Utilizing Rice Hull Ash and Biomass as Ameliorants Enhanced Soybean Yield and Nutrient Uptake in Tidal Swamps Under Saturated Soil Culture

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ABSTRACT

Saturated soil culture (SSC) is a promising technology for cultivating soybeans in acidic soil in tidal swamps. The objectives of this study were to measure nutrient uptake in the soybean plant using a saturated soil culture technique and to assess the impact of ameliorant addition in the form of rice biomass and rice hull on soybean yield. Two factors, rice biomass, and rice hull ash, were used in a split plot factorial design to set up the experiment. Four levels in the main factor included without biomass immersion, one immersion of short (3 cm above the root) rice stubble, one immersion of regular (panicle harvested only) rice straw, and two immersions of regular rice straw cut in the soil. The four levels in the subfactor were 0 t ha^{-1}, 0.25 t ha^{-1}, 0.50 t ha^{-1}, and 0.75 t ha^{-1} of rice hull ash doses. Ameliorant in the form of biomass and rice husk increases soil quality in tidal swamps by enhancing pH, soil nutrients (N, P, K, S), CEC, cations, and base saturation, also reducing toxic compounds and improving soil texture. Application of ameliorant also increases soybean nutrient uptake and eventually increases the productivity of soybeans in tidal swamp acid soil. The best treatment of the first and second factors was one immersion of biomass with a regular cut of rice straw and 0.5 t ha^{-1} ash rice hull ash addition to the tidal swamp soil, respectively.

Keywords: Nitrogen; Potassium; Pyrite; Marginal land; Soybean production

INTRODUCTION

Glycine max (L.) Merr, or soybean, is one of Indonesia's main food crops (BPS, 2018). Due to its distinct chemical makeup, soybeans are one of the most valuable plant-based meals available, providing 60% of the world's vegetable protein, which is regarded as superior to animal protein substitutes (Wijewardana et al., 2019). Isoflavone content in soybeans has various benefits for humans because it plays an anticancer compound and prevents degenerative diseases, such as coronary heart disease and hypertension (M. Akram, 2011; Muchlish & Krisnawati, 2014). In Indonesia, soybean consumption reached 2.2 million tons, and 53.32% of it was fulfilled by import (Surahman et al.,

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2018). The extensification program by tidal swamp utilization is beneficial to increasing soybean production (Firdaus, 2015; Toyip et al., 2019).

Problems with cultivation in tidal swamp areas are associated with soil quality. The tidal swamp soil exhibits elevated levels of acidity, aluminum content, and pyrite concentration (Fanning et al., 2017). Furthermore, the limited availability of vital minerals in the soil becomes a factor that restricts the growth of soybean plants (Mukhlis et al., 2021). In tidal swamp environments, saturated soil culture (SSC) has shown to be an effective new technology for maintaining soil limitations for plant growth. The goal of this technology concept was to regulate water levels several centimeters below ground level in order to maintain soil quality. A sufficient supply of nutrients is necessary for the growth and production of soybeans (Calabi-Floody et al., 2018).

To ensure the sustainability of crop production in the tidal swamp area, ameliorants may make more nutrients available in the soil (Xiu et al., 2019). In a tidal swamp environment, the use of ameliorants raises the pH of the soil and the availability of nutrients (Maftu'Ah et al., 2021). Agricultural waste product biomass has the potential to be used directly or through extensive processing as an ameliorant (Bhowmick et al., 2018). It has been demonstrated using numerous research that the use of ameliorants, primarily rice husk ash or its combination with other forms can boost the yield of food crops, such as soybeans, in acidic tidal swamp soil (Sagala et al., 2021), maize (Ghulamahdi et al., 2023), and paddy (Saputra & Sari, 2021; Yartiwi et al., 2023). However, the application of rice biomass directly from newly planted plants and shallowed into the soil in tidal swamp areas has not been widely implemented. This experiment uses the combination of rice hull and rice biomass in an acid soil tidal swamp to increase soil quality. Improvement of soil quality eventually leads to rising crop production in tidal swamp soil, particularly for soybeans.

The purpose of this study was to acquire technology for biomass usage and ascertain the optimum rates of rice husk ash as an ameliorant to enhance the soil quality in tidal swamps, particularly in terms of raising nutrient content and yielding more soybean crops.

MATERIALS AND TECHNIQUES

Study Area

Figure 1. Research location map for Simpang Village, East Tanjung Jabung Regency, Berbak District, Jambi Province, Indonesia, with coordinates of -1.270796S and 104.113425E.

Simpang Village (1.270796 S, 104.113425 E), Berbak District, East Tanjung Jabung Regency, Jambi Province, Indonesia, was the location of the experiment (Figure 1) from May to November 2018. Plant tissue's nitrogen, phosphorus, potassium, and calcium were analyzed in the Post-Harvest Laboratory, Faculty of Agriculture, IPB University. The area of the experiment was an acid soil tidal swamp. The research location is near the Batanghari River. When it rains heavily at the same time as high tide, river runoff reaches agricultural land, resulting in the formation of pyrite. The pyrite layer that undergoes an oxidation process causes the land to have the potential to experience increased acidity.

Soil Observation

Soil chemical and physical properties from the site were examined in the Soil Laboratory, Soil Research Institute, Ministry of Agriculture, Republic of Indonesia. The soil chemical properties are presented in Table 1.

Table 1. The tidal swamp's saturated soil culture's properties both before and after rice biomass was applied

Characteristics of the Soil	Starting Point	One time immersion of a short rice stubble	Once immersion of regular rice straw	Twice immersion of regular 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
P_2O_5 Olsen	-	-	51.00	37.00
P_2O_5 Bray	68.80	166.30	-	-
K_2O	83.00	71.00	608.00	200.00
Calcium (cmol(+) kg^{-1})	0.70	1.10	10.50	5.83
Magnesium (cmol(+) kg^{-1})	0.71	0.56	0.67	0.62
Potassium (cmol(+) kg^{-1})	0.08	0.07	0.64	0.25
Natrium (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
Aluminium (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

Experimental Design

This experiment was arranged in a split-plot factorial design with three replications. The model of the experiment was:

$$Y_{ijkl} = \mu + \rho_i + \alpha_j + \varepsilon_{ij} + \beta_k + (\alpha\beta)_{jk} + \varepsilon_{ijk} \quad (1)$$

Whereas:

Y_{ijk} = Observed values in the i-th replication, j-level biomass utilization treatment, treatment with the k^{th} level of husk ash

μ = Grand mean of the values observed

ρ_i = Repetition's effects at level i

α_j = Effect of biomass utilization treatment at the j^{th} level.

ε_{ij} = The influence of the ith replication error and the j^{th} level of biomass utilization.

β_k = Effect of the k^{th} level of husk ash dose treatment.

$(\alpha\beta)_{jk}$ = The interaction effect of the j^{th} level of biomass utilization treatment and the k^{th} level of husk ash dose treatment.

ε_{ijk} = Error's impact on the i replication, j-level biomass utilization treatment, and k-level husk ash dosage.

The application of rice biomass was the primary factor, This had four levels: without using biomass= 0.00 ton ha^{-1} (T0), one immersion of short rice stubble= 1.00 ton ha^{-1} (T1), one immersion of regular cut rice straw= 3.80 ton ha^{-1} (panicle harvested only) (T2), and two immersion of regular rice straw to the soil= 3.80 ton ha^{-1} (T3). Short rice stubble was prepared by harvesting rice straw and leaving it 3 cm above the ground. Usually, harvesting merely chops the rice panicle made up of the usual cut rice straw. The doses of rice hull ash were the subfactor, which had four levels as well: 0 t ha^{-1} (A0), 0.25 t ha^{-1} (A1), 0.50 t ha^{-1} (A2), and 0.75 t ha^{-1} (A3). All combinations treatment were T0A0, T0A1, T0A2, T0A3, T1A0, T1A1, T1A2, T1A3, T2A0, T2A1, T2A2, T2A3, T3A0, T3A1, T3A2, and T3A3. Each combination treatment was repeated four times, resulting in 64 experimental units.

Application of Rice Biomass

Land preparation was carried out after the rice harvesting season so that rice stubble remained. With the exception of the control treatment (T0), the rice biomass was completely submerged in the soil layer. Using a manual tractor, the rice straw was mixed straight (one way) into the soil and left there for ten days. After that, the inundation water was decreased to muddy the soil. Using a singkal funnel maker, the trench for the SSC treatment was dug (SPS SSC IPB). In the second immersion, the treatment consisted of two periods of immersion, two inundations, and then digging the SSC trench. After the field was cleansed of rice stubble in the control treatment and submerged for 10 days, an SSC trench was installed. A five-day incubation period was followed by treatments of 1 t ha^{-1} agricultural lime ($CaCO_3$ + $MgCO_3$ 80%), phosphorus fertilizer (27 kg ha^{-1}), and 40 kg ha^{-1} potassium fertilizer on all plots.

The rice hull for the ash form was collected from rice milling shelters. The rice hull was then burned in the open area, followed by air cooling, and then incubated for one week. The ash resulting from the rice hull was 17.26% w/w. Ash was used to cover the planting hole with seeds. The dimensions of the experimental plot were 2 m x 5 m x 0.25 m. Plots and replications were spaced apart by as much as 30 and 50 centimeters, respectively. With two seeds in each planting hole, the plants were spaced 40 cm apart by 12.5 cm, yielding 400,000 plants per hectare. The hand tractor was used to create the planting furrow. Prior to sowing, the seeds were combined with a 20 g kg^{-1} seed concentration of carbosulfan 25.53% and an inoculant of Rhizobium sp. containing up to 5 g per kg of seed. A week after planting, there was replanting. Two, three, and four weeks after planting, 4.6 g l^{-1} of nitrogen fertilizer were applied. By applying an insecticide (*cypermethrin*) at a dosage of 0.5 l ha^{-1}, illnesses and pests were avoided. After planting, weeds were manually controlled three and six weeks later. The number of pods (pods per plant), grain weight on square 2.5 m^{-2} (g), production per hectare, and the soybean crop's level of nutrient uptake (nitrogen, phosphorus, potassium, and calcium) were the variables that were observed.

Nutrient Analysis

Using H_2SO_4 and H_2O_2 solutions, the wet digestion method was used to analyze nutrients. The distillation method (N-Kjeldahl) was used to test the absorption of nitrogen nutrients. A spectrophotometer set at 693 nm was used to measure the amount of phosphorus nutrient present in plant tissue. An atomic absorption spectrophotometer was used to measure Ca, and a flame photometer was used to measure K.

Analysis Statistical

The analysis of variance (ANOVA) was performed using Statistical Analysis Software (SAS) version 9.4. ANOVA is used to test research hypotheses by comparing population means between treatments. The observation variables used in ANOVA are the number of pods, seed weight, and productivity. At a 5% level of confidence, the Duncan Multiple Range Test (DMRT) was used to assess any significant differences between treatments. Additionally, a Pearson's correlation analysis was performed to examine the connection between soybean yield and nutrient uptake.

RESULTS AND DISCUSSION

Soil Physical and Chemical Characteristics

Based on a chemical examination, the contents of rice biomass were found to be 12.08 %, 7.92 percent, 1.3 percent, 0.09 percent, 0.52 percent, and 0.19 % for ash, silicate, nitrogen, phosphorus, potassium, and calcium, respectively. Rice hull ash contains 1.25% humic acid. Applying biomass and rice hull ash improved the soil's physical and chemical characteristics in the tidal swamp land (Mini & Lekshmi, 2018). The pH of the soil in all treated plots was higher than in the initial condition. Before biomass immersion, the soil's actual pH (pH H_2O) was very acidic (pH 3.9). However, the pH of the soil could be raised to 4.2 (light acidic), 6.2 (neutral), and 5.7 (very light acidic) after ameliorant application treatments of immersion of short rice stubble, one immersion of regular cut rice straw, and two immersions of regular cut rice straw. Since soybeans have a high nutrient availability, the increased pH of the soil was more favorable for plant growth.

Following the application of rice hull ash and biomass, the soil's texture changed. An additional indicator of the ameliorant's impact was the tidal swamp's increased pH, N, P, K, S, cations, cation exchange capacity (CEC), humic acid, and base saturation (Table 1). Because of this beneficial effect, the soil conditions were more favorable for the growth of soybean plants. Utilizing rice husk ash and biomass could also aid in reducing the quantity of dangerous chemicals present (Table 1). This result was consistent with earlier research showing that the application of ameliorants raised soil

CEC, increased the availability of organic C, decreased the toxicity of Fe and Al ions, and increased the availability of several nutrients, including silicate, phosphorus, potassium, and calcium (Contin et al., 2007; Mini & Lekshmi, 2018), enhanced the pH by releasing an anion OH^- (Saputra & Sari, 2021), enhanced soil microbial activity, increased soil aeration and porosity, and decreased requirement for potassium fertilizer because it might be an alternate source of potassium (Luo et al., 2018).

Effects of Ameliorants on Soybean Nutrient Uptake

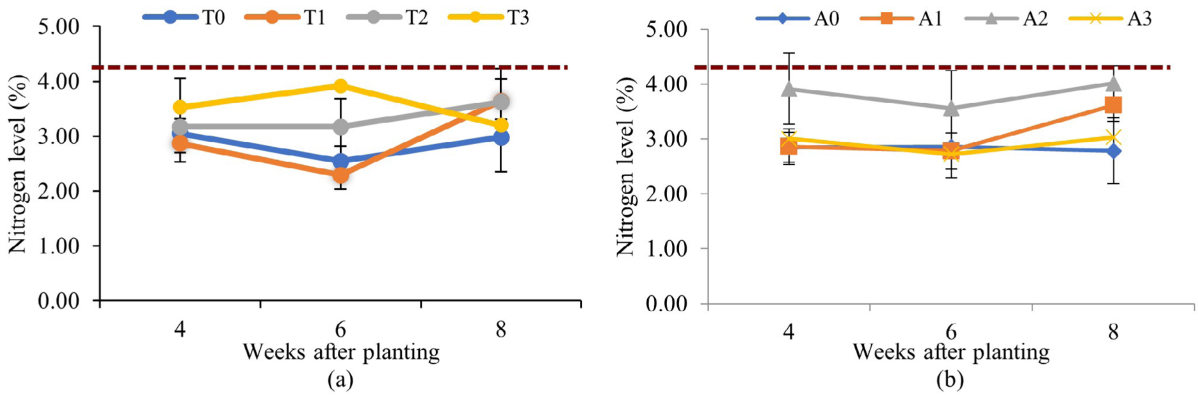

Figure 2. Under saturated soil culture in the tidal swamp, the impact of rice biomass (a) and rice hull ash (b) on the nitrogen level of soybean. T0 = not including rice biomass; One time immersion of a short rice stubble (T1) and one time immersion of a normal cut rice straw (T2) T3 is the standard cut of rice straw immersed twice. In terms of rice hull ash, A0 is equal to 0 tons ha^{-1}, A1 is equal to 0.25 tons ha^{-1}, A2 is equal to 0.50 tons ha^{-1}, and A3 is equal to 0.75 tons ha^{-1}. Based on the soybean's minimal nitrogen requirement of 4.25%, a broken line was created (Hellal & Abdelhamid, 2013)

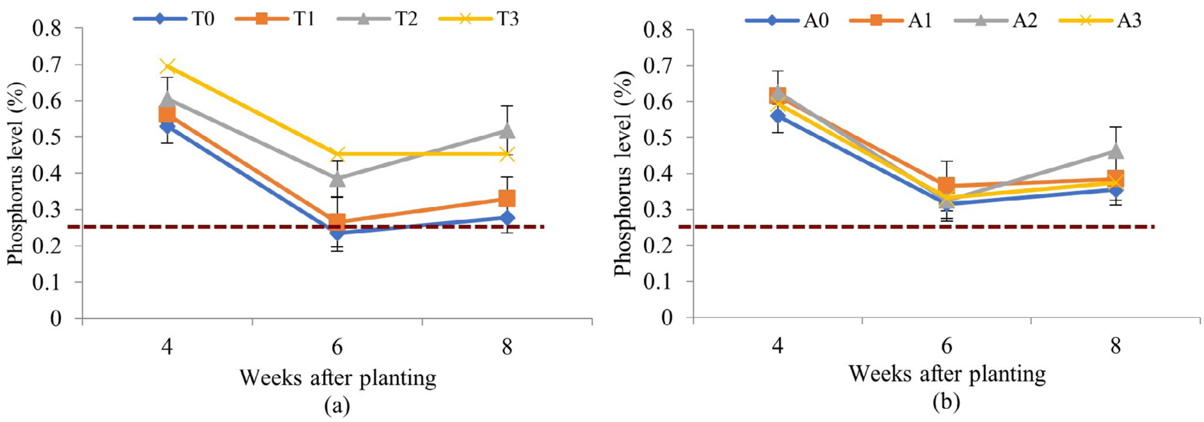

Figure 3. Under saturated soil culture in the tidal swamp, the impact of rice biomass (a) and rice hull ash (b) on the phosphorus level of soybean. T0 = not including rice biomass; One time immersion of a short rice stubble (T1) and one time immersion of a normal cut rice straw (T2) T3 is the standard cut of rice straw immersed twice. In terms of rice hull ash, A0 is equal to 0 tons ha^{-1}, A1 is equal to 0.25 tons ha^{-1}, A2 is equal to 0.50 tons ha^{-1}, and A3 is equal to 0.75 tons ha^{-1}. Based on the soybean's minimal phosphorus requirement of 0.25%, a broken line was created (Hellal & Abdelhamid, 2013)

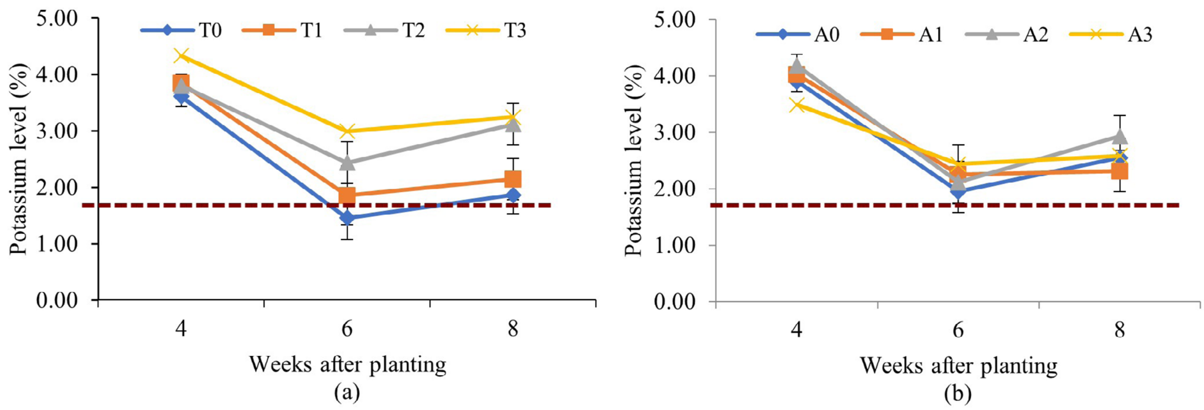

Figure 4. Under saturated soil culture in the tidal swamp, the impact of rice biomass (a) and rice hull ash (b) on the potassium level of soybean. T0 = not including rice biomass; One time immersion of a short rice stubble (T1) and one time immersion of a normal cut rice straw (T2) T3 is the standard cut of rice straw immersed twice. In terms of rice hull ash, A0 is equal to 0 tons ha^{-1}, A1 is equal to 0.25 tons ha^{-1}, A2 is equal to 0.50 tons ha^{-1}, and A3 is equal to 0.75 tons ha^{-1}. Based on the soybean's minimal potassium requirement of 1.7%, a broken line was created (Hellal & Abdelhamid, 2013)

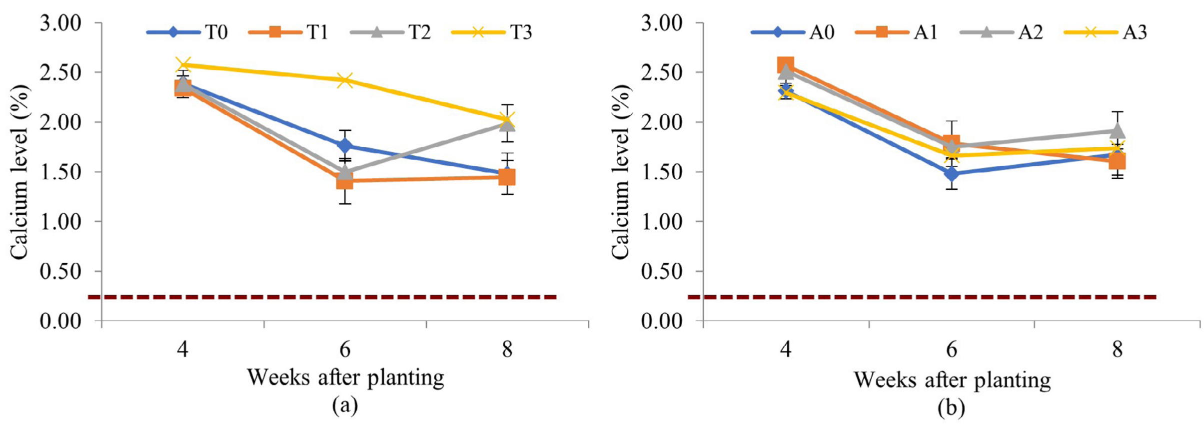

Figure 5. Under saturated soil culture in the tidal swamp, the impact of rice biomass (a) and rice hull ash (b) on the calcium level of soybean. T0 = not including rice biomass; One time immersion of a short rice stubble (T1) and one time immersion of a normal cut rice straw (T2) T3 is the standard cut of rice straw immersed twice. In terms of rice hull ash, A0 is equal to 0 tons ha^{-1}, A1 is equal to 0.25 tons ha^{-1}, A2 is equal to 0.50 tons ha^{-1}, and A3 is equal to 0.75 tons ha^{-1}. Based on the soybean's minimal calcium requirement of 0.35%, a broken line was created (Hellal & Abdelhamid, 2013)

Each week that the soybean crop was observed, the amount of nitrogen in it changed. Over time, there was an improvement in the uptake of nitrogen. Compared to the treatments at 6 WAP and 4 WAP, the nitrogen content at 8 WAP (weeks after planting) was the highest in all of them, while the nitrogen level at 4 WAP exhibited the opposite tendency (Figure 2). When compared to the other treatments, the two immersions of standard-cut rice straw mixed with 0.5 t ha-1 rice hull ash demonstrated the best absorption of calcium, potassium, and phosphorus (Figure 3-5).

Previous research findings corroborated the higher nutrient absorption shown in this study due to ameliorant addition. Pane et al. (2014) demonstrated that adding rice hull ash and rice straw compost to the soil could boost the maize plant's uptake of phosphate and nitrogen. Plants growing rice may absorb more phosphorus if rice hull ash is applied. High quantities of silicon found in rice hull ash can increase the amount of P that is available in the soil for plant absorption (Thind et al., 2017). The increase in plant nutrient uptake or even nutrient status in plant tissue was caused by an increase in nutrient availability in the soil. This statement was supported by Mini & Lekshmi (2018), who added rice hull to lowland soil to boost soil phosphorus and nitrogen availability, which improved rice tissue's phosphorus and nitrogen status. Furthermore, as seen by the increases in pH, organic carbon, phosphorus availability, and total nitrogen, the addition of rice hull ash and composted rice straw improved the chemical properties of ultisol-type soil (Pane et al., 2014).

The current experiment demonstrated an increase in potassium and calcium uptake as influenced by ameliorant immersion in addition to the rise in nitrogen and phosphorus content in the soybean tissue (Figure 4-5). An earlier investigation by Sasli (2011) revealed that adding rice hulls to peat soil could boost plant productivity by increasing potassium availability. An analogous outcome was revealed by Melati & Asiah (2008) in soybeans given a rice husk ash treatment. The possible correlation between the ameliorant addition and the increase in calcium uptake could be explained by the calcium concentration of rice husk ash, which can range from 0.44 percent to 0.46 percent and 0.48 % (Tamtomo et al., 2015).

The four macronutrients necessary for plants to have sufficient amounts for their vital roles in plant growth and metabolism are nitrogen, phosphorus, potassium, and calcium (Marschner, 1986; Mitra, 2015). Proteins, amides, coenzymes, nucleic acids, nucleotides, and hexane amines are all composed of nitrogen. Phosphorus serves as a constituent element of sugar-phosphate nucleic acids, nucleotides, coenzymes, phospholipids, and phytate acid. Phosphorus elements play a role in reactions involving ATP. Potassium is essential to plants because it is a cofactor for over 40 enzymes and because it keeps cells under normal circumstances and turgidity. Calcium is a component of the lamellae of the cell wall and a cofactor for the enzymes that hydrolyze phospholipids and ATP—furthermore, Ca components function as secondary messengers in the control of metabolism (Marschner, 1986).

Effects of Ameliorant on Soybean Production

ANOVA statistical analysis revealed that there was no interaction in the soybean production component between the application treatment of rice hull ash and rice biomass. Pod count per plant, seed weight, and productivity are some productivity factors (t ha^{-1}). One immersion of normal-cut rice straw (T2) produced the highest results on the first factor when considered as a single factor; nevertheless, it did not differ substantially from two immersions of regular-cut rice straw (T3) (Table 2). As evidenced by the increase in the number of pods per plant, seed weight, and productivity by roughly 34.5 percent, 36.1 percent, and 26.4 percent relative to the control (T0), respectively, the best treatment improved production.

Based on the most significant number of pods per plant, seed weight, and production, the second-factor result revealed that 0.5 t ha^{-1} rice hull ash was the optimum treatment (Table 2). The best treatment significantly increased the number of pods per plant, seed weight, and productivity compared

Table 2. Impact of rice hull ash ameliorants and biomass on soybean yield in tidal swamps

Treatments	Count of pods (pods on each plant)	weight of Seed* (g)	Productivity (ton ha^{-1})
A. First element = application of rice biomass			
Not including rice biomass (control)	36.37c	515.42c	2.06c
One time immersion of a short rice stubble	37.13bc	530.01bc	2.12bc
one time immersion of a normal cut rice straw	48.95a	701.62a	2.81a
standard cut of rice straw immersed twice	47.67ab	680.83ab	2.72ab
B. Second element = the dosage of rice hull ash (ton ha^{-1})			
0.00 (control)	31.53c	449.46c	1.8c
0.25	42.05b	594.45b	2.4b
0.50	51.38a	749.97a	2.93a
0.75	45.15b	634.01b	2.58b

* Measured using a 2.5 x 2.5 m2 land sample size. Based on DMRT at α 5%, means in the same column within the same factor followed by different letters differ significantly

Table 3. The correlation coefficients between soybean yield and nutrient absorption measured by Pearson

	Nitrogen	Phosphorus	Potassium	Calcium	Soybean Yield
Nitrogen	1.000	0.3110	0.1230	0.0670	0.5320*
Phosphorus		1.000	0.8640**	0.8490**	0.8760**
Potassium			1.000	0.8850**	0.7330**
Calcium				1.000	0.7460**

Note: Significant at α 5% for *, and at α 1% for mark **

to the control by 62.9%, 668.8%, and 62.7 percent, respectively. Prior research has verified that adding rice hull ash to soybeans (Melati & Asiah, 2008) and rice hull coupled with composted straw to sweet potatoes (Tamtomo et al., 2015) and sweet corn (Seipin et al., 2016). Furthermore, using a mathematical equation of $y = 1.1494x + 1.9971$ (F=0.115 Sig= 0.766), where x is the ash doses, and y is the soybean yield, the regression approach demonstrated the relationship between rice hull ash doses and soybean yield. The coefficient of determination (R^2) was 0.617, and the regression coefficient was 0.785. According to that regression equation, the addition of rice hull ash might have a 0.5 t ha^{-1} impact on the potential output of soybeans under saturated soil culture in the tidal swamp.

As indicated in Table 3, the correlation technique demonstrates a link between soybean yield and nutrient uptake, similar to the regression results. Soybean productivity increased due to increased nitrogen uptake under saturated soil culture in the tidal marsh. Every macronutrient that was measured, including calcium, phosphorus, potassium, and nitrogen, showed a strong and positive relationship with soybean output (α 1%). It was believed that all of the nutrients listed were required in significant amounts to promote plant growth. Enhancing the tidal swamp's soil chemical and biological properties using an ameliorant could help plants absorb nutrients in the right amount and make more nutrients available to them. Similar findings about the impact of ameliorant treatment on growth media and the relationship between crop productivity and macronutrients have already been published (Harahap, 2014; Melati & Asiah, 2008; Prasetyo et al., 2010).

CONCLUSION

Soybean yield and nutrient uptake were enhanced in the tidal swamp soil by adding rice biomass and rice hull ash ameliorants. One immersion of standard-cut rice straw was the optimum treatment of biomass ameliorant application for enhancing soybean yield in tidal swamp soil. 0.5 t ha^{-1} was the most effective addition of rice hull ash. The improvement of soybean production was highly supported by Nitrogen, Phosphorus, Potassium, and Calcium uptake in the plant tissue.

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