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Rice Yield Related to Fertilizers Applied by Farmers on Two Areas of Marginal Peat Soil in Bengkulu Indonesia

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Abstract: The research was intended to identify amounts of fertilizers applied by small-scale farmers related to rice yield cultivated on marginal peat soils in irrigated paddy fields in Bengkulu. The study was conducted at two peat areas; Pekik Nyaring Village, Air Hitam irrigated rice fields in Central Bengkulu and Sumber Makmur Village, Air Manjuto irrigated areas, Mukomuko Bengkulu Province from June to September 2020. A combination of purposive, snowballing samples was used to find 65 farmers as key informants. Collected data and information about fertilizers applied by farmers for paddy cultivation. Multiple regression analysis was used to find cumulative and partial contribution and significance effect of the fertilizers applied to rice yields. The result showed that fertilizers applied by the farmers significantly increase rice yield but the fertilizers played not great portion and urea fertilizer gave the highest contribution. Rice yield harvested by farmers was lower compare to the average rice productivity in Bengkulu because the doses of fertilizers applied were lower than the recommend dose. Rice yield can be improved through increasing the fertilizers dose. Optimum dose of fertilizers applied should be 567 kg Urea ha^{-1}, 323 kg SP-36 ha^{-1}, 790 kg ha^{-1} or 912 kg NPK ha^{-1}. High soil porosity and lateral water conductivity however may cause inefficiency of fertilizers applied in marginal peat soils because soluble nutrients in peat solution carried out the fertilizers from root zone by water flow.

Keywords: Fertilizers, Irrigated, Low Productivity, Marginal Peat Lands, Paddy Yield

Introduction

Rice is a strategic commodity in Indonesia (Mariyono, 2014) due to the status as the main staple food (Aprillya *et al*., 2019a). However, rice production in Indonesia is insufficient to meet population needs (Mustikarini and Santi, 2020). In 2019, rice production in Indonesia was about 54.6 M tons harvested from rice fields of 10.67 Mha (BPS-Statistics Indonesia, 2020). Furthermore, since 2000, Indonesia has begun importing rice which reached its peak in 2018 with a total import of 2.14 M tons. If Indonesia does not want to depend on rice imports, paddy production must continue to be increased (Aprillya *et al*., 2019b).

Indonesian government had targeted of rice self-sufficiency and to become the world's food basket by 2045 (Sulaiman *et al*., 2018). Considering limitations in the availability of highly productive arable land, development and optimizing of peatland for paddy production is an alternative option to ensure national food security (Surahman *et al*., 2018). The area of peatland in Indonesia covers about 16 to 27 Mha (Jaya *et al*., 2018; Page *et al*., 2007) or about 20.073 Mha (Rieley *et al*., 1996) and in Bengkulu covered about 63,000 ha (Wahyunto *et al*., 2004). However, the utilization of peatland for agriculture faces many obstacles such as acidity, low base saturation, organic acid toxicity and nutrient deficiency (Septiyana *et al*., 2017) both macro and micronutrients (Maftu'ah and Nursyamsi, 2019).

Peat soil is marginal soil for agriculture due to its low fertility (Ompusunggu *et al*., 2020). Peat contains an abundance of Nitrogen (N), but a low in mineral nutrients. In addition, the nitrogen is mainly in form of organic nitrogen, which is not directly available to plants (Moilanen *et al*., 2010). Peat soils are acidic in nature (pH 3.3-4.7), low content of exchangeable bases and total P_2O_5 and K_2O (HCl 25%) (Hikmatullah and Sukarman, 2014). The physical constraints of peat soil related to low nutrients availability, high macro-pore flow and soil hydraulic conductivity (Kechavarzi *et al*., 2010; Mustamo *et al*., 2016) causing nutrients leached (Maftu'ah *et al*., 2014). Based on these properties, the peat soils were grouped as oligotrophic (Wheeler and Proctor, 2000) ombrogenous peat (Sahfitra *et al*., 2020). Therefore, an appropriate management of marginal peat soil for rice cultivation is necessary to overcome these various constraints.

The fertility status of peat soils can be improved by applying an optimum fertilization (Allamah *et al*., 2018). Deficiency of N, P and K nutrients will cause less optimum on plant growth, while the excessive amount of N, P, K nutrients can both inhibit plant growth and cause environmental pollution (Duan *et al*., 2007). Rice yields were increased by applying fertilizer N, P and K in sufficient amounts (90 N, 90 P_2O_5 and 90 kg K_2O ha^{-1}) to overcome deficiencies and maintain soil fertility (Dogbe *et al*., 2015). N, P and K fertilizers affected the growth and the flowering time of rice (Ye *et al*., 2019). Furthermore, the grain numbers per panicle increased by 31.4, 23.9 and 48.2% and the panicle numbers increased by 55.1, 29.2 and 6.7% after application of N, P, K fertilizers. Application of 315 kg urea ha^{-1}, 35 kg SP-36 ha^{-1} and 90 kg KCl ha^{-1} resulted in the best effects on the growth of rice plants grown on the peat tidal lowland indicated by the highest both maximum number of tillers and productive tillers (Aksani *et al*., 2018).

Recommendation rate of N fertilizer for rice was with low productivity (5 tons ha^{-1}) needed 200 kg urea ha^{-1}, medium productivity (5-6 tons ha^{-1}) needed 250-300 kg urea ha^{-1} and high productivity (>6 tons ha^{-1}) needed 300-400 kg urea ha^{-1} (Buresh, 2010). P and K recommendation following government legislation for rice cultivation adjusted to nutrient status in soil in low nutrient status of P and K was 100 kg SP36 and 100 kg KCl ha^{-1}, medium status of P and K was 75 kg SP36 ha^{-1} and 50 kg KCl ha^{-1} and in high nutrient status of P and K was 50 kg SP36 ha^{-1}and 50 kg KCl ha^{-1} (Samijan *et al*., 2017). High productivity (5.73±0.49 t ha^{-1}) was produced from the application of 60 kg P_2O_5 ha^{-1} or about166 kg SP36 ha^{-1} in tidal peat soil (Masganti and Nurmili, 2017). Therefore, each region has different soil fertility characteristics, so that the recommended fertilizer rate is less relevant to the varying soil fertility conditions in each region.

Most peatlands in Bengkulu had been built irrigation dam and channel facilities such as irrigation infrastructures of Air Manjuto covered areas 9,493 ha, Air Alas 4,500 ha, Air Seluma 7,467 ha, Air Riak Siabun 1,500 ha, Air Hitam 1,500 ha, Peninjauan 1,411 ha and Penago 1,084 ha (Zulkarnain, 2016). Some parts of rice fields in these irrigation areas had been converted to oil palm plantation by local farmers because of lack of water supply, pest and disease attacks and low productivity of rice field and sometimes the failure of harvest due to low soil fertility (Yanti *et al*., 2013; Astuti *et al*., 2011). Therefore, evaluating fertilizers applied to marginal peat soils for rice cultivation is important for sustainable staple food production in Bengkulu. This study was aimed to determine significant effect of N, P, K, NPK compound fertilizers and dolomite applied by small-scale farmers and optimum level of them to rice yield cultivated on marginal peat soils at two irrigated rice field in Bengkulu Indonesia.

Materials and Methods

A case study was to evaluate N, P, K, NPK compound fertilizers and dolomite applied by small-scale farmers related to rice yields cultivated on marginal peat soils at 2 (two) irrigated peat rice fields in Bengkulu; Sumber Makmur village, Air Manjuto irrigated area in Mukomuko Regency and Pekik Nyaring Village, Air Hitam irrigated area in Central Bengkulu Regency, Bengkulu Province (Fig. 1) conducted from June to September 2020. Flow chart of the research showed in Fig. 2.

Good climatic conditions and landscapes covering the irrigated rice fields favor for intensively rice farming systems however peat soil fertility could be constraint for sustainable rice cultivation. Rainfall average 295.8 mm month^{-1} with number rainy days of 19 days in a month. Maximum temperatures were range between 32- 34°C and minimum temperatures range between 22-23°C with relative humidity in in range between 80-88%. These cultivated rice fields are covered in marginal peat soils.

A combination of purposive, snowballing samples was used to find 65 farmers as informants who had planted rice on their paddy's fields. Collected data and information about the sustainable rice cultivation on marginal peat soils involved a broad attribute of ecological, economical, socio-cultural, technological and institutional and policies dimensions based on farmers perspectives. This study however only used quantitative data of the rice yields, amount of urea, SP36, KCl, NPK (15% N, 15% P_2O_5, 15% K_2O, 9% S) fertilizers and dolomite applied by the farmers on the previous planting season.

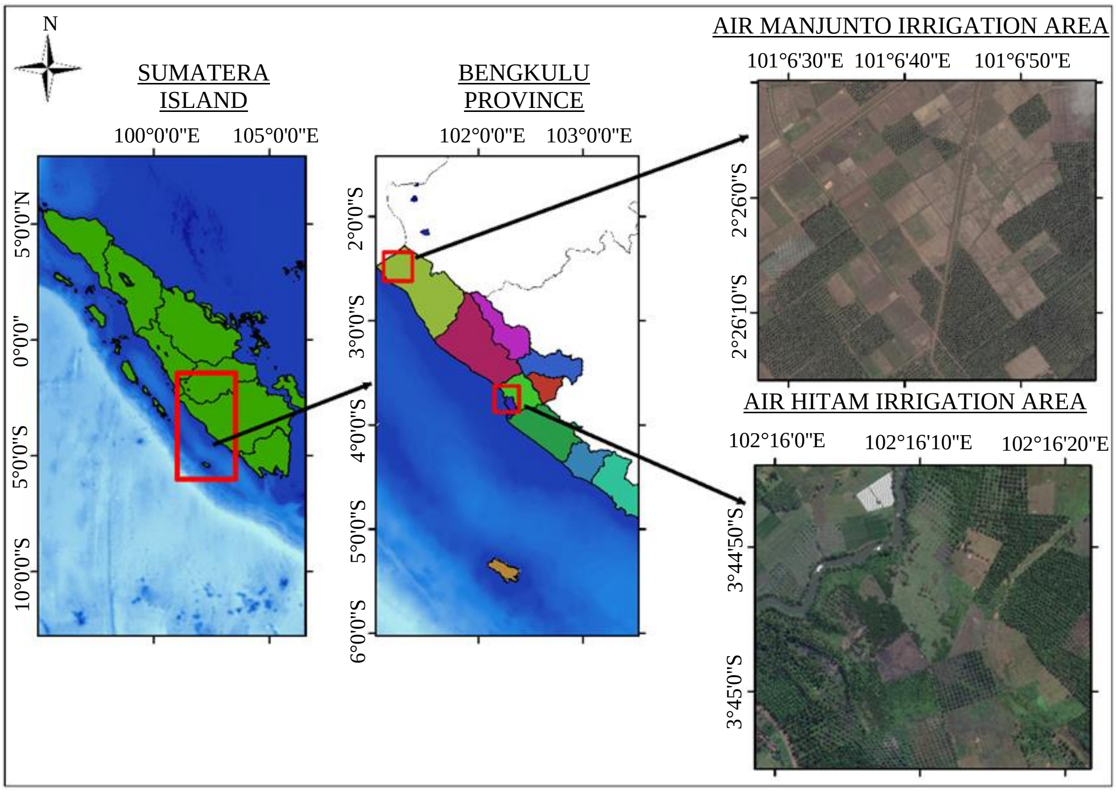

Fig. 1: Two site research of rice peat soils in Bengkulu

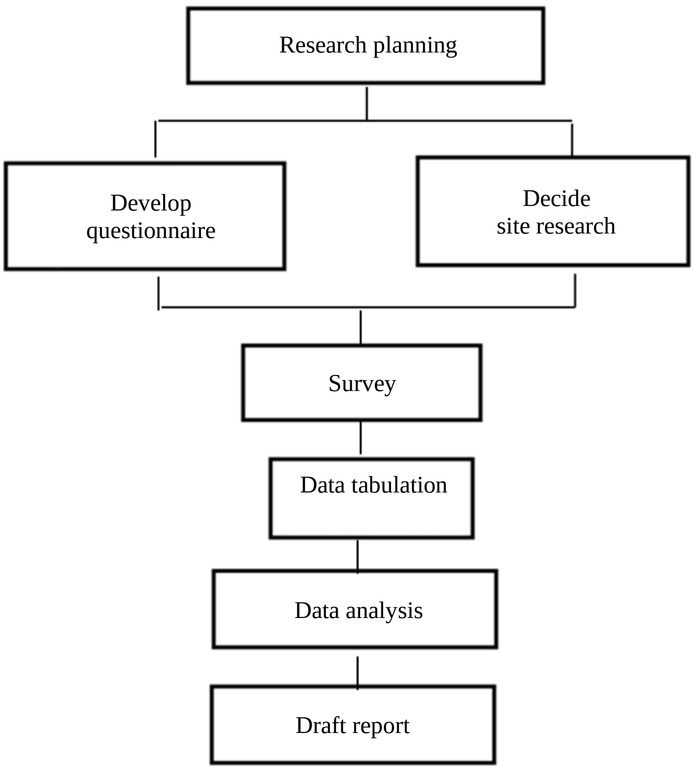

Fig. 2: Reseach flow chart

Multiple regression analysis was used to find cumulative and partial contribution and significance effect of the fertilizers applied to rice yields. The regression model which Y is the continuous response variable as dependent variable while X_1, X_2, Xp as the predictor variables or independent variable (Alexopoulos, 2010) revealed as follow:

$$\begin{aligned} Y &= \beta_0 + \beta_{UR} X_{UR} + \beta_{SP36} X_{SP36} + \beta_{KCL} X_{KCL} \\ &+ \beta_{NPK} X_{NPK} + \beta_{DOL} X_{DOL} + \sigma(Y) \end{aligned} \quad (1)$$

Where:
Y = The rice yield (kg ha^{-1})
β_0 = The intercept
β_{UR} = The regression coefficient of urea
X_{UR} = Urea (kg ha^{-1})
β_{SP36} = The regression coefficient of SP36
X_{SP36} = SP36 (kg ha^{-1})
β_{KCl} = The regression coefficient of KCl
X_{KCl} = KCl (kg ha^{-1})
β_{NPK} = The regression coefficient of NPK
X_{NPK} = NPK (kg ha^{-1})
β_{DOL} = The regression coefficient of dolomite
X_{DOL} = Dolomite (kg ha^{-1})
$\sigma(Y)$ = The residual standard deviation.

To find optimum level of each fertilizer applied, partial analysis used polynomial regression (Ekpenyong *et al.*, 2008) between rice yield and each fertilizer applied as follow equation; for example relation between rice yield and urea applied:

$$Y = \beta_0 + \beta_1 X_{UR} + \beta_2 X_{UR^2} + \sigma(Y) \quad (2)$$

Where:
Y = The rice yield (kg ha^{-1})
β_0 = The intercept
β_1 and β_2 = The regression coefficient of urea
X_{UR} = The urea (kg ha^{-1})
$\sigma(Y)$ = The residual standard deviation

The optimum dose of each fertilizer applied to rice yield could be determined from (Young and Loomis, 2014):

$$\beta_1 + 2\beta_2 X_{UR} = 0 \quad (3)$$

Where:
β_1 and β_2 = The regression coefficient of urea
X_{UR} = The urea (kg ha^{-1})

Multiple regression analysis and partial analysis with polynomial regression between the rice yields and each fertilizer applied used SPSS and Excel software facility.

Results

Farmers in Pekik Nyaring village, Air Hitam and Sumber Makmur village, Air Manjuto irrigation area still continue to cultivate paddy field for rice production although harvested rice indicated a low productivities. An average rice yield from previous planting calender harvested about 2,858 kg ha^{-1} at Air Hitam area and about 3,060 kg ha^{-1} at Air Manjuto area and average yield from two location was about 2,982 kg ha^{-1}. The effect of fertilizers applied by farmers was significant to rice yields at the marginal peat soils on two locations with the significance value of Sig. 0.020* as shown in Table 1.

The average rice yield 2,982 kg ha^{-1} was based on fertilizers application with amount of 125 kg urea, 106 kg SP36, 76 kg KCl, 141 kg NPK and 167 kg dolomite ha^{-1}. Coefficients and significance test of the fertilizers applied related to rice yield on marginal peat soil as shown Table 2:

$$\begin{aligned} Y &= 2272.741 + 3.026 X_{UR} + 1.547 X_{SP36} - 3.732 X_{KCl} \\ &+ 2.332 X_{NPK} + 0.725 X_{DOL} + 283.163 \text{ with } R^2 = 0.199* \end{aligned} \quad (4)$$

Based on the equation, application of the fertilizers by the farmers increased in rice yield to 2,982 kg ha^{-1} comparing without fertilizer resulted in 2272.741 kg ha^{-1}, or additional increasing rice yield about 710 kg ha^{-1} only. Application of dolomite as ameliorant for neutralizing soil pH and nutrient supply for calcium and magnesium almost no effect with the value 0.16% to rice yield on these marginal peat soils. Every kg of dolomite applied by the farmer to the rice field would increase only about 0.232 kg ha^{-1} harvested rice grain.

Relation between rice yields and each fertilizer applied by the farmers to the paddy field on two peat soils in Bengkulu was shown in Table 3.

Table 1: Analysis of variance rice yield related to fertilizers applied

Model	Sum of squares	df	Mean square	F	Sig.
Regression	2.807E7	5	5614002.37	2.925	0.020*
Residual	1.133E8	59	1919592.23		
Total	1.413E8	64			

Table 2: Coefficients and significance test of the fertilizers applied

	Unstandardized coefficients				
Variable	B	Std error	Std coefficient B	t	Sig.
Constant	22272.741	282.163		8.026	0.000
Urea	3.026	1.209	0.331	2.503	0.015
SP36	1.547	2.012	0.112	0.769	0.445
KCl	3.732	2.302	-0.345	-1.621	0.110
NPK	2.332	1.271	0.346	1.834	0.072
Dolomite	0.725	1.055	0.125	0.687	0.495

Relation between rice yield and fertilizers applied by farmers was shown in equation below

Table 3: Polynomial regression, R^2, optimum level of each fertilizer applied by the farmers

Fertilizer	Equation	R^2	Mean fertilizer	$\delta Y/\delta X = 0$	Max. rice yield
Dolomite	$Y = 2943.3+0.2324 X_{DOL}$	0.0016	167		
Urea	$Y = 2272.7+8.0591 X_{UR}-0.0071X_{UR}^2$	0.1750	125	567	4559
SP36	$Y = 2577+5.7433 X_{SP36}-0.0089X_{SP36}X^2$	0.0330	106	323	3504
KCl	$Y = 2857.4+2.053 X_{KCl}-0.0013X_{KCl}^2$	0.0160	76	790	3667
NPK	$Y = 2449.3+5.1077 X_{NPK}-0.0028X_{NPK}^2$	0.1370	141	912	4778

Application of SP36 by the farmers in an average 106 kg ha^{-1} was not significant to rice yields. Every kg SP36 applied by the farmers could raise 5.7 kg rice grain from the cultivated peat soils. Application of KCl fertilizer applied by the farmers had an effect about 3.3% to the rice yield cultivated on two locations of the marginal peat soils so every kg KCl applied would give additional harvested rice grain only about 2.052 kg ha^{-1}. NPK compound with average 141 kg ha^{-1} contributed 13.7% to improving rice yield and each kilogram of NPK applied increased only about 5.105 kg ha^{-1} rice grain. Urea applied by the farmers with average dose 125 kg ha^{-1} contributed only 17.5% to the harvested rice. Every kg urea applied to the rice field could additional increase in harvested rice grain about 8 kg ha^{-1}.

Discussion

The rice productivities from these areas were far below or about 65% only comparing to rice productivity in Bengkulu 4,603 kg ha^{-1} and national rice productivity 5,114 kg ha^{-1} (BPS-Statistics Bengkulu, 2020). Fertilizers applied was significantly effect to the rice yields however the application of fertilizers contributed only about 19.9% to the harvested rice. The doses of fertilizers applied by small-scale farmers to provide available plant nutrients namely nitrogen, phosphorus, potassium, calcium and magnesium in these areas were far below the recommended doses in order to harvest in high yields.

Fertilizers applied by the farmers increased in rice yield about 710 kg ha^{-1} and the result was slightly better than other peat areas which lime application with dolomite 500 kg ha^{-1} and fertilizers applied with urea 100 kg ha^{-1}, TSP 200 kg ha^{-1} and KCl 125 kg ha^{-1} on rice field with peat thickness 150 cm, top soil with peat decomposition of sapric only produced rice in range 2,000-2,500 kg ha^{-1} (Azhari *et al*., 2017).

Liming with dolomite was almost no effect to rice yield. From previous study, soil acidity in these field was range between pH 4.8 and pH 5.2 (Riwandi *et al*., 2009), pH 4.7 and pH 6.1 and cation exchange capacity (CEC) in range 29.68-81.90 cmols kg^{-1} (Akmaldi *et al*., 2020). Ameliorated acid peat soil with doses of dolomite up to 10,000 kg ha^{-1} was followed by linearly increase in soil pH, available P, exchangeable K, Ca, Mg and CEC (Ilham *et al*., 2019). Application of dolomite up to 2,000 kg ha^{-1} on peat soil revealed rice growth and yield increase in linearly trend (Idwar *et al*., 2004). When soil acidity in peat soil was range between pH 5.0 and pH 5.6, application of lime for amelioration soil acidic constraint for rice growth required dolomite from 2,600 kg ha^{-1} to 5,490 kg ha^{-1} (Gultom and Mardaleni, 2014). Neutralizing soil acidity and improving nutrient content in cultivated peat soil, it should implemented ameliorants and fertilizers applied. Amelioration treatments could improve soil pH, raise available nutrients and increase in soil adsorption for nutrient exchanges (Ratmini, 2012).

SP36 applied gave effect 3.3% was not significant to rice yields. Nitrogen and phosphorus are applied to agricultural systems in large quantities and a deficiency of either nutrient leads to yield losses and triggers complex molecular and physiological responses (Vinod and Heuer, 2012). Deficiency in phosphorus can severely limit rice yields (Islam *et al*., 2008). P deficiency caused a significant reduction in the net photosynthesis rate in rice plants (Balemi and Negisho, 2012). Phosphorus deficiency on rice can significantly reduce yields often noticed on low pH soils (Fageria, 2014).

KCl fertilizer applied also had a minute effect to the rice yield. Application doses of SP36 and KCl applied by the farmers almost equal to the recommend dose but the effects of these were very tiny to the rice yields. Lower rice yield when fertilizers applied in higher amount could be caused by continuous leaching of soluble minerals. Phosphorus could lose from root zone about 90% within 15 days through continuous leaching (Maas *et al*., 2000). Furthermore, potassium was the easiest nutrient lost from root zone because potassium was a mobile one charge cation. Also, lime applied in peat in short time reacted with peat acid solution H-organic to be Ca- and Mg-organic in organic colloid and then carried away with sub surface water flow lose from paddy fields. Efficiencies of N, P and K were only 24.8, 10 and 25.4% in rice paddy, respectively, most of which is lost through volatilization and leaching (Liu *et al*., 2019).

The NPK fertilizer applied was not significant effect to improve rice yields cultivated on the two marginal peat soils. The optimum dose NPK needed for the highest yield of rice cultivated on the two marginal peat soils was 912 kg NPK ha^{-1}. The optimum NPK doses mean 136.8 kg N, 136.8 kg P and 136.8 kg K ha^{-1} could increase rice yield to 4,778 kg ha^{-1}.

Urea affected significantly to the rice yield in two peat soils but its applied was not efficient. High N loss and low N use efficiency, caused by high N fertilizer inputs and inappropriate fertilization patterns, have become important issues in the rice (*Oryza sativa* L (Liu *et al*., 2016). Improper N management during cultivation due to improper management may cause the missing of N application during a certain developmental stage (Xiong *et al*., 2018). Nitrogen, the most important mineral nutrient for plants, is critical to agricultural production systems. Furthermore, N deficiency severely affects rice growth and decreases rice yields (Zhang *et al*., 2015). The amount of urea applied by the farmers was far below the recommend dose for high productivity 300-400 kg ha^{-1}. The optimum dose of urea needed for the highest rice yield projected 4,559 kg ha^{-1} on two peat soils was 567 kg ha^{-1}.

In order to reach equal productivity with average rice field in Bengkulu Province and national rice productivity, application of fertilizers by the local farmers should be added in huge amount of these fertilizers. However, fertilizers application to paddy fields should be managed properly in order to avoid nutrients loses from root zones because of sub surface flow away. Nutrients lose through drainage leaching caused inefficiency nutrient availability from fertilizers applied in porous peat soils should be concerned for implementation good agricultural practices in paddy cultivation in peat soils (Pulunggono *et al*., 2019).

Conclusion

Rice cultivations on irrigated marginal peat soils in Bengkulu Province produced lower yield than irrigated rice field in mineral soils. In order to get maximum yield, the fertilizers for paddy cultivation in peatland needed enormous dose of nitrogen, phosphorus, potassium in combination with good agricultural practices to prevent nutrients loses carried away by subsurface drainage. Cultivation of marginal peat soil for rice production should be initiated with ameliorant to overcome the acidic constraint by broadcasting lime Optimum level of fertilizers were 567 kg Urea ha^{-1}, 323 kg SP36 ha^{-1}, 790 kg KCl ha^{-1}, or 912 kg NPK compound ha^{-1}.

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Author’s Contributions

Muhammad Faiz Barchia: Designed the research plan, participated in all experiments and contributed to the writing of the manuscript.

Andi Ishak: Verified the analytical methods, analyzed the data.

Satria Putra Utama: Carried out the experiments.

Ridha Rizki Novanda: Coordinated the mouse work.

Ethics

Concerning peat conservation and rice production problems, there is no conflict of interest from authors facing with them.

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