Direct application of reactive phosphate rock on improving maize yield in tidal swampland

A F Siregar1, Husnain2, I W Suastika1, N P S Ratmini3, I A Sipahutar1 and A Nassir4

1 Indonesian Soil Research Institute, Bogor, Indonesia
2 Indonesian Center for Agricultural Land Resources Research and Development, Bogor, Indonesia
3 South Sumatera Assessment Institute for Agricultural Technology, Palembang, Indonesia
4 OCP SA

E-mail: adha_siregar@yahoo.com

Abstract. Tidal swampland soil is characterized by low soil acidity and P availability, and high Al, Fe, S, and Na concentrations. Due to its productivity, tidal swampland needs an improved specific location technology. Reactive phosphate rock (RPR) which is characterized by its high reactivity and residual effect, and slow release is an option to overcome the P problem. The objective of this research was to study the effect of direct application of reactive phosphate rock in increasing maize yield in tidal swampland. The experiment was conducted at farmer’s field in Banyu Urip Village, Banyuasin District, South Sumatera. The research was arranged using randomized block design with four treatments and four replicates. The treatments consisted of farmers’ practice (P1), recommended single fertilizer (P2), recommended compound fertilizer (P3), and recommended RPR package (P4). The results showed that P4 treatment was able to improve plant growth and maize yield up to 25% compared to farmers’ practice. RPR package consists of RPR, dolomite, manure, Urea, and KCl of 1, 1, 2, 0.4, and 0.4 t ha⁻¹, respectively, in tidal swamp land achieved maize production up to 8.25 t ha⁻¹. This RPR package could be an applicable option in improving maize yield in tidal swamp land.

1. Introduction

As the consequence of increasing population growth, the demand of food, fibre, and animal feed would continue to grow. To achieve the food demand, Indonesian government has a target to become the world’s food basket by 2045 [1]. Due to limited of arable area, wetlands such as tidal swampland become an option to increase food production. This tidal swampland spreads mostly in Papua, Sumatra, and Kalimantan islands [2]. Tidal swampland occupies about 20,132,790 ha [3] and about 1,007,178 ha of it is located in South Sumatra [4].

Despite its large area, tidal swampland has some limiting factors, such as soil acidity and toxicity due to high Al and Fe concentrations, salinity, nutrient deficiency such as phosphorus (P), and high water table for an extended period [5-7]. This low P nutrient availability is related to low soil pH. This low soil pH will increase the solubility of Al, Fe, and Mn ions which can absorb P by forming Al-P bonds [8]. Based on its inundation and drainage intensity, tidal swampland is divided into four types, namely A, B, C, and D types [9]. Type A swampland is a condition having a high inundation or low tide which undergoes draining every day. The B type one is the inundation only occurs during high tide undergoing draining every day. As the type C and D tidal swamplands do not experience any
inundation during high or low tide but undergoes draining in Type C and a little bit draining in Type D every day. Moreover, it is noticed that the groundwater table fluctuation affects the tidal swampland characteristics and fertility of [10].

Regarding those limiting factors, an appropriate land management is needed to increase land productivity. Application of reactive phosphate rock (RPR) could be an option in improving maize yield in tidal swampland. Rock phosphate is the main natural materials for phosphate fertilizers and other phosphate products. The biggest deposit of rock phosphate (of about 75% of world deposits) is located in Morocco and then followed by China, Algeria, Syria, and Yordania [11]. Direct application of phosphate rock has become an attractive alternative due to its economic value, agronomically useful, and environmentally friendly. RPR which is characterized by low solubility, high reactivity and residual effect, and slow release. This low solubility and high reactivity of RPR have discourage its direct application where its chemical composition allows rapid dissolution in the soil solution and become as a P source in acid soils like in tidal swamplands.

Maize as one of the main food crops requires phosphorus as an essential nutrient for the growth cycle especially during flowering and grain filling stages [12]. Most of maize cultivation use high amount of P fertilizer to ensure the productivity, however, in certain condition like in acid soil the efficiency of P fertilizer is still low. Therefore, previous research activities have been addressed to rock phosphate direct application as P fertilizers as they have lower costs, agronomically more useful, and environmentally friendly than soluble P [13-16]. The low solubility characteristic of RPR has proven to have beneficial effects on plant growth in acid soils where soil acidity slowly releases plant available P [17]. Moreover, Kasno and Sutriadi [17] stated that RPR contains some accessory minerals that may provide micronutrients to improve plant growth. In this present work, the objective was to study the effect of the direct application of reactive phosphate rock (RPR) in improving maize yield in tidal swampland.

2. Methodology

2.1. Site description

The study was conducted in farmer’s field at Banyu Urip Village, Tanjung Lago, Banyuasin Sub District, Sumatera Selatan Province that lies on -2°66’308” S and 104°72’818” E. The soil is categorized as tidal swampland type C and the pyrite was found at >50 cm soil depth.

2.2. Field experiment

The field experiment was conducted at farmer’s field with a plot dimension 12 m x 50 m and was arranged using Randomized block design with four treatments and four replicates. The treatments are shown in Table 1. This experiment was started from June to October 2017. Maize of Pioneer 27 variety was used as an indicator plant with a planting space 75 cm x 25 cm.

This present study used Morocco RPR with 29.93 % P$_2$O$_5$ content and 10.94 % P$_2$O$_5$ solubility in 2% citric acid. The RPR was broadcasted during land preparation and incubated for three to five days, and then followed with lime application incubated for three to five days. Manure was put in plant hole at planting time, and Urea and KCl fertilizers were applied twice, 50% each at 7 and 30 days after planting (DAP). Harvesting activity was conducted at 110 DAP.

Table 1. List of treatments in this study.

| Treatments | Remarks |
|-------------|---------|
| P1 (Farmers practice) | 250 kg Urea ha$^{-1}$ + 100 kg SP-36 ha$^{-1}$ + 200 kg NPK ha$^{-1}$ |
| P2 (Recommendation based on PUTK with single fertilizer) | 400 kg Urea ha$^{-1}$ + 250 kg SP-36 ha$^{-1}$ + 100 kg KCl ha$^{-1}$ + 1 t dolomite ha$^{-1}$ + 2 t of manure ha$^{-1}$ |
| P3 (Recommendation based on PUTK with compound fertilizer as NPK 15:15:15) | 270 kg Urea ha$^{-1}$ + 84 kg SP-36 ha$^{-1}$ + 400 kg NPK ha$^{-1}$ + 1 t dolomite ha$^{-1}$ + 2 t of manure ha$^{-1}$ |
| P4 (Recommended RPR package) | 1 t RPR ha$^{-1}$ + 400 kg Urea ha$^{-1}$ + 400 kg KCl ha$^{-1}$ + 1 t dolomite ha$^{-1}$ + 2 t of manure ha$^{-1}$ |

Note: The manure that used was chicken manure.
2.3. Sampling and analyses methods

A composite soil sample was taken for initial soil analysis. Plant growth parameters as plant height, number of leaves, and stem diameter were observed at 2, 14, 28, 42, 56 DAP and at harvest time. Yield components observed consisted of yield, grain weight per cob, 1,000 grain weight, and biomass dry weight.

Statistical analysis using SPSS 20.0 was conducted with analysis of variance (ANOVA) and followed with Duncan’s Multiple Range Test (DMRT) procedures at P <0.01.

3. Results and discussions

3.1. Soil characteristic

Initial soil analysis results of the study site was presented on table 2. The site is categorized as tidal swampland type C where tidal swampland does not experience inundation event at high or low tide but undergoes draining every day [9]. With this condition, type C has the possibility for maize cultivation. In addition, there are some advantages in developing swampland such as water availability, resistant to seasonal drought, and provide a longer cropping period [5].

In the study site was, it found pyrite with a depth >50 cm and soil pH value of 4.3. Under waterlogged condition, this pyrite is in reduced condition and harmless, however, if this pyrite layer is exposed to air and oxidized, it will decrease the soil pH tremendously and will inhibit any plant growth. Moreover, under high soil acidity, clay mineral as montmorillonite will release Al$^{3+}$ into soil solution which lead to inhibit plant growth due to Al toxicity and nutrients deficiency. In term of effectiveness in acid soil such as tidal swampland, RPR shows its high effectiveness in acidic soil containing high concentration of Al, Fe, and Mn [18].

Soil texture was categorized as loam while soil C and organic N were categorized as high and medium contents (table 2). Soil P available was medium (24.35 mg kg$^{-1}$) with high P retention, which could lead to low soil P availability and low fertilizer efficiency. Exchangeable cation was categorized as low to medium level showing that nutrient availability at the site was relatively low.

Table 2. Initial soil analysis of study site at Banyu Urip Village, Tanjung Lago, Banyuasin Sub District, South Sumatera.

| Soil Properties                        | Values       | Criteria*          |
|----------------------------------------|--------------|--------------------|
| pH (1:5)                               |              |                    |
| H$_2$O                                  | 4.3          | Very acid          |
| KCl                                     | 3.8          | Very acid          |
| Texture                                |              |                    |
| Sand (%)                               | 1.15         | Loam               |
| Silt (%)                               | 34.45        |                    |
| Clay (%)                               | 64.40        |                    |
| Organic matter                         |              |                    |
| C (%)                                   | 4.65         | High               |
| N (%)                                   | 0.24         | Medium             |
| C/N                                     | 19.37        | High               |
| P-Bray 1(mg.kg$^{-1}$)                  | 24.35        | Very high          |
| K$_2$O Morgan (mg.kg$^{-1}$)            | 55           | Medium             |
| Exchangeable cation (NH$_4$-Asetat 1N, pH7) |              |                    |
| K (cmol(+) kg$^{-1}$)                   | 0.29         | Low                |
| Ca (cmol(+) kg$^{-1}$)                  | 2.01         | Low                |
| Mg (cmol(+) kg$^{-1}$)                  | 0.6          | Low                |
| Na (cmol(+) kg$^{-1}$)                  | 0.49         | Medium             |
| Total cation (cmol(+) kg$^{-1}$)        | 3.39         |                    |
| Cation exchange capacity (cmol(+) kg$^{-1}$) | 29.42        | High               |
| Base saturation (%)                    | 11.25        | Very low           |
| Al saturation (%)                      | 4.85         | Very low           |

*Bala Penelitian Tanah [19].
3.2. Effect of treatments on plant growth parameters

The effect of treatments on plant height is shown in Table 3. The result showed that there was no significant difference among treatments on plant height at 14, 28, and 42 DAP. However, at 56 DAP and harvest time, P4 treatment gave significant difference on plant height. The highest plant height was shown by P4 treatment while the lowest one by P1 treatment (farmer’s practice) being not significantly different from P2 and P3 treatments. P4 treatment with application of RPR as a complete package with manure and dolomite additions has underlined the importance of those inputs in improving crop performance on tidal swampland and this result is in agreement with previous result [20]. Recommended RPR package seems both environmentally and economically sound and a promising option for tidal swampland.

Table 3. Effect of treatments on plant height of maize.

| Treatment | 14 DAP | 28 DAP | 42 DAP | 56 DAP | Harvest |
|-----------|--------|--------|--------|--------|---------|
| P1        | 12.03 a| 56.75 a| 122.85 a| 210.65 a| 212.85 a|
| P2        | 11.71 a| 57.80 a| 116.53 a| 209.85 a| 215.45 a|
| P3        | 13.03 a| 61.20 a| 121.58 a| 216.60 a| 224.40 a|
| P4        | 12.54 a| 63.05 a| 128.10 a| 253.20 b| 265.20 b|

Note: Values followed by similar alphabet is statistically similar at \( \alpha = 5\% \).

The effect of treatments on stem diameter is presented in Table 4. The result showed that there was no significant difference on stem diameter at 14 and 28 DAP. It shows that stem diameter at P4 treatment increased and significantly different at harvest time. P4 gave the highest stem diameter throughout the observation, meanwhile farmer practice resulted in the lowest stem diameter average of 5.95 cm (Table 4). The increasing stem diameter in P4 was up to 36.64% compared to P1 treatment. Apart from the effect of RPR under P4 treatment, the N input derived from single fertilizer as Urea with sufficient dosage had increased the stem diameter compared to other treatments. Previous research stated that Urea performance in the acidic form is immediately hydrolysed in the soil to produce ammonium which is available for plant [21].

Table 4. Effect of treatment on stem diameter of maize.

| Treatment | 14 DAP | 28 DAP | 42 DAP | 56 DAP | Harvest |
|-----------|--------|--------|--------|--------|---------|
| P1        | 1.77 a | 2.84 a | 4.05 a | 5.67 a | 5.95 a |
| P2        | 1.71 a | 3.16 a | 4.46 ab| 5.70 a | 6.12 a |
| P3        | 1.85 a | 3.40 a | 4.18 a | 5.87 a | 6.20 a |
| P4        | 1.91 a | 3.19 a | 4.96 b | 7.72 a | 8.13 b |

Note: Values followed by similar alphabet is statistically similar at \( \alpha = 5\% \).

Table 5 shows the effect of treatments on the number of leaves. The result showed that throughout the observation, P4 treatment gave the highest number of leaves and significantly different at harvest observation. In line with other agronomy parameters, P1 treatment as farmer practice gave the lowest number of leaves.

It is recognized that leaves provide energy for growth and development [22] and play an important role during photosynthesis that leads to the growth and yield. The present result showed in line results where the highest number of leaves at P4 treatment followed by the highest yield (Table 5 and 6). Under P4 treatment, maize plants could uptake sufficient nutrient with the improving soil acidity and to produce a higher yield.
Table 5. Effect of treatment on number of leaves of maize.

| Treatment | 14 DAP | 28 DAP | 42 DAP | 56 DAP | Harvest |
|-----------|--------|--------|--------|--------|---------|
| P1        | 3.85 a | 5.45 a | 6.25 a | 12.50 a| 11.36 a |
| P2        | 3.73 a | 5.20 a | 6.48 a | 12.45 a| 13.50 a |
| P3        | 3.95 a | 5.43 a | 6.53 a | 12.93 a| 14.03 a |
| P4        | 4.18 a | 5.69 a | 6.60 a | 15.50 b| 17.93 b |

Note: Values followed by similar alphabet is statistically similar at α = 5%.

3.3. Effect of treatments on yield and yield component

The effect of treatment on yield and its component is presented on Table 6. The result showed that the highest yield was achieved at P4 treatment as much as 8.25 t ha\(^{-1}\) and significantly different. Meanwhile farmers practice as in P1 treatment had the lowest yield of 6.56 t ha\(^{-1}\) (Table 6). Application of RPR technology in tidal swampland could improve the maize yield up to 25.76% compared to farmer practice. The increasing yield on P4 treatment might be attributed to the P availability from RPR application in combination with manure as in agreement with previous study [20,23].

Furthermore, grain weight per cob followed a similar trend to grain yield, as P4 treatment produced the highest grain weight per cob of 1,490.88 gr and was significantly different. The low grain yield under P1 treatment might be due to soil acidity as no dolomite application. As in acid soil with a high concentration of Al and Fe, most phosphorus ions are fixed by Al and Fe [24]. It is known that phosphorus plays an important role at several plant key processes including photosynthesis, development of roots, and crop yield and quality [25,26]. Regarding to biomass dry weight and 1,000 grains weight, the result showed no significant difference among treatments. However, P4 tended to increase the biomass weight and 1,000 grains weight (Table 6).

The previous result that has been conducted in Indonesia has proven that Morroco RPR containing the highest citric acid extractable P\(_2\)O\(_5\) among the phosphate rocks tested gave significant effect in improving maize yield in acid soil [17,18]. Moreover, RPR with its residual effect could contribute phosphorus for plant uptake up to six planting seasons [17].

Table 6. Effect of treatment on yield component of maize.

| Treatment | Biomass dry weight per plant (g) | Grain weight per cob (g) | 1,000 grains weight (g) | Yield (t ha\(^{-1}\)) |
|-----------|---------------------------------|--------------------------|------------------------|----------------------|
| P1        | 86.45 a                         | 1,287.50 a               | 234.63 a               | 6.56 a              |
| P2        | 91.21 a                         | 1,310.50 a               | 309.58 a               | 7.59 a              |
| P3        | 93.40 a                         | 1,398.88 a               | 307.35 a               | 7.78 a              |
| P4        | 95.78 a                         | 1,490.88 b               | 320.90 a               | 8.25 b              |

Note: Values followed by similar alphabet is statistically similar at α = 5%.

4. Conclusions

Type C tidal swampland with its limiting factors such as low soil pH and P availability has a potential for maize cultivation with an appropriate fertilizer management. Application of RPR incorporated with dolomite, Urea, KCl, and manure could improve the maize yield significantly up to 8.25 t ha\(^{-1}\). This result has proven that recommended RPR package could be a promising option for improving maize productivity in tidal swampland with its environmentally friendly sound and residual effects since RPR is a natural source of P with no chemical added on it.

Acknowledgments

All authors contributed equally to this manuscript.
References

[1] Sulaiman A A, Simatupang P, Kariyasa IK, Subagyo K, Las I, Jamal E, Hermanto, Syahyuti, Sumaryanto and Suwandi 2008 Sukse Swasemba Indonesia Menjadi Lumbung Pangan Dunia 2045 (in Bahasa) (Jakarta: IAARD Press)

[2] Ritung S, Wahyunto, Nugroho K, Sukarman, Hikmatullah, Suparto and Tafakresnanto C 2015 Sumberdaya Lahan Pertanian Indonesia: Luas, Penyebaran dan Potensi Ketersediaan (in Bahasa) (Jakarta: IAARD Press)

[3] Nugroho K and Suriadikarta D A 2010 Kapasitas produksi bahan pangan lahan rawa Analisis Sumber Daya Lahan Menuju Ketahanan Pangan Berkelanjutan (in Bahasa) eds Sumarno and Nata Suharta (Jakarta: Badan Litbang Pertanian) ISBN 978-602-8977-06-7 pp 71–87

[4] Mulyani A and Sarwani M 2013 Karakteristik dan potensi lahan sub optimal untuk pengembangan pertanian di Indonesia (in Bahasa) Jurnal Sumberdaya Lahan 7(1)

[5] Noor M, Syahbuddih H and Sarwani M 2013 Lahan Rawa: Penelitian dan Pengembangan (in Bahasa) (Jakarta: IAARD)

[6] Wignyosukarto B S 2013 Leaching and flushing of acidity in the reclamtion of acid sulphate soil, Kalimantan, Indonesia Irrig. Drain 62 75–81

[7] Anda M, Siswanto A and Subandiono R E 2009 Properties of organic and acid sulfate soils and water of a ‘reclaimed’ tidal backswamp in Central Kalimantan, Indonesia Geoderma 149 54–65

[8] Kselik R A L 1990 Water management on acid sulphate soils Pulau Petak, South Kalimantan. Papers Workshop on Acid Sulphate Soils in The Humid Tropics: Water management and soil fertility (Jakarta: Agency for Agricultural Research and Development/AARD and The Land and Water Resource Group/LAWOO) pp 249–276

[9] Grant R F, Desai A R and Sulman B N 2012 Modelling contrasting responses of wetland productivity to changes in water table depth Biogeoosciences 9 4215–4231

[10] USGS 2013 U.S. Geological Survey, Mineral Commodity Summaries, January 2015 https://minerals.usgs.gov/minerals/pubs/commodity/phosphate_rock/mcs-2015-phosp.pdf

[11] Vasconcellos C A, Pitta G V E, Franca G E and de Alves V M C 2000 Fósforo para o milho? Cultivar 12 8–9

[12] Silva U C, Medeiros J D, Leite L R, Morais D K, Cuadros-Orellana S, Oliveira C A, de Paula Lana U G, Gomes E A and Dos Santos V L 2017 Long-Term Rock Phosphate Fertilization Impacts the Microbial Communities of Maize Rhizosphere Front. Microbiol. 8 1266 doi: 10.3389/fmicb.2017.01266

[13] IFDC 1978 Proceedings of Seminar on Phosphate Rock for Direct Application International Fertilizer Development Center, Muscle Shoals, Alabama, USA

[14] Sanchez P A, Shepherd K D, Soule M J, Place F M, Buresh R J, Izac A M N, Mukwenye A V, Kwesiga G R, Ndiritu C G and Woomer P L 1997 Soil fertility replenishment in Africa: an investment in natural resource capital In Replenishing Soil Fertility in Africa Soil Science Society of America Special Publication No. 51, Madison, WI, USA

[15] Ahn P M 1993 Tropical Soils and Fertilizer Use (UK: Longman)

[16] Husnain, Rochayati S, Sutridi M T, Nassir A and Sarwani M 2014 Improvement of soil fertility and crop production through direct application of phosphate rock on maize in Indonesia Procedia Engineering 83 336–343

[17] Kasno A and Sutridi M T 2012 Indonesian rock phosphate effectiveness for maize crop in Ultisols soils AGRIVITA 34(1) DOI: http://doi.org/10.17503/agrivita.v34i1.134

[18] Adembaa J S, Kwacha J K, Esilabab A O and Ngaric S M 2015 The Effects of Phosphate Fertilizers and Manure on Maize Yields in South Western Kenya East African Agricultural and Forestry Journal 81(1) 1–11 http://dx.doi.org/10.1080/00128325.2015.1040640

[19] Lambert R J, Mansfield B D and Mumm R H 2014 Effect of leaf area on maize productivity Maydica 59 58–64
[20] Waigwa M W, Othieno C O and Okalebo J R 2003 Phosphorus availability as affected by the application of phosphate rock combined with organic materials to acid soils in Western Kenya Expl. Agric. 39 395–407 DOI: 10.1017/S0014479703001248

[21] Adnan A, Mavinic D S and Koch F A 2003 Pilot-scale study of phosphorus recovery through struvite crystallization-examining to process feasibility Journal of Environmental Engineering and Science 2(5) 315–324

[22] Raghothama K G 1999 Phosphate acquisition Annu. Rev. Plant Biol. 50 665–693 doi: 10.1146/annurev.arplant.50.1.665

[23] Schachtman D P, Reid R J and Ayling S M 1998 Phosphorus uptake by plants: from soil to cell Plant Physiol 116 447–453 doi: 10.1104/pp.116.2.447

[24] Balai Penelitian Tanah 2009 Petunjuk Teknis Analisis Kimia Tanah, Tanaman, Air dan Pupuk (in Bahasa) (Bogor: Balai Penelitian Tanah)

[25] Demari G H, Carvalho I R, Nardino M et al. 2016 Importance of nitrogen in maize production International Journal of Current Research 8(08) 36629–36634

[26] Imanudin M S, Armanto M E and Bakri 2019 Determination of planting time of watermelon under a shallow groundwater table in tidal lowland agriculture areas of South Sumatra, Indonesia Irrigation and Drainage Journal 68(3) 488–495 https://doi.org/10.1002/ird.2338