The use of soil ameliorants and fertilizers to increase the yields of rice and maize in ultisols Lampung, Indonesia

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Abstract. The Ultisols has high soil acidity, Al and Fe concentration and low organic matter, base saturation, and CEC, that limit the growth of rice and maize. The research aimed to evaluate the effectiveness of the application of fertilizers, soil ameliorant, and their combinations to improve Ultisol productivity including to increase rice and maize crops yields. This research was conducted at the Taman Bogo experimental station, Lampung Timur District, for two growing seasons (GS-1 and GS-2) in 2019. Field experiment used randomized block design with eight treatments and three replications. The treatments were included control, recommendation dosage of fertilizers (for rice: 250 kg urea ha^{-1}, 200 kg SP-36 ha^{-1}, 75 kg KCl ha^{-1}; for maize: 300 kg urea ha, 175 kg SP-36 ha^{-1}, 100 kg KCl ha^{-1}), and combination of the recommendation dosage of fertilizers, manure, biofertilizer, and rock phosphate. Recommendation dosage of fertilizer was determined using upland soil test kit (made by Indonesian Soil Research Institute). The result showed that soil ameliorant and biofertilizer application gave significant effect to improve soil chemical physic properties and plant yields.

1. Introductions
Optimization of the suboptimal land utilization is needed to support the national food security program. Suboptimal land is a land with poor soil physical, chemical, and biological properties. One of the suboptimal lands is acid dry land which is distributed in Sumatra, Kalimantan and Sulawesi [1]. Acid dry land area in Indonesia reaches 108.8 million ha and about 62.64 million ha is suitable for food crop and plantation [2].

The acid dry land of Ultisol and Oxisols occupy the widest area in Indonesia [3]. Total area of Ultisol in Indonesia up to 45.8 million ha or about 25% of the total land area of Indonesia [4]. Previous research stated that the parent material of Ultisol determined the mineral composition. Generally, Ultisol has a potency of Al toxicity and low organic matter content, poor nutrient content, especially phosphorous an exchangeable cations, i.e Ca, Mg, Na and K also, the soil has high Al content, low cation exchange capacity (CEC) and susceptible to erosion [5].

Low nutrients availabilities in Ultisol might be due to intensive base wash while organic matter content is low due to the rapid decomposition process and partly due to erosion carries it away. The Ultisol
which has a kandic horizon, the fertility level depends on organic material on the topsoil layer. Kaolinite domination of Ultisols does not contribute to CEC so that CEC only depends on organic matter content and clay fraction. Therefore, the improvement of Ultisol productivity can be conducted via soil amelioration, fertilization, and organic material addition [6].

An improved technology is needed to optimized acid dry land productivity. To overcome soil acidity, liming application is one of the option, while the use of phosphorous (P) source derived from natural resources could overcome the low availability of P in acid dry land [7]. Ginting et al. [8] reported that application of rock phosphate can increase soil pH. Moreover, organic matter application is also required in Ultisol. The application of organic matter has a positive effect on the solubility of natural P in the soil because organic acids can dissolve Ca-P, Al-P, Fe-P by supplying protons and complexing cations so that P will be available for plants [9]. One of the efforts so support the development of intensive agriculture in tropical areas, can also be done by empowering soil biological resources. Fredrickson [10] reported that various microbial species contained in biological fertilizers can increase microbial activity and function in enhancing plant growth and development.

The research aimed was to study the effect of ameliorant, organic matter, biofertilizer, and their combination in improving Ultisol productivity, as well as in increasing rice and maize yields of rice and maize.

2. Materials and methods

This research was conducted in the experimental station of Indonesian Soil Research Institute at Taman Bogo, Purbolinggo, Lampung Timur. This field experiment was conducted for two planting seasons in 2019. A randomized block design was set with three replications. The treatments consists of T1 (control); T2 (recommendation dosage of fertilizer); T3 (50% recommendation dosage of fertilizer + 2 t ha⁻¹ of manure); T4 (50% of recommendation dosage of fertilizer + 10 t ha⁻¹ of manure), T5 (50% recommendation dosage of fertilizer + 2 t ha⁻¹ of manure + 1 t ha⁻¹ of Rock Phosphate); T6 (50% recommendation dosage of fertilizer + 2 t ha⁻¹ of manure + 10 t ha⁻¹ of Biochar); T7 (50% recommendation dosage of fertilizer + 2 t ha⁻¹ of manure + biofertilizer for), and T8 = 50% recommendation dosage of fertilizer + 2 t ha⁻¹ of manure + 1 t ha⁻¹ of Rock Phosphate + 10 t ha⁻¹ biochar + biofertilizer). The dose of biofertilizer was 0.5 kg of biofertilizer for 25 kg rice seeds and 1 kg of biofertilizer for corn seeds.

The experimental plot size was 3.75 m x 20 m for each treatmnet. Rice plant Situpatenggang variety was cultivated on first planting season during rainy season (WS) followed with maize Bisi-18 variety in second planting season during dry season (DS). Planting space for rice and corn was 25 cm x 25 cm (3 to 5 seedling per hole) and 25 cm x 75 cm (one seed per hole), respectively. The fertilizer recommendation dose for rice was 250 kg Urea ha⁻¹, 200 kg SP-36 ha⁻¹, and 75 kg KCl ha⁻¹. Meanwhile for maize, the dose was 300 kg Urea ha⁻¹, 175 kg SP-36 ha⁻¹ and 100 kg KCl ha⁻¹.

Soil samples were taken twice, initial and after harvesting and soil parameters consists of soil pH H₂O, organic C and N, exchangeable cations as K, Ca, Mg, Na, AL and H, CEC, base saturation, water content, bulk and particle density, pore space and permeability. Furthermore, agronomy parameters consist of plant height, number of tillers of rice, number of corn leaves, yield and biomass.

All data was analysed for analysis of variance (ANOVA) and followed with Duncan Multiple Range Test (DMRT) at α 5%.

3. Results and discussion

3.1. Results of soil chemical analysis before planting.

The initial soil analysis result is presented in table 1. The value of pH H₂O was categorized as very acid with very low of organic C and N, and CEC. Meanwhile available P₂O₅ was categorized as very high. Ultisols are generally formed as a deep sectional soil, yellow-red color and have low natural fertility [11]. Acid dry land mostly found in low base saturation <50% (dystrik) and udic soil moisture regime or
rainfall >2,000 mm year⁻¹ [12]. High rainfall intensity will accelerate soil weathering process, therefore during soil formation in tropical climates will follow with intensive nutrient leaching and caused soil becomes acidic due to low base and high aluminum saturation [8]. Soils types in tropical and wet climated generally dominated by podsolic soil, red and yellow or included Ultisols, Oxisols dan Inceptisols [13]. Initial soil analysis showed the high value of available $P_{2}O_{5}$, this might be due to the residue of rice husk biochar from the previous activities in this site. Inorganic fertilizer application such as SP-36 is commonly used to overcome $P$ deficiency on acid dry land, however this inorganic fertilizer is easy to dissolved then fixed by Al and Fe which abundantly available in acid soil and become less available for plants. The high Al solubility in acid soils can increase the fixation of phosphorus ($P$), so that the available $P$ content is low [14,15].

### Table 1. Initial soil analysis of study site.

| No | Soil chemical properties       | Value | Status        |
|----|--------------------------------|-------|---------------|
| 1  | pH H₂O                         | 4.29  | very acid     |
| 2  | C- organic (%)                 | 0.88  | very low      |
| 3  | N- organic (%)                 | 0.8   | very low      |
| 4  | $P_{2}O_{5}$ Bray 1 (ppm)      | 40    | very high     |
| 5  | CEC (cmol(+)/kg)               | 4.21  | very low      |
| 6  | BS (%)                         | 27.5  | low           |
| 7  | Al exchangeable (cmol(+)/kg)   | 1.53  | -             |
| 8  | H exchangeable (cmol(+)/kg)    | 0.79  | -             |

3.2. The effect of treatments on soil chemical and physical properties.

The effect of treatments on soil chemical and physical properties is presented in Table 2 and 3. The results showed that the T5 (50% recommendation dose + 2 t ha⁻¹ of manure + 1 t ha⁻¹ of Rock Phosphat) treatment had a significant effect on increasing soil available $P_{2}O_{5}$, exchangeable Ca and Mg, CEC, BS and as well as decreased the exchangeable Al and H compared to control. Meanwhile, T5 also gave significant effect on increasing soil pore space and permeability.

The high value of $P_{2}O_{5}$, exchangeable Ca, and BS at T5 might be related to addition of rock phosphate. Its known that rock phosphate has high solubility under acidic conditions, therefore it is very suitable as a source of $P$ on acid dry land such as Ultisols, Oxisols and Inceptisols. Moreover, rock phosphate has a long-term residual effect due to its slow release characteristic, therefore once time application of rock phosphate could supply $P$ up to several planting season.

Rock phosphates beside its $P$ content, it has a high CaO content (>40%) with high reactivity and it is suitable for acid soils. The concentration of $P_{2}O_{5}$ of rock phosphate from Indonesia is varied up to 40% $P_{2}O_{5}$. The reactivity of rock phosphate varies from <1 to 18% $P_{2}O_{5}$ and this reactivity will determine the $P$ release from rock phosphate [16].

3.3. The effect treatments on plant growth and yield

The results of agronomy and yield parameters are showed in Table 4 and 5. The result showed the effect of treatments on increasing plant height and number of tillers of rice plant significantly compared to control. T4 (50% of recommendation dosage of fertilizer + 10 t ha⁻¹ manure) showed the highest rice plant height and number of tillers. This might be related to organic matter application as manure, whereas organic matter could increase available $P$ in the soil either directly or indirectly. The direct effect is related to the nutrient content in organic matter includes $P$. Indirect effect is showed from the decomposition process of organic matter that produce organic acids. These organic acidcs could bind Al and Fe to form organic metal compound [17].
Table 2. The analysis results of soil chemical properties after harvesting at the second planting season in 2019

| Treatment | Ekstrak 1:5 | Organic matter (%) | Bray 1 P2O5 (ppm) | Cation exchange rate (NH4-Acetate 1N, pH 7) (cmol(+)/kg) | KCl 1N |
|-----------|-------------|---------------------|-------------------|--------------------------------------------------------|-------|
|           |             |                     |                   | pH H2O Walkley & Black C Kjedahl C/N Exch. K Exch.Ca Exch. Mg Exch. Na CEC Base saturation Exch. Al Exch. H |       |
| T1        | 4.6 a       | 0.94 a              | 0.097 a           | 9.7 ab        | 30.7 d | 0.097 abc | 0.433 d | 0.110 b | 0.180 ab | 6.96 c | 12.0 c | 1.72 a | 0.343 a |
| T2        | 4.5 a       | 0.96 a              | 0.097 a           | 10.0 ab       | 42.8 cd | 0.090 bc | 0.477 cd | 0.097 b | 0.153 ab | 5.99 d | 13.7 bc | 1.56 ab | 0.333 a |
| T3        | 4.5 a       | 0.99 a              | 0.097 a           | 10.3 a        | 45 bed  | 0.113 ab | 0.603 ed | 0.150 ab | 0.140 b  | 7.91 a | 12.7 c | 1.45 ab | 0.327 a |
| T4        | 4.5 a       | 0.98 a              | 0.097 a           | 10.3 a        | 46.5 bc | 0.117 ab | 0.737 bc | 0.213 a | 0.220 ab | 8.65 a | 15.0 bc | 1.23 ab | 0.307 a |
| T5        | 4.6 a       | 0.89 a              | 0.097 a           | 9.3 b         | 63.2 a  | 0.103 abc | 1.057 a | 0.140 ab | 0.227 ab | 7.08 c | 21.3 a | 1.08 b | 0.320 a |
| T6        | 4.4 a       | 0.97 a              | 0.100 a           | 9.7 ab        | 40.5 cd | 0.127 a | 0.600 cd | 0.120 b | 0.157 ab | 7.45 bc | 13.7 bc | 1.46 ab | 0.357 a |
| T7        | 4.4 a       | 0.99 a              | 0.097 a           | 10.3 a        | 41.1 cd | 0.077 c | 0.560 cd | 0.123 b | 0.263 a  | 8.46 a | 12.3 c | 1.65 ab | 0.350 a |
| T8        | 4.5 a       | 1.00 a              | 0.100 a           | 10.0 ab       | 58.6 ab | 0.127 a | 0.983 ab | 0.133 b | 0.193 b  | 7.92 ab | 18.0 a  | 1.17 ab | 0.350 a |

Means in a row or column followed by the same letter are not significantly different at 5% level by DMRT

Table 3. Results of analysis of soil physical properties of the soil after harvest in the second growing season in 2019.

| Treatments | Water content (% vol) | Bulk density (g cc⁻¹) | Particle density (%) volume | Pore space % volume | Water availability | Permeability cm h⁻¹ |
|------------|-----------------------|-----------------------|-----------------------------|--------------------|-------------------|---------------------|
| T1         | 15.90 a               | 1.330 a               | 2.425 b                     | 45.85 b            | 13.00 a           | 12.045 abc          |
| T2         | 17.15 a               | 1.340 a               | 2.565 a                     | 48.10 ab           | 11.90 a           | 10.645 bc           |
| T3         | 13.55 a               | 1.235 a               | 2.510 ab                    | 51.65 a            | 9.90 a            | 17.450 ab           |
| T4         | 15.00 a               | 1.320 a               | 2.565 a                     | 47.85 a            | 10.35 a           | 8.985 c             |
| T5         | 17.85 a               | 1.360 a               | 2.560 a                     | 45.90 b            | 9.70 a            | 18.700 a            |
| T6         | 14.75 a               | 1.360 a               | 2.580 a                     | 47.10 ab           | 9.90 a            | 15.100 abc          |
| T7         | 15.55 a               | 1.395 a               | 2.580 a                     | 45.90 b            | 11.85 a           | 15.295 abc          |
| T8         | 17.95 a               | 1.320 a               | 2.505 ab                    | 48.15 ab           | 11.80 a           | 14.545 abc          |

Means in a column followed by the same letter are not significantly different at 5% level by DMRT.
Table 4. Plant height and number of tiller of Situpatenggang rice variety for the first planting season in 2019.

| Treatment | Plant height (cm) | Amount of tiller | 30 DAP | 60 DAP | Harvest time | 30 DAP | 60 DAP | Harvest time |
|-----------|-------------------|-----------------|--------|--------|--------------|--------|--------|--------------|
| T1        | 40.3 bc           | 77.9 b          | 116 ab | 7.30 b  | 10.03 b      | 7.83 a |
| T2        | 41.0 abc          | 85.4 ab         | 109 b  | 9.47 ab | 12.30 ab     | 6.27 a |
| T3        | 39.3 bc           | 84.0 ab         | 113 ab | 8.20 b  | 13.43 a      | 7.93 a |
| T4        | 41.0 abc          | 91.0 a          | 120 ab | 11.50 a | 14.83 a      | 7.20 a |
| T5        | 42.7 ab           | 88.7 a          | 114 ab | 8.80 ab | 12.00 ab     | 6.83 a |
| T6        | 37.8 c            | 84.5 ab         | 122 a  | 8.80 ab | 12.20 ab     | 7.60 a |
| T7        | 43.8 ab           | 89.7 a          | 114 ab | 7.30 b  | 13.10 ab     | 6.50 a |
| T8        | 45.6 a            | 90.7 a          | 117 ab | 9.47 ab | 14.20 a      | 6.10 a |

Means in a column followed by the same letter are not significantly different at 5% level by DMRT

Table 5. Weight of wet biomass and dry grain of Situpatenggang rice variety at the first planting season in 2019.

| Treatments | Wet biomass weight | Weight dry grain |
|------------|--------------------|------------------|
|            | 10 plant (kg)      | t ha⁻¹ | 10 plant (kg) | t ha⁻¹ |
| T1         | 1.350 cd           | 12.3 d | 0.220 b       | 3.00 b |
| T2         | 1.297 d            | 20.6 bc| 0.343 a       | 4.27 a |
| T3         | 1.40 bcd           | 21.5 bc| 0.337 a       | 4.20 a |
| T4         | 1.673 ab           | 28.5 a | 0.363 a       | 3.83 ab|
| T5         | 1.583 abcd         | 24.8 ab| 0.373 a       | 4.03 ab|
| T6         | 1.640 abc          | 20.2 bc| 0.350 a       | 4.13 a |
| T7         | 1.473 bcd          | 17.5 cd| 0.343 a       | 3.70 ab|
| T8         | 1.810 a            | 26.0 ab| 0.317 a       | 3.57 ab|

Means in a row or column followed by the same letter are not significantly different at 5% level by DMRT

Table 6 and 7 showed the effect of treatments on agronomy and yield component parameters of maize. The result showed that the T5 significantly increased plant height, number of leaves, wet biomass and dried grain weight compared control. Rock phosphate is an effective source of P for acid soils such as Ultisols [18]. Phosphor plays an important role as a molecular component in ATP, ADP, NAD and NADPH which controls various reaction in plants such as photosynthesis, respiration, protein amino acid synthesis and nutrient transport [19]. Phosphor (P) is also a makro nutrient that is very important root development, especially early growth [20]. Buddh [21] reported that vegetative growth of plants, especially young roots, is strongly influenced by the distribution and availability of phosphorus in the soil. Previous research showed that by applying 1,000 kg rock phosphate ha⁻¹ for five planting seasons on Oxisols and Ultisols increased maize yields between 30 to 90% and revenue as 90% to 170% with higher R/C ratio.
Table 6. Plant height and number of leaves of BISI-18 maize variety at the second planting season in 2019

| Treatments | Plant height (cm) | Number of leaves |
|------------|------------------|------------------|
|            | 30 DAP | 60 DAP | Harvest time | 30 HST | 60 HST | Harvest time |
| T1         | 39.0 e | 97 e   | 117 b     | 7.30 e   | 9.37 d | 10.13 c   |
| T2         | 48.6 e | 116 de | 127 b     | 8.43 d   | 10.47 d | 11.90 b   |
| T3         | 63.2 d | 146 cd | 155 ab    | 9.17 cd  | 13.07 e | 12.43 b   |
| T4         | 78.5 ab | 185 ab | 176 a     | 10.37 b  | 14.80 ab | 14.43 a   |
| T5         | 87.4 a | 196 a  | 194 a     | 10.67 ab | 15.67 a | 14.93 a   |
| T6         | 74.9 bc | 182 ab | 186 a     | 10.37 b  | 14.70 ab | 14.40 a   |
| T7         | 65.7 cd | 155 bc | 176 a     | 9.53 c   | 13.47 bc | 14.40 a   |
| T8         | 86.6 a | 187 ab | 194 a     | 11.13 a  | 15.50 a | 15.63 a   |

Means in a column followed by the same letter are not significantly different at 5% level by DMRT

Note: DAP: days after planting

Table 7. Weight of wet biomass and dried maize grain of BISI-18 variety at the second planting season in 2019.

| Treatments | Wet biomass t ha\(^{-1}\) | Dried maize grain t ha\(^{-1}\) |
|------------|----------------------------|-------------------------------|
|            | 10 plant (kg)              | 10 plant (kg)                 |
| T1         | 0.36 c                     | 0.23 d                        |
| T2         | 1.18 a                     | 0.58 cd                       |
| T3         | 0.71 abc                   | 0.70 bc                       |
| T4         | 0.58 bc                    | 0.92 abc                      |
| T5         | 0.89 ab                    | 1.28 a                        |
| T6         | 0.96 ab                    | 1.03 abc                      |
| T7         | 0.49 bc                    | 0.64 cd                       |
| T8         | 0.89 ab                    | 1.09 ab                       |

Means in column followed by the same letter are not significantly different at 5% level by DMRT

4. Conclusions
The T5 (50% recommendation dosage of fertilizer + 2 t ha\(^{-1}\) manure + 1 t ha\(^{-1}\) Rock Phosphate) treatment had a significant effect on improving soil chemical (increasing P\(_2\)O\(_5\), exchangeable Ca, BS and decreasing exchangeable Al and H) and physical (soil permeability) properties and maize growth and yield. Meanwhile T3 increased dry weight of rice grain significantly.

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