Effect of Phosphorus and Calcium Availability as Influenced by Manure, Rock Phosphate, and Dolomite on Soybean Yield

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Abstract. Soybean (Glycine max) contains nutritional components such as high protein which support health needs and improve the quality of life. However, to achieve this standard, soybean productivity needs to be increased. Manure, rock phosphate, and dolomite are potential alternatives in improving soybean production. This study aims to examine phosphorus and calcium availability as influenced by manure, rock phosphate, and dolomite to increase soybean yield. The experiment consisted of six treatments groups with four replications using a completely randomized block design. Furthermore, the groups include T0 (Control), T1 (5 t ha⁻¹ manure + 2.5 t ha⁻¹ rock phosphate), T2 (5 t ha⁻¹ manure + 5 t ha⁻¹ rock phosphate), T3 (5 t ha⁻¹ + 2.5 t ha⁻¹ dolomite), T4 (5 t ha⁻¹ manure + 5 t ha⁻¹ dolomite), and T5 (5 t ha⁻¹ manure + 5 t ha⁻¹ rock phosphate + 5 t ha⁻¹ dolomite). The results showed that phosphorus and calcium availability were significantly influenced by manure, rock phosphate, dolomite, and simultaneously increase soybean yield. Also, the best number of filled pods, 100-seed weight and yield were obtained with the application of 5 t ha⁻¹ manure + 5 t ha⁻¹ rock phosphate + 5 t ha⁻¹ dolomite (20 pods plot⁻¹, 0.62 g, and 260.89 g plot⁻¹ respectively). Therefore, based on the results, phosphorus and calcium obtained from manure, rock phosphate and dolomite potentially increase soybean yield.

1. Introduction

Soybean (Glycine max) is a rich source of nutritional components due to its edible oil and high protein content, as compared to other cereal and legume species [1]. Qi et al., showed that soybeans contain 14% moisture, 18% oil, 30% carbohydrate, and 38% protein. Furthermore, it is one of the most valuable plants in the world. Soyabean not only serve as a good source of protein but also as a staple food in most Asian countries. In addition, it is also used animal feeds, oilseeds and biofuels [3]. Soy protein offers multiple benefits to consumers meanwhile, it is also becoming one of the most studied ingredients because it supports nutritional needs. Therefore, soybean consumption is beneficial in maintaining a quality healthy life [1]. This plant also contains high level of isoflavones, genistein and daidzein which are used in medicine to prevent breast and prostate cancer [4].

The Indonesian government declared soybean as one of the national food programs because of its importance to the people [5]. In addition, FAO also supported agricultural policies and food production incentives to enable production of highly nutritious foods such as soybeans with equal priority as staple foods to strike a balance between consumer, and farmer protection. Meanwhile, improvement in productivity is expected to increase competitiveness as many soybean-based industries are continually established. These industries produce tempeh, soy sauce, tauco, tofu, and soymilk [5]. The increasing soya bean demand is due to the development of feed industries. Furthermore, USDA (2020) in a report
stated that Indonesia imports 83% its soybeans to fulfil domestic consumption. About 2-3% of imported soybeans were used as animal feed, while majority are consumed as, processed food in form of tofu and tempeh by small-scale food industries. Indonesia, constitute the fourth largest USA soybean market, importing about one third of the country’s soybeans hence, doubling exports since 2007.

Rehabilitation, expansion, diversification, and intensification are required to suppress soybean imports and increase production in Indonesia. The marginal use of soil such as Alfisols, was one of the expansion efforts to increase soybean production [7]. However, Alfisol is acidic in nature (pH 4.9) [8] [9], have low fertility indicated by low to moderate base saturation (BS), and low cation exchange capacity (CEC) [10]. Meanwhile, soil acidity is one of the major factors which decreases soil quality and hamper crop production. Therefore, the adoption of soil amendments, capable of improving soil chemical properties is necessary [11]. In this study, the alfisol problem was solved by adding manure, dolomite, and rock phosphate. Bado et al. [12], stated that manure and dolomite showed significant liming effect on soil acidity by reducing exchangeable acidity and increasing pH, while liming with rock phosphate increased base saturation and exchangeable Ca. Furthermore, manure is also suitable for increasing soil nutrients and water availability, microbial activity, as well as root development [10]. In addition, rock phosphates are suitable as source of phosphate in acidic soils [13]. Sufficient P levels in the soil is essential for crop production [14]. Meanwhile, Dolomite also increased soybean production due to the calcium content which plays a role in flower formation and apical growth [15].

Therefore, it was hypothesized that the application of manure, dolomite and rock phosphate constitute possible alternative management practices to improve phosphate and calcium availability to increase soybean production. This study aims to examine the effect of manure, rock phosphate, and dolomite application on the availability of phosphate and calcium, and its effect on the soybean yield. The production components were separated into number of filled pods per plot, 100-seed weight, and seed yield, per plot. Based on literature studies, there are no previous data on this research.

2. Materials and Methods

This study was performed on an experimental field located at Sukosari, Jumantono, Karanganyar using alfisols soil which contain 0.69% organic carbon and moderate cation exchange capacity (16.13 cmol(+) kg⁻¹). The experiment field had the least acidic pH (5.6), moderate total N (0.26%), very low P and K (2.63 ppm and 0.24 cmol(+) kg⁻¹ respectively). Furthermore, alfisols had unstable soil aggregation, low organic matter and acidify rapidly after continuous cultivation [67]. Based on the chemical analysis, the manure had a pH of 6.6, C-Organic 14.34%, total N 1.72%, available P 0.31 ppm, and available K 0.49 cmol(+) kg⁻¹. The total P and pH of rock phosphate were 1.97% and 8.1 respectively, while dolomite indicated available Ca 21 cmol(+) kg⁻¹ and pH 7.1.

This experiment utilized six treatments and four replications via the completely randomized block design. The treatment includes T0 (Control), T1 (5 t ha⁻¹ manure + 2.5 t ha⁻¹ rock phosphate), T2 (5 t ha⁻¹ manure + 5 t ha⁻¹ rock phosphate), T3 (5 t ha⁻¹ + 2.5 t ha⁻¹ dolomite), T4 (5 t ha⁻¹ manure + 5 t ha⁻¹ dolomite), and T5 (5 t ha⁻¹ manure + 5 t ha⁻¹ rock phosphate + 5 t ha⁻¹ dolomite). Furthermore, manure, rock phosphate, and dolomite were spread on the soil surface, ploughed and uniformly mixed before planting the soybean. The plot size was 2 × 1 m, hence, the total plant population was 60 per plot using 20 × 25 cm planting space. Irrigation was carried out via surface irrigation method where water was distributed throughout the surface of the experimental field and seep into the soil. Weeds around the soybean plants were controlled using hand weeding.

The chemical properties of the soil before and after the experiment were analyzed. Moreover, soil samples were collected by randomly selecting five points and thereafter homogenized. The composite soil samples were air dried, crushed, passed through a 2 mm size sieve and analysed. The variables observed include pH (soil:water ratio 1:2) [16], total P (HCl 25%) [17], available P (Bray I) [18], available Ca (NH₄OAc 1 N pH 7) [16] and cation exchange capacity (NH₄OAc 1 N pH 7) [16], number of filled pods, 100 seed weight, and seed yield. Analysis of variance (ANOVA) was used to analyse these variables using 5% significance level (SPSS). Furthermore, the Duncan’s Multiple Range Test (DMRT) at 5% significance level was also used to evaluate the specific differences between mean pairs.
3. Result and Discussion
The ANOVA analysis indicated that combination of manure, rock phosphate, and dolomite have significant effects on pH (Table 1) as the highest pH was obtained in T2, T4, and T5 (6.7) whereas the lowest was obtained in control (6.3). This result was consistent with Biratu et al. [19] and Cai et al. [20], which stated that manure application significantly increased soil pH. In addition, manure had a significant liming effect on soil acidity by increasing pH and reducing exchangeable acidity [12]. Schmidt and Knoblauch [21] reported that the increase in pH due to manure was dependent on the amount of calcium oxide which neutralize the acidity, prevent protein degradation resulting to release of ammonia into the environment, and metabolic activities of organic compounds. Organic matter in manure tend to increase the release of cations to the soil solution, hence, it maintains or even increase pH [22].

Several previous studies have reported that the addition of dolomite increase pH and decrease Fe, Mn, Zn and Cu(23;24;25). Septiyana [26] also reported that the increase in soil pH caused by dolomite was due to the Ca and Mg content which are rapidly dissolved. Therefore, the application of dolomite in acid soils increase Mg and Ca content. These two elements had the lowest concentration and were insufficient for plant growth. Kumari and Phogat [27] also reported that rock phosphate contains readily soluble calcium carbonate and its dissolution potentially increase pH. Furthermore, Yang et al. [28] reported that Ca neutralized soil acidity.

Cation Exchange Capacity (CEC) was significantly increased by manure, rock phosphate and dolomite (Table 1). Application of 5 t ha\(^{-1}\) manure + 5 t ha\(^{-1}\) rock phosphate + 5 t ha\(^{-1}\) dolomite (29.26 cmol(+) kg\(^{-1}\)) significantly increased CEC on an average of 40% compared to control (20.84 cmol(+) kg\(^{-1}\)). The highest value for organic matter (4.91%) was recorded for the application of 5 t ha\(^{-1}\) manure + 5 t ha\(^{-1}\) rock phosphate + 5 t ha\(^{-1}\) dolomite. This result was congruent with Biratu et al. [19] which reported that organic fertilizers such as manure, supply macro and micro nutrients. In addition, it is also used in long-term to increase the cation exchange capacity and reduce the release of nutrients. Yuniarti et al. [29] stated that the soil CEC was increased by adding organic matter and phosphate which contribute to the number of negative charges, thereby, increasing CEC. Wiyantoko and Rahmah [30] reported that cation exchange in the soil occurred due to the negative charges of the colloids that absorbs cation in form of exchange. Rock phosphate is a unique source of phosphorus fertilizer because it was complexed with phosphate and calcium [31]. The increased Ca level contributed to the overall cation exchange capacity of all the soil types, indicating improvement in nutrient retention and soil fertility, which result in increased spinach production[32]. Dolomite also increases the content of Ca and Mg, improves P availability, and reduce the exchangeable Al [33]. Hence, increasing CEC.

Table 1 shows that manure, rock phosphate, and dolomite significantly affected total P. The highest total P was obtained by cultivating with 5 t ha\(^{-1}\) manure, 5 t ha\(^{-1}\) rock phosphate and 5 t ha\(^{-1}\) dolomite (35.17 mg 100 g\(^{-1}\)), which increased the total P by 481% compared to control (6.05 mg 100 g\(^{-1}\)). This result was in line with Ahmed et al. [34]. which reported that the addition of manure to soil increased the soil total phosphorus contents in long-term. Furthermore, many previous studies have demonstrated that manure application significantly increases total P [35];[36];[37]. Ali et al. [38] stated that rock phosphate coupled with manures, maintain higher levels of P in soil solution for a longer period. Throughout the process of mineralization, cow manure releases P into the soil [39]. Meanwhile, Yuniarti et al. [29] stated that rock phosphate is a natural rock that contains high amount of phosphate minerals. Hanum et al. [40] reported that an increase in P fertilizer dosage potentially caused a rise in total P of soil. These previous reports were in line with this study which shows that the total P of 5 t ha\(^{-1}\) manure with 5 t ha\(^{-1}\) rock phosphate is higher than 5 t ha\(^{-1}\) manure with 2.5 t ha\(^{-1}\) rock phosphate. Furthermore, Shreckhise et al. [41] reported that increase in total P retention was recorded after the application of dolomite and micronutrient fertilizer.

Available P was significantly affected by manure, rock phosphate and dolomite (Table 1). Application of 5 t ha\(^{-1}\) manure, 5 t ha\(^{-1}\) rock phosphate and 5 t ha\(^{-1}\) dolomite(2.64ppm) significantly increased available P on an average of 48% compared to control. This is possibly due to the type of manure and rock phosphate used in this experiment, which contains phosphorus, thereby gradually releasing the available P into the soil. Minardi et al. [42] argued that the use of organic matter (manure) increased the soil P availability and fertility. Meanwhile, soil with ameliorant combination of rock
phosphate and quail manure gave significant result for available P. This result was in line with previous reports [43]. Kasno and Sutriadi [44] showed that the application of phosphate fertilizers using rock phosphate increased available P. In addition, this content was considerably improved by liming with dolomite [45][23][46]. Dolomite is a form of agricultural lime with 33% CaO% and 20% MgO, it improves soil chemical properties by increasing the availability of P, Ca and Mg [33]. Furthermore, Cong [47] also showed that the addition of phosphorus to the soil is important to obtain optimal plant growth and productivity.

Manure, rock phosphate and dolomite significantly affect available Ca as shown in Table 1. The highest available Ca was recorded with T5 (0.62 g), while the lowest was observed in control (2.43 cmol(+) kg-1). Previous studies showed that Ca content increased significantly with manure treatments [21]. Furthermore, Suntoro et al. noted that the increase in Ca was due to the application of cow manure through the process of mineralization, as well as the addition of dolomite. Damrongrak et al. [24] reported that dolomite liming improved the Ca content while Suriyagoda et al. [45] also added that 10 t ha-1 dolomite increased available Ca concentration. Also, Septiyania et al. reported that exchangeable-Ca increased in peat soil using Ca and Mg from dolomite material (30% CaO and 18% MgO). Kasno and Sutriadi, (2012) meanwhile, showed that rock phosphate increased Ca content. Rock phosphate has a high Ca content (ranging from 24-33%) which potentially increases CEC and soil pH and affect oil palm yields [48]. Therefore, rock Phosphate ensure a sustainable supply of P thereby, creating high root density for better nutrient exploration.

**Table 1.** Effect of Manure, Rock Phosphate, and Dolomite on pH, CEC, Total Available P, and Ca

| Treatments | pH   | CEC (cmol(+) kg-1) | Total P (mg 100 g-1) | Available P (ppm) | Available Ca (cmol(+) kg-1) |
|------------|------|-------------------|----------------------|------------------|---------------------------|
| T0         | 6.3  | b                  | 20.84 d              | 6.05 f           | 62.15 c                    | 2.43 d                     |
| T1         | 6.4  | ab                 | 22.19 ed             | 10.62 e          | 67.28 c                    | 4.45 c                     |
| T2         | 6.7  | a                  | 26.45 ab             | 13.82 d          | 73.70 bc                   | 6.40 b                     |
| T3         | 6.5  | ab                 | 24.38 bc             | 18.87 c          | 85.23 ab                   | 6.49 b                     |
| T4         | 6.7  | a                  | 27.92 a              | 25.66 b          | 90.41 a                    | 9.02 a                     |
| T5         | 6.7  | a                  | 29.26 a              | 35.17 a          | 92.09 a                    | 9.68 a                     |

The number followed by the same letters on the same row are not significantly different according to Duncan Multiple Range Test (DMRT) at 5% level.

As indicated in Table 2, manure, rock phosphate and dolomite affect the number of filled pods (p<0.05). The treatment, with T5 (1218 pods plot-1), presented the highest number of filled pods compared to control (890 pods plot-1). This is consistent with Minardi et al. [49] which showed that manure, significantly increased the number of filled of pods independently. Piravenea and Seran, reported that the application of manure and rock phosphate in excess increased the number of pod. Phosphorus in rock phosphates play a role in energy transformation in plants [51] and also increased the filling of soybean seeds [52]. Dida and Etisa [53], reported that liming with dolomite constuits the main management practice used in neutralizing soil acidity and aluminum which indirectly supplies calcium to plants and effectively increases pod numbers. The use of lime in legume production is believed to improve soil health status by increasing P and Ca availability. Kabir et al. [54] reported that Ca deficiency leads to high percentage of aborted seeds (empty pods) and improperly filled pods. In addition, Calcium (Ca) is required by legume from the inception of fruit formation until it becomes fully grown pods [15].

The effect of manure, rock phosphate and dolomite on 100 seed weight are presented in Table 1, where the highest 100 seed weight was recorded with T5 (0.62 g) compared to the lowest recorded in the control (0.44 g). Previous studies reported that manure significantly increased the weight of 1000 seeds [52] and 100 [55][56]. Furthermore, Isa and Bashir [57] stated that manure increased vegetative growth of plants and yield components such as the 100 seed weight. Waheed et al. [58] stated that phosphorus plays a role in cell division and enlargement, respiration and photosynthesis, therefore, it is the most important nutrient that controls plant growth and yield. Furthermore, Domingues et al. [59] noted that calcium from dolomite serve vital physiological functions in plants, such as pollen
germination and tube growth, organization of cell walls by calcium pectates, stabilization of membranes, and elongation of the roots. Hence, manure, rock phosphate and dolomite significantly affect 100 seed weight.

Table 2. Effect of Manure, Rock Phosphate, and Dolomite on Number of Filled Pods, 100-Seed Weight, and Seed Yield

| Treatments | Number of Filled Pods (pods plot⁻¹) | 100-Seed Weight (g) | Seed Yield (g plot⁻¹) |
|------------|-------------------------------------|---------------------|-----------------------|
| T0         | 890 b                               | 0.44 d              | 105.50 d              |
| T1         | 953 b                               | 0.61 c              | 181.25 c              |
| T2         | 943 b                               | 0.59 b              | 207.25 b              |
| T3         | 898 b                               | 0.46 b              | 214.19 b              |
| T4         | 1038 b                              | 0.53 b              | 219.31 b              |
| T5         | 1218 a                              | 0.62 a              | 260.89 a              |

The number followed by the same letters on the same row are not significantly different according to Duncan Multiple Range Test (DMRT) at 5% level.

Soybean yielded significantly with manure, rock phosphate and dolomite (P<0.05) (Table 2). The highest value was obtained in T5 (477.75 g plot⁻¹) compared to control (211.00 g plot⁻¹). Several studies have been reported similar results in soybean (49;7;60). It was concluded that manure application resulted in the production of seeds with the highest weight. Are et al. [61] also noted an increase in yields resulting from nutrient accumulation in the soil after the application of organic fertilizer. This study was consistent with Cong [47], which demonstrated that the application of P fertilizer (rock phosphate) increased corn productivity. Similarly, Masruroh et al. [62] also noted that the combination of rock phosphate and manure, increased seed weight per plot of soybean. In addition, liming with dolomite showed high crop yield as reported by several researchers [46][12][63], while application to lowland rice fields tend to increase grain yield [45]. Recently, Triatmoko et al. [7] reported that soybean production was affected by the availability of nutrients, especially phosphorus and calcium. In addition, Santos et al. [64] showed that the increase in soil Ca levels were directly related to the availability of nutrients shown to efficiently increase soybean productivity. Meanwhile, Yang et al. [28] stated that plant nutrients are essential in increasing crop yields. Duaja and Buhaira [65] also revealed that the availability of nutrients in soil affected soybean yield. Similarly, Hellal et al. [66] stated that phosphorus deficiency resulted in reduction of crop yield.

4. Conclusion

Based on the results, the application of manure, rock phosphate and dolomite improve phosphorus as well as calcium availability and increase soybean yield. The T5 treatment (5 t ha⁻¹ manure + 5 t ha⁻¹ rock phosphate + 5 t ha⁻¹ dolomite) have the best result in improving soil chemical properties (pH, total P, available P and available calcium), and increasing soybean yield (number of filled pods, 100-seed weight, and seed yield), meanwhile, these results are considered useful for farmers.

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