ton ha-1 of rice hull ash; A1 = 0.25 ton ha-1 of rice hull ash; A2 = 0.50 ton ha-1 of rice hull ash; A3 = 0.75 = ton ha-1 of rice hull ash; WAP = weeks after planting. The broken line was made based on the minimum potassium requirement in soybean, i.e. 1.7% (Hellal et al. 2013)

**Figure 4.** The effect of rice biomass (left) and rice hull ash (right) ameliorants on the calcium level of soybean under saturated soil culture in the tidal swamp. T0 = without rice biomass; T1 = once immersion of short rice stubble; T2 = once immersion of normal cut rice straw; T3 = twice immersion of normal cut rice straw; A0 = 0 ton ha-1 of rice hull ash; A1 = 0.25 ton ha-1 of rice hull ash; A2 = 0.50 ton ha-1 of rice hull ash; A3 = 0.75 = ton ha-1 of rice hull ash; WAP = weeks after planting. A broken line was made based on the minimum calcium requirement in soybean, i.e. 0.35% (Hellal et al. 2013)