



The application of rock phosphate increases the growth and yield of rice on acid sulphate soil of South Kalimantan, Indonesia

Suriyanti Ahmad¹, Sri Nuryani Hidayah Utami^{2*}, Azwar Ma'as², Wahida Annisa Yusuf³, and Husnain⁴

¹Post Graduate School, Faculty of Agriculture, Universitas Gadjah Mada
Jln. Flora no. 1, Bulaksumur, Sleman, Yogyakarta 55281, Indonesia

²Department of Soil Science, Faculty of Agriculture, Universitas Gadjah Mada
Jln. Flora no. 1, Bulaksumur, Sleman, Yogyakarta 55281, Indonesia

³Indonesian Swampland Agricultural Research Institute (ISARI)
Jln. Kebun Karet, Lok Tabat, Banjarbaru 70712, Indonesia

⁴Indonesian Centre for Agricultural Land Resource Research Development (ICALRD)
Jln. Ir. H. Juanda No. 98, Bogor 16123, West Java, Indonesia

*Corresponding author: nuryani@ugm.ac.id

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Abstract

A swampland has considerable potential in agriculture. This land has high soil acidity level, and high iron content. Therefore, the application of ameliorant to acid sulfate soil is essential to improve the soil and make it more suitable for rice cultivation. This study aimed to know the effects of phosphorus (P) from Moroccan Rock Phosphate (MRP) and fertilization on swamp rice (*Oryza sativa* L.). The experiment was conducted in the experimental location of Indonesian Swampland Agricultural Research Institute (ISARI), Puntik Village, Barito Kuala District, South Kalimantan and arranged in a randomized nested design consisting of 100 kg.ha⁻¹ TSP (Control), 750 kg.ha⁻¹, 1,000 kg.ha⁻¹, and 1,250 kg.ha⁻¹ of Moroccan rock phosphate with four replications in each treatment. The yield component of grain increased significantly at 3.77 ton.ha⁻¹. The highest of grain yield was obtained in the application of 1,000 kg.ha⁻¹ MRP. Meanwhile, significant positive correlation was observed between plant height and the number of spikelets per panicle. The application of phosphate fertilizer can increase soil pH, which affects the growth and yield of rice plants such as plant height and yield.

INTRODUCTION

The swampland is a marginal land that has considerable potential in agricultural development, especially food crops. This land area in Indonesia is estimated to reach 34.12 million ha, of which around 19.19 million ha are potential as agricultural areas (Noor and Maftuah, 2020). Utilizing swamp land as marginal land for agriculture is not as easy as using fertile land that has been widely used. One of the marginal characteristics of this land is the high soil

acidity level, high iron content and shallow pyrite layer (Khairullah and Koesrini, 2020). Acid sulphate soil is a type of tidal soil that has the potential to be developed as agricultural land for food crops (Sosiawan et al., 2020).

According to Soil Survey Staff (2014), acid sulphate soils are characterized by the existence of a sulfuric horizon, and they generally contain large amounts of iron, causing low soil pH. In flooded soils, ferric iron is reduced to the more soluble form of ferrous iron. As a result, ferrous iron levels in soil solution

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can increase to 300 ppm or higher. The high level of dissolved iron in the soil affects the iron concentration in the roots (Annisa and Nursyamsi, 2017).

The form of phosphorus (P) in the acid sulphate soil is mainly an organic form and various inorganic forms, especially as a less soluble phosphate as a compound with the elements of aluminum (Al), iron (Fe), and calcium (Ca). P is mainly attached to the oxides of Fe⁻ and Al⁻ (hydroxides), with an absorption reaction including the precipitation of metal phosphates. Farmers' soil management practices and soil properties influence the availability of P and P forms in tropical soils. (Nishigaki et al., 2018; Sugihara et al., 2012).

Macro P nutrient deficiency is the main obstacle to rice production in swamps. The application of rice straw and wild grass in fresh form can increase the concentration of iron in a form that is easily absorbed by plants. Another role of mature organic matter in acid sulphate soils is to maintain non oxidation conditions, thereby reducing the release of Fe²⁺ ions, increasing the Fe³⁺ content in the soil solution, resulting in suppression of pyrite oxidation. Good quality organic material that is not easily decomposed can reduce toxic materials in the soil such as heavy metals by means of chelation (Annisa et al., 2017).

In tidal swampland used, phosphate deficiency is a major constraint due to low levels of phosphate in the soil and strong phosphate absorption by the soil. The application cost of water-soluble P fertilizer imported from abroad or is produced by local is more expensive than using rock phosphate fertilizer (Yu et al., 2019). Therefore, in the field, special Phosphorus nutrient management is needed, especially for farmers with limited resources so that they can increase crop yields with low-cost inputs (Nishigaki et al., 2019).

Phosphorus is a nutrient that is less agile in the soil, so the soil requires the application of phosphate chemical fertilizers as an available source for optimal crop production. However, the availability of nutrients from chemical fertilizers is not more than 20 % and forces poor farmers to double the optimal amount of P fertilizer application (Ditta et al., 2018). The high-quality rock phosphate (RP), which is the major sources of important P-fertilizers used as a raw material for the production of chemical phosphate fertilizers and suitable for acid soils as low pH helps dissolve RP and increase the P available to plants. Rock phosphate is one of the most important natural

sources of Phosphor and a raw material for the manufacture of phosphate chemical fertilizers (Ditta et al., 2018). Direct application of phosphate rock is suitable for acid soil because its low soil pH helps dissolve RP, thereby increasing the availability of phosphate for plants. The application of rock phosphate fertilizer, which has high reactivity, especially on acid soils, has residual effects, and is slow to be available, is an effective and inexpensive solution to solve the P problem in acid soils. (Bacelo et al., 2020).

The application of ameliorant to acid sulfate soil is expected to improve the soil condition, making it more suitable for rice cultivation. There are major challenges in the utilization of acid sulphate soils since the rice yields at the farm level are < 2 ton.ha⁻¹ per season, below (3.8 ton.ha⁻¹ per season) of the national average (Shamshuddin et al., 2014). Thus, this study aimed to ensure the influence of rock phosphate on several growth variables and yields of lowland rice grown on acid sulphate soils.

MATERIALS AND METHODS

The experiment was conducted at the Belandean Research farm of Indonesian Swampland Agricultural Research Institute, Barito Kuala District, South Kalimantan from May to September 2019. The variables observed were agronomic parameters (number of tillers, plant height, yield) and soil properties. There were four treatments of field trial in this study, consisting of 100 kg.ha⁻¹ TSP (Control), 750 kg.ha⁻¹ Moroccan Rock Phosphate (MRP 1), 1,000 kg.ha⁻¹ Moroccan Rock Phosphate (MRP 2), and 1,250.kg ha⁻¹ Moroccan Rock Phosphate (MRP 3).

The treatments were arranged in a Nested design with four replications. After tillage, the plots were irrigated until they were saturated/flooded, and then left for twenty-four hours to dry until they reached field capacity. After that, fertilizer (TSP) and Moroccan Rock Phosphate (MRP) were applied to each treatment plot. N fertilizer at a dose of 100 kg.ha⁻¹ and K fertilizer at 50 kg.ha⁻¹ were applied uniformly according to the recommended dose (RD). After that, the rice seedlings were planted. Plant maintenance includes weeding, watering, and harvesting. Weeding was carried out three times when weeds were observed. Plant height was observed using a ruler by measuring from the base

of the stem to the tip of the longest leaf. The number of tillers was observed by counting all the stems planted. The rice was harvested when 90 % of the grains in the panicle were hard when pressed, changing color from green to light brown. Harvesting was done by cutting off the above ground part of the plant and separating grains from the rice straw.

The soil properties were analyzed, including soil pH, electrical conductivity (EC), organic carbon (OC), total nitrogen (TN), available phosphorous, and iron. The soil pH was measured electrometrically in 1:2.5 (w/v) (soil/water suspensions) (Hendershot et al., 2007). Organic carbon was determined by the wet digestion (oxidation) (Reed and Martens, 1996). Total nitrogen was determined by the Kjeldahl method (Okalebo, 2002). Available phosphorus was determined by the Olsen method (Delgado et al., 2010). Iron were extracted by DTPA and measured with atomic absorption spectro-photometer (Lindsay and Norvell, 1978). Data collected in each treatment (number of tillers, plant height and yield) were subjected to analysis of variance (ANOVA) using MINITAB, and the means between treatments were

compared using the least significant difference (LSD) test at $\alpha= 0.05$ (Lesik, 2009).

RESULTS AND DISCUSSION

Site description

The study site location was hydrologically affected by tidal water, classified as type B overflow (over flows only at high tide). According to the Soil Taxonomy classification system, the soil was classified into Typic Sulfaquent whose pH decreases to 3.26 after being oxidized (Table 1). The oxidation of pyrite produces ferrous iron ions, Fe^{2+} , SO_4^{2-} and H_2 ions, decreasing soil pH to very acidic (Soil Survey Staff, 2014). According to Dent and Pons (1995), soil pH <2.5 or 3 after being given H_2O_2 indicates a strong sulfuric acidity. Low soil pH affects phosphate uptake. According to Gustafsson et al. (2012), the solubility of PO_4-P increases with the increasing soil pH in the low to moderate pH range due to absorption/desorption processes involving iron. This is consistent with the high number of measured

Table 1. Initial chemical properties of the acid sulphate soil studied

Parameters	Value
pH H ₂ O	3.26
Organic C (%)	8.71
Total N (%)	0.44
Exchangeable potassium (Cmol (+).kg ⁻¹)	0.17
Available P (g.kg ⁻¹)	39.82
Fe ²⁺ (g.kg ⁻¹)	315.80

iron ions, namely 315 mg.kg⁻¹. One of the obstacles to rice growth on acid sulphate soils is iron poisoning. In acid sulphate soils, large amounts of Al and Fe are released into the environment during pyrite oxidation (Shamshuddin et al., 2004), which affects rice growth (Azman et al., 2011). The soils in this site had 8.7 % organic C content, 0.44 % N, 21.74 C/N, and 39.82 cmol (+).kg⁻¹ P-Bray.

Soil properties

The results showed that the soil pH value in all locations was around 4.45 (acid soil reaction) (Figure 1a). The optimum soil pH for rice is 5.5–7.0 in inundated conditions/lowland rice. Meanwhile, in inundated

swamps, rice can grow in acidic pH conditions even though the production is not as good as in non-swampy land. In the figure, it can be seen that the pH of the soil increased when phosphate rock was applied. This increase in pH likely resulted in the deposition of Fe as Fe hydroxide. Rice roots can absorb Fe²⁺/ferrous iron only in soluble form, not Fe(OH)₃. Therefore, to reduce the toxicity effect of Fe²⁺, the soil pH needs to be immediately raised to above 4. This can be done by applying Moroccan rock phosphate at a rate of 750 kg.ha⁻¹ or higher. Low soil pH in acid sulphate soils supports the formation of Diphosphate ions (HPO_4^{2-}) and increases the activity of Ca^{2+} reacting with HPO_4^{2-} to form insoluble calcium diphosphate

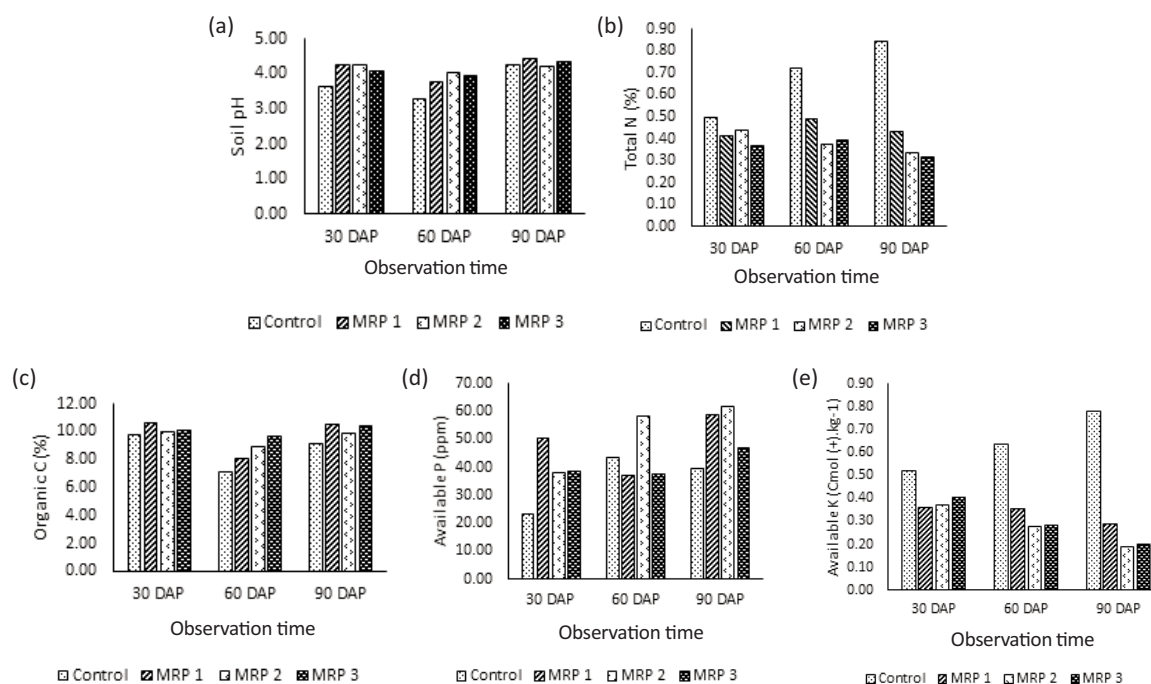


Figure 1. Effects of Moroccan rock phosphate on dynamics of soil pH (a), Total N (b), Organic C (c), Available P (d), and Available K (e). Control= 100kg.ha⁻¹TSP, MRP 1= 750 kg.ha⁻¹MRP, MRP 2= 1,000 kg.ha⁻¹MRP, MRP 3= 1,250 kg.ha⁻¹MRP.

and hydroxy-apatite. This proves that the increase in pH of the solution results in the deposition of Fe hydroxide. Furthermore, the released Fe²⁺ can be absorbed by rice through its roots, causing toxicity (Shamshuddin et al., 2014). The rice plant flows O₂ downward through the roots, creating an oxidized zone around it. Iron hydroxide will settle as a brown crust, preventing absorption of Fe²⁺. Shamshuddin et al. (2013) mention that rice defends itself from Fe²⁺ toxicity by hydrolyzing Fe³⁺ in water to produce acidity. If the pH of the water is > 3, the reaction follows the reverse order, precipitating Fe as Fe(OH)₃. This Fe(OH)₃ coats the rice roots, preventing further absorption of Fe²⁺. This is the specialty of rice plant that can be adaptive in stagnant conditions because of its ability to oxidize iron.

There were no significant differences in total N of soil, organic carbon and available phosphorus values between treatments of MRP (Figure 1b, 1c, and 1d). The Olsen's extractable phosphorus in the acid sulphate soils ranged from 39.3 mg.kg⁻¹ to 61.7 mg.kg⁻¹. The highest of concentration of available phosphorus were observed in plots MRP 1 (750 kg.ha⁻¹ Moroccan rock phosphate) and MRP 2 (1,000 kg.ha⁻¹ Moroccan rock phosphate). The average available phosphorus based on the rice producing areas (soils) of Belandean experimental farm was 51.66 mg.kg⁻¹. P is generally less agile in the soil

compared to other plant nutrients due to its strong iron absorption in swamps.

The total P content (Figure 1e) of swamplands was generally high, presumably due to the addition of sediment in runoff water in swamps. Schmitter et al. (2010) also reported large spatial variations in the physico-chemical properties of soils in rice fields in Northwest Vietnam. The results of this study were in line with the opinion of the importance of providing/ applying site-specific fertilizers based on the variability of soil P conditions and the response of rice to fertilization in increasing the availability of P. In this study, the P content of the soil was not sufficient for phosphate needs by rice plants, therefore the response of rice plants to the addition of P to this soil as fertilizers would be desired.

Effects of MRP application on the plant height (cm) and number of tillers of rice on acid sulphate soil

The application of MRP fertilizers significantly promoted the growth of rice (Table 2 and Table 3). Compared to the control (TSP) treatment, the plant height and number of tillers of rice treated with Moroccan rock phosphate at 1000.kg ha⁻¹ (MRP 2) increased by 3.6 % and 15.4 %, respectively. For all of the P sources namely control (TSP) and MRP applied, plant height increased with the increasing

Table 2. Plant height of rice as affected by Moroccan Rock Phosphate (MRP) application on acid sulphate soil

Treatments	30 DAP	60 DAP	90 DAP
Control	50.95 ± 2.54	61.95 ± 4.21	73.15 ± 2.95
750 kg.ha ⁻¹ MRP	47.25 ± 2.44	57.55 ± 3.87	66.40 ± 5.94
1,000 kg.ha ⁻¹ MRP	53.35 ± 3.13	68.00 ± 4.17	75.80 ± 3.61
1,250 kg.ha ⁻¹ MRP	49.25 ± 3.41	64.05 ± 5.11	64.00 ± 4.38

Remarks: MRP = Moroccan Rock Phosphate, DAP= Days After Planting

Table 3. Number of tillers of rice as effected by Moroccan Rock Phosphate (MRP) application on acid sulphate soil

Treatments	30 DAP	60 DAP	90 DAP
Control	14.80 ± 4.21	20.70 ± 2.10	21.70 ± 2.29
750 kg.ha ⁻¹ MRP	14.30 ± 3.87	19.30 ± 1.27	19.70 ± 1.41
1,000 kg.ha ⁻¹ MRP	15.30 ± 4.17	22.65 ± 0.77	25.05 ± 1.31
1,250 kg.ha ⁻¹ MRP	15.20 ± 5.11	24.40 ± 1.61	27.60 ± 3.35

Remarks: MRP = Moroccan Rock Phosphate, DAP= Days After Planting

P rates. The shortest plant heights (66.40 cm) were observed in plots MRP 1 (750 kg.ha⁻¹ Moroccan rock phosphate), while the tallest plant heights (75.80 cm) were observed in plots MRP 2 (1,000 kg.ha⁻¹ Moroccan rock phosphate) (Table 2). Plants heights at 60 DAP and 90 DAP in all treatments were significantly (p= 0.05) increased by rock phosphate application over controls (triple super phosphate). The increase in plant height with phosphorus fertilizer application was also reported earlier by Noonari et al. (2016) Detailed study of the data revealed that plant height of paddy grown on soil fertilized with 50 % SSP + 50 % RP showed comparatively higher, which was at par with 25 % SSP + 75 % RP and 100 % SSP at different growth stages of paddy. P plays a role in the formation of cell components (membranes) and various important processes in plant metabolism, including those related to plant physiology, as well as increasing the development and yield of rice (Ye et al., 2019).

The results showed that despite all different treatments, the number of tillers per hill increased until 90 DAP (Table 3). All phosphorus treatments produced significantly higher number of tillers compared to control (TSP). The highest number of tillers were recorded in the application of Moroccan rock phosphate at 1,000 kg.ha⁻¹, while the lowest number of tillers (10 to 12) were recorded in the

MRP 1 plots (750 kg.ha⁻¹ Moroccan rock phosphate). The number of tillers per hill significantly increased (P < 0.05) with the increasing P rate up to 1,250 kg.ha⁻¹ Moroccan rock phosphate. Similar to previous research reporting the same results, the number of tillers was positively influenced by the fulfillment of plant water and nutrient needs. Therefore, if there is an increase in the number of tillers per plant, there will be an increase in nutrient uptake, dry matter weight and dry grain yield. (Masni and Wasli, 2019).

Effects of MRP application on the rice grain yields on acid sulphate soil

The reaction of rice plants to phosphor fertilization with various P sources and application rates is shown by the grain yield in Figure 2. The yield of harvested dry grain was seen to increase with the increasing rate of P application from all sources. The trend of increasing grain yield was in the order of MRP 2 > MRP 1 > Control (TSP) > MRP 3, and the increase was significant (P < 0.05). The highest increase in grain yield was achieved by the addition of P from Moroccan phosphate rock at a rate of 1,000 kg.ha⁻¹ by 3.77 ton.ha⁻¹. The highest increase in grain yield due to P application was caused by an increase in the number of tillers and plant height (Table 2 and 3) due to increased P uptake by plants.

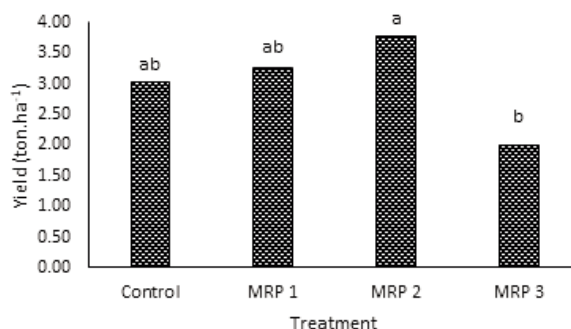


Figure 2. Effects of P Sources and application rates on the rice grain yields on acid sulphate soil. Control= 100kg.ha⁻¹ TSP, MRP 1= 750 kg.ha⁻¹ MRP, MRP 2= 1,000 kg.ha⁻¹ MRP, MRP 3= 1,250 kg.ha⁻¹ MRP

Table 4. The correlation of grain yield with yield component on acid sulphate soil

Parameters	Grain yield	Plant height	Panicles of height	The number of spikelet per panicle	1000-grain weight
Grain yield	-				
Plant height	0.62 ^{ns}	-			
Number of panicles	0.51 ^{ns}	0.45 ^{ns}	-		
The number of spikelets per panicle	0.053 ^{ns}	0.002 ^{**}	0.007 ^{**}	-	
1000-grain weight	0.09 ^{ns}	0.02 [*]	0.08 ^{ns}	0.013 [*]	-

Remarks: (ns)= not significant; (**)= significant (P<0.01); (*)= significant (P<0.05)

The presence of P available in the soil is related to the uptake of other essential plant nutrients because of the important P function in the roots of rice plants. Besides, the observations from the current study showed that yield components attributed were significantly related to the yield of harvested dry grain (Table 4). This means that the performance of rice plants, in this case the yield of harvested dry unhulled rice, is highly dependent on the improvement of soil fertility and productivity. Based on the increase in rice yields in this research, farmers should adopt the use of P fertilizer for improved soil fertility and sustainable productivity.

CONCLUSIONS

The results proved that the application of phosphorus fertilizers in the form of TSP and MRP increased the weight of rice dry grain yields on acid sulphate soil in the order of 1000 kg.ha⁻¹ Moroccan rock phosphate > 750 kg.ha⁻¹ Moroccan rock phosphate > Control (100 kg.ha⁻¹ TSP) > 1,250

kg.ha⁻¹ Moroccan rock phosphate . The highest dry grain yield was observed in the application of 1,000 kg.ha⁻¹ Moroccan rock phosphate . The application of phosphate fertilizer can increase soil pH, which affects the growth and yield of rice plants such as plant height and yield.

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