Enhancing the fertility of soil and the yield of soybean in a dry climatic area of Vertisol South Lombok using combination of bioorganic-phosphate and inorganic fertilizers

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Abstract. Vertisol of South Lombok is the center of soybean production on Lombok Island which is productively vulnerable due to climate change. Erratic pattern of rainfall may threat the production of soybean in this dry climatic area which may be exaggerated by climate change. Therefore, it is needed efforts to maintain or even to increase the yield of soybean through adding both bioorganic and inorganic fertilizers. This study aimed to assess the effect of combination of bioorganic and inorganic fertilizer on enhancing the fertility of soil and the yield of soybean. This experiment used a randomized block design (RBD) with 4 treatments and 5 replications. The treatments were 50% of the recommended dosage of inorganic fertilizers plus 10 g per plant of bioorganic-phosphate (P1), 75% of the recommended dosage of inorganic fertilizers plus 10 g per plant of bioorganic-phosphate (P2), 100% of recommended dosage of inorganic fertilizer (P3), and control. Parameters observed consisted of soil pH, available-P. Exchangeable-K, organic-C, cation exchange capacity (CEC), base saturation (BS), and the yield of soybean. The results showed that the treatment of 75% of the recommended dosage of inorganic fertilizers plus 10 g per plant of bioorganic-phosphate (P2) increased the soil P-available from 10.71 on the control to 22.59 ppm on the P2 treatment, and resulted from the highest yield of soybean. Thus, this treatment is recommended if the combination of the fertilizers to be applied in the Vertisol South Lombok for adapting to climate change.

1. Introduction
Climate change has several negative impacts on crop cultivation systems. Climate change may cause harvest failure due to erratic rainfall patterns, extended dry season, high intensity of extreme weather and air temperature [1]. Soybean is one of the crops which is vulnerable to those climate change effects. Rain fed Vertisols of South Lombok is one of the main areas for growing soybean, which is also extremely vulnerable to the climate change. This is not only because of lack of soil organic matter (SOM) which can hold more water, but also due to the characteristic of vertisol which can be either swelling in wet conditions or shrinking in dry conditions [2]. These conditions of soil cause the continuity of nutrient availability and uptake by plants to be hampered. Therefore, the productivity of plants is unable to be optimal.

In terms of sustainable cultivation of soybean, it requires proper treatment to fulfil nutrient sources and conserve fertility of soil. Soil fertility is defined as the capacity of soil to supply plant...
nutrients with adequate amounts, proper balance and suitable proportions required for maximum plant growth [3]. Therefore, inorganic fertilizers are necessary to be administered into the soil, since it may meet the amount of nutrients needed by plants. The inorganic fertilizers contain rich nutrients which are required for plant growths [4]. Cultivated soil contains insufficient amounts of plant nutrients to achieve maximum crop yields. Thus, both organic and inorganic or mixed organic-inorganic fertilizers are necessary to be added to the plant crops [5]. An excess use of inorganic fertilizers for the long period in agroecosystem likely accelerates the process of soil deterioration which is indicated by less amounts of SOM, low amounts of N in total and P-available as well as declining the number of biological properties in soil [6]. Hence, an efficient management strategy of nutrient availability is essential to yield a high number of plant products and preserve soil fertility.

According to previous study in Ethiopia Africa, the application of combined organic and inorganic fertilizers increased the productivity of maize, wheat, rice, and tomatoes without negative effects on crops and soil fertility [4]. Integrated nutrient management is the alternative way which is characterized by reducing intake of inorganic fertilizers and increasing uptake of organic materials such as livestock manure, vermicompost and compost, in a study area of Bangladesh [7]. The application of combined organic and inorganic fertilizers plays an important role for maintaining soil fertility and has a high positive effect on microbial biomass and soil health [6]. In China, Ye et al. [8] suggested utilisation of inorganic fertilizers might be more efficient if it is mixed with bio-organic fertiliser to produce higher plant productivity. In addition, in Thailand the organic fertilizer added with plant growth-promoting rhizobacteria (PGPR) is commonly known as bio-organic fertilizers [9]. The application of bio-organic fertilizer on dry land is able to enhance soil organic matter and increase soil microbial biomass, nitrogen and phosphorus content [10]. Furthermore, the use of bioorganic fertilizers has future developing prospects since this is likely to not only increase the productivity of plants but also be environmentally friendly [9]. Susilowati and Arifin [11] asserted formulation of organic fertilizers added by phosphate solubilizing microorganisms (PSMs) are known as bioorganic-phosphate fertilizers.

This study aimed to assess the effect of combination of bioorganic and inorganic fertilizer on enhancing the fertility of soil and the yield of soybean in Vertisol of Lombok Island, which is until now there is no information reported about this issue from this dry climatic area. Bioorganic-phosphate has a crucial role to enhance an availability of phosphate and provide a favourable environment for plant growth which may be used to adapt to the climate change.

2. Materials and methods

The field experiment was conducted in the 1st dry season (March – July 2019) on a Vertisol in Semoyang Village, South Lombok. This location is a rain fed area with erratic rainfall (870–1220 mm/year) and high average temperature (maximum average = 31 °C) [12]. The experiment was laid out in a randomized complete block design (RCBD) with five replicates for each treatment. The size of experiment plot was 3 × 5 m and *Argomulyo soybean variety* was planted in 30 cm and 20 cm distance between and within rows, respectively. The recommended doses of NPK fertilizers for soybean plants are 25 kg Urea, 100 SP-36, and 75 Kg KCl plus 5 tones rice straw mulch per ha. Bioorganic-phosphate application was organic fertilizer (a mixture of 1 part of cow manure and 1 part of bran) contained 10 cfu phosphate solubilizing bacteria (PSB) per gram [11]. Following treatments were used in this experiment: without fertilizer application (control); 50% of recommended doses of inorganic fertilizer, plus 10 g of Bioorganic-phosphate per hole (P1); 75 % of recommended doses of inorganic fertilizer, plus 10 g of Bioorganic-phosphate per hole (P2); 100% of recommended doses of inorganic fertilizer (P3).

Parameters of soil chemical properties observed before the experimental treatments consisted of soil pH-H_2O (potentiometer 1:2.5), cation exchange capacity (CEC), exchangeable-cations (extracted with 1 N NH_4OAc), base saturation (BS), organic-C (Walkley-Black method), P_2O_5-HCl 25%. K_2O-HCl 25%, whereas after the experiment comprised of total-N (Kjeldhal method), available-P (Olsen P method), organic-C, exchangeable-cations (K^+, Na^+, Ca^{2+},Mg^{2+}), CEC, BS, and the grain yield of
soybean. Grain yield was adjusted to 12% moisture content. Data set was statistically analyzed by using one-way analysis of variance. Data were expressed as means with standard error (SE). The difference among treatment means were determined by the least significant difference (LSD) test at $p \leq 0.05$. The degree of relationship between each parameter of soil chemical parameters and soybean yields was calculated using the coefficient of correlation.

3. Results and discussion

3.1. The descriptive characteristics of soil prior to the treatment

Table 1 presents the results of chemical soil analysis of CEC, base saturation (BS), C-organic, P$_2$O$_5$-HCl 25%, K$_2$O-HCl 25%. The order of soil in the research area was a Vertisol with dark gray, heavy clay, sticky and moist in characteristics. In addition, the soil tends to crack into a variety of diameter once drought. Soil is slightly acidic (pH 6.40). Rain fed Vertisol in the Lombok potentially undergoes shrinking and swelling processes [13]. Irrigation condition in this study was semi-technical irrigation.

| Soil Characteristic       | Value  | Unit       | Relative Level* |
|--------------------------|--------|------------|-----------------|
| CEC                      | 28.09  | Cmol(+)/kg | High            |
| Ca-exchangeable          | 12.65  | Cmol(+)/kg | High            |
| Mg-exchangeable          | 2.51   | Cmol(+)/kg | High            |
| K- exchangeable          | 1.55   | Cmol(+)/kg | Very high       |
| Na- exchangeable         | 0.76   | Cmol(+)/kg | High            |
| Base Saturation (BS)     | 67     | %          | High            |
| C-organic                | 1.11   | %          | Low             |
| P$_2$O$_5$ (HCl 25%)     | 80     | mg/100g    | Very high       |
| K$_2$O (HC25%)           | 100    | mg/100g    | Very high       |

*Source: Balittan [14]

The result shows that CEC and BS were at high level. The high values were shown in the P$_2$O$_5$-HCl 25% and K$_2$O-HCl 25%, but with low C-organic, as also reported in other part of Lombok Island [15]; [16]. According to those characteristics, the soil in the research area was reasonably categorized as medium fertile soil, with lack of organic matters. In terms of nutrient, high level of CEC causes high concentration of cation which can be absorbed by plants. Jones & Jacobsen [17] asserted that CEC is a good indicator to describe the ability of the soil to maintain and supply cationic nutrients, such as Ca$^{2+}$, Mg$^{2+}$, K$^+$, NH$_4^+$, Cu$^{2+}$ for plants. The following study also showed that the level of alkaline saturation in the soil was high. Hailegnaw et al. [18] stated that the CEC has a positive correlation to the base saturation (BS) of the soil. The content of Ca and Mg cations in the experimental soil was rich because Vertisols in South Lombok developed from limestone. The nutrient content of Ca, Mg, K, and Na varies depending on the location and the Ca content, especially in soil derived from calcareous parent material [19].

3.2. The effect of the fertilization treatment on various of soil chemical properties

The treatment has a statistically significant ($p<0.05$) to alter some parameters of chemical characteristics, including pH, Availability-P content, C-organic content, and K-exchange. The detail results are summarized in the Table 2. Treatment with fertilizers either a single inorganic or combination of inorganic and phosphate bioorganic shows an increase in pH, thus improving the soil acidity becoming neutral. In this study, expected pH (6.6-7.3) was achieved by treating the soil with the combination (bioorganic and inorganic) of fertilizer. This result confirmed a study by [20] suggesting that organic-mixed NPK fertilizers significantly improve the pH of the soil. The change of pH becoming neutral would cause a beneficial effect for soy plant growth. Baath and Anderson [21] revealed that soil acidity is positively correlated with soil microbial biomass. In addition, Geisseler
and Scow [22] argued that the bacterial abundance and biodiversity is substantially determined by the soil acidity. Their statement was inferred by the findings that more bacterial diversity was found in neutral than acidic soil. Therefore, it is likely to argue that a neutralizing pH will provide the availability of macronutrients for the plants and provide optimal environment for soil microbes to release N, P and K for the plant growth.

Table 2. Results of Analysis of Soil Chemical Properties after the treatment.

| Treatments | pH (H₂O) | Total-N (%) | Availability-P (ppm) | Organic-C (%) | K | Na | Ca | Mg | CEC | BS |
|------------|----------|-------------|----------------------|---------------|---|----|----|----|-----|----|
| Control    | 6.37     | 0.04        | 10.71                | 1.21          | 1.59 | 0.80 | 1.95 | 0.75 | 26.15 | 65 |
| P1         | 6.64     | 0.05        | 15.90                | 1.32          | 1.73 | 0.77 | 2.97 | 0.65 | 27.85 | 65 |
| P2         | 6.62     | 0.06        | 22.59                | 1.31          | 1.75 | 0.80 | 2.78 | 0.70 | 27.65 | 65 |
| P3         | 6.56     | 0.05        | 13.65                | 1.22          | 1.68 | 0.79 | 2.00 | 0.67 | 26.78 | 64 |

LSD (%) 0.09 2.05 0.01 0.05 0.79

Note: significant at p < 0.05; NS = Not significant means in a column with the same letter are not significantly different (p < 0.05); control group is without fertilizer; P1: 50% of recommended doses of inorganic fertilizer, plus 10 g of bioorganic-phosphate per hole; P2: 75% of recommended doses of inorganic fertilizer, plus 10 g of bioorganic-phosphate per hole; P3: 100% of recommended doses of inorganic fertilizer.

In the following study, soil properties such as availability-P, organic-C, exchange-K, and CEC were statistically increased, compared to the control group. Availability-P concentration in the group with fertilizer combination has significantly different not only in the control group, but also in the group treated with single inorganic fertilizer. Availability-P concentration reached a peak in the group treated with the combination of bioorganic-phosphate and 75% inorganic fertilizer. This result showed that Phosphate Solubilizing Bacteria (PSBs) contained in bioorganic phosphate fertilizer potentially transforms insoluble phosphate (both organic and inorganic) to soluble phosphate. Alori et al. [23] reported that biofertilizer–PSMs applied to maize causes enhancing the bioavailability of phosphate to crop, P-labelled phosphate uptake, and significant improvement of the maize yields. Phosphate inorganic is transformed to available P by inorganic solvent such as organic acids, siderophores, protons, hydroxyl ions and CO₂ secreted into the environment [24]. These solvents dissolve P-inorganic to release phosphate from its binding cation (Ca²⁺). As a result, there is a substitution of H⁺ and Ca²⁺ to form organic Ca and P complex for the growing plants.

Table 2 shows the content of C-organic in 50% and 75% recommended fertilizers are not statistically different. Nevertheless, the content of both treatments is significantly higher than the control or 100% fertilizer-treated groups. This finding supports that the administration of organic fertilizer can improve the content of C-organic immediately. An increase in C-organic content was followed by increasing levels of CEC and exchangeable-K. Several studies revealed that the integrated use of inorganic fertilizer with organic fertilizer like manure significantly increases soil organic C content, total N, and the available soil nutrients [25]. The mechanism of organic fertilizers in contributing to remains elusive. However, it likely to argue that the mechanism is associated with the presence of organic colloid facilitating the absorption and release of K within the balance process of K in the soil [26].

In this study, treatments with fertilizers results in insignificant influence on the alteration of N-total content. There are some plausible reasons to explain this phenomena. First, nitrogen secreted into the environment by rhizobium was absorbed by the plants while rhizobium was no longer active to bind
nitrogen in the air. The other possible reason is that the overall yield of N$_2$ fixation by rhizobium is transferred to the plant to compensate for the P absorption rate in supporting the metabolic processes of the plant.

Statistically, the value of alkaline saturation in the combination treatment of fertilizers, inorganic single fertilizer treatment and control is the same. These results suggest that soil conditions after the experiment did not occur a noticeable reduction in cations resulting in decreased BS. However, it is noted that the highest number of cations occurs in the treatment of combination fertilizers that include 75% recommended inorganic fertilizer doses where this condition may be due to the increasing number of exchange-K.

3.3. The effect of the fertilization treatment on soybean yield.

The experimental treatment had a significant effect (P < 0.05) on soybean yields as indicated by the weight of dried seeds per plant (g/plant) (Table 3). Soybean yield per ha is a conversion of dry weight of dried seeds (g/plant) multiplied by the number of plants per ha, as much as 166000 plants.

Table 3. The analysis of soybean yield due to the administration of a variety of fertilization.

| Fertilization Treatment | Dry grain weight (g/plant) ± SE | Soybean Yield (tonnes/ha) * |
|------------------------|---------------------------------|-----------------------------|
| Control                | 8.44(a) ± 1.20                  | 1.40                        |
| P1                     | 13.25 (b) ± 1.22                | 2.19                        |
| P2                     | 16.33 (c) ± 1.98                | 2.71                        |
| P3                     | 13.46 (b) ± 1.21                | 2.23                        |

Note: *Convert from dry grain weight (g/plant) multiplied by 166000 plants

The highest soybean yield was recorded in the treatment with bioorganic-phosphate in combination to fertilizer plus 75% recommended inorganic fertilizer. Statistically, soybean production in the treatment of bioorganic-phosphate combination fertilizer plus 50% dose of inorganic fertilizer is equal to the treatment of 100% of the recommended fertilizer. These results show that the administration of bioorganic-phosphate fertilizer with a dose equivalent to 1.6 tones/ha can reduce 50% of the recommended dose of inorganic fertilizer. While the inclusion of 75% recommended inorganic fertilizer is proven to produce soybeans about 21.32% higher than the treatment of 100% recommended fertilizer dose. This result implies that the input of bioorganic-phosphate fertilizer in Vertisols is useful in the process of providing nutrients that can be absorbed by plants, so that the balance of nutrients in plants is fulfilled for optimization of plant metabolic processes. Application of the mixed use of chemical with bioorganic fertilizer has been proven to be highly beneficial in terms of balanced nutrient supply [27].

Furthermore, correlation tests are conducted to determine the chemical properties that have a high correlation with plant production (Table 4). Strong correlation coefficient between soybean yields and some chemical properties of soil including soil pH, N-total, P-available, Exchangeable-K and CEC, and the moderate correlation with C-organic. These results illustrate that there are several important factors that affect soybean yields in Vertisols, namely NPK levels in equilibrium, soil-pH, C-organic content and CEC.

Table 4. The correlation coefficient of several soil properties with the soybean yield (n=15).

| Parameters | correlation coefficient |
|------------|------------------------|
| Dry grain weight (g/plant) | 0.89 0.98 0.90 0.94 0.69 0.80 |
| soil-pH (%) | (s) (s) (s) (s) (m)** (s) |
| total-N (%) | (s)* |
| Available-P (ppm) | (s) |
| Exchangeable-K (Cmol(+)/kg) | (s) |
| organic-C (%) | (m)** |
| CEC Cmol(+)/kg | (s) |

Note: *s =high correlation; ** m=moderate correlation
4. Conclusion
Soil fertility and soybean crop were optimally improved by applying a combination of 10 g of bioorganic phosphate fertilizer per hole (equivalent to 1.6 tonnes per ha) and 75% of recommended dosage of inorganic fertilizers. The improvement in soil fertility was indicated by increasing the amount of P-available, K-exchangeable, C-organic and CEC which were higher than that of either control treatment or recommended 100% dosage of inorganic fertilizer. The amount of soybean production treated by the treatment was 2.71 tonnes per ha, while by the treatment of 100% of the recommended dosage was slightly lower (2.23 tonnes per ha). This means that there is an increase in soybean yield by 21.32%. Moreover, integrated nutrient management might be an alternative approach to sustainable fertility management characterized by increasing plant productivity and decreasing inorganic fertilizer use. Therefore, this is an alternative solution for sustainable fertility and soil productivity in Vertisols for adapting to climate change in a dry climatic area of South Lombok.

References
[1] Oseni T O and Masarirambi M T 2011 J. Agric. & Environ. Sci. 11(3) 385–91
[2] Dengiz M O, Saglam F, Sarioglu E, Saygin F, and Atasoy C 2018 Open J. Soil Sci. 2(1) 20-7
[3] Khadka D, Lamichhane S, Bhurer K P, et al 2018 J. Nepal Agric. Res. Counc. 4 33–47
[4] Roba T B 2018 Open Access Libr. J. 5(6) 1-11
[5] Quansah G W 2010 American Journal of Plant Sciences 5(6) 1-11
[6] Singh B and Ryan J 2015 Managing Fertilizers tp Enhance Soil Health (Paris, France: IFA)
[7] Mamia A, Amin A, Roy T S, and Faruk G M 2018 Bangladesh Agronomy Journal 21(1) 77–81
[8] Ye L, Zhao X, Bao E, et al 2020 Sci. Rep 10 177
[9] Teamuromong N, Wanapu C, Chankum Y et al 2010 Production and application of bioorganic fertilizers for organic farming systems in Thailand: a case study Microbes at work (Berlin: Springer) 293–312
[10] Sun L and Yan N 2019 Ekoloji Derg. 28(107) 3541–50
[11] Susilowati L E and Arifin Z 2020 Jurnal Pempadu 1(4) 429-36
[12] Ma’shum M, Tisdall J M, Borrell A K, et al. 2009 Field Crops Res. 110(3) 197–206
[13] Dulur N W D, Kusnarta I G M, and Wangiyanwa W 2017 Jurnal Agroteksos 25(1) 102–8
[14] Balittan 2005 Petunjuk teknis: Analisis kimia tanah, tanaman, air dan pupuk (Bogor, Indonesia: Balittan)
[15] Kusumo B H, Sukartono and Bustan 2018 IOP Conference Series: Earth and Environmental Science 129(1) 012023
[16] Kusumo B H, Sukartono S, and Bustan B 2018 IOP Conference Series: Materials Science and Engineering 306(1) 012014
[17] Jones C and Jacobsen J 2005 Plant nutrition and soil fertility Nutr. Manag. Modul. 2 (11) 1–11
[18] Hailegnaw N S, Mercel F, Prahke K, et al. 2019 J. soils sediments 19 2405–16
[19] Kasno A, Setyorini D, and Widowati L R 2021 IOP Conf. Ser.: Earth and Environ Sci. 648 012015
[20] Islam M A, Islam S, Akter A, Rahman M H, et al Agriculture Plant Science 7(3) 18
[21] Bååth E and Anderson T H 2003 Soil Biol. Biochem. 35(7) 955–63
[22] Geisseler D and Scow K W 2014 Soil Biol. Biochem. 75 54–63
[23] Alori M A, Glick B R, and Babalola O O 2017 Front. Microbiol 8 971
[24] Sharma S B, Sayed R Z, Trivedi M H and Gobi T A 2013 Springer Plus 2 587
[25] Zuoping Z, Sha Y, Fen L, Puhui J, Xiaoying W, and Yan’an T 2014 Int. J. Agric & Biol. Eng. 7(2) 45–55
[26] Nursyamsi D, Idris K, Sabiham S, Rachim D A, and Sofyan A 2007 Jurnal Tanah dan Iklim 26 13–28
[27] Ayeni L S and Adetunji M T 2010 Malaysia Journal of Soil Science 21(1) 13-18