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Utilization of gypsum from tin smelting waste and organic fertilizers for mung bean and edamame productivity in Ultisol

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Abstract: Mung beans and edamame are important cash crops with significant global potential. However, their production in Indonesia has declined, primarily due to nutrient deficiencies caused by soil acidity, especially in Ultisols. In Bangka Belitung, gypsum waste from tin mining activities offers an opportunity to improve soil quality when combined with organic fertilizers, potentially serving as an alternative to commercial calcite sources. This study evaluates the effects of gypsum waste and organic fertilizers on the productivity of mung beans and edamame in Ultisols. A split-plot randomized block design was used, with calcite sources as the first treatment: no calcite (P1), commercial agricultural calcite (P2), and gypsum waste (P3). The second treatment involved organic fertilizers: commercial compost (K1), chicken manure (K2), and cow manure (K3). Growth parameters (plant height and number of leaves) and productivity (flower-to-pod and filled-pod percentages) were measured. Data were analyzed using Analysis of Variance (ANOVA) followed by Duncan's Multiple Range Test (DMRT) at a 95% significance level. The combination of commercial agricultural calcite and chicken manure was most effective for mung bean growth and productivity. For edamame, the combination of gypsum waste and cow manure enhanced growth and productivity. This study demonstrates the potential of gypsum waste as a sustainable alternative to commercial agricultural lime in improving soil fertility in Ultisols, thereby increasing the productivity of these globally significant crops.

Keywords: Calcite ($CaCO_3$), Edamame, Gypsum waste, Mung bean, Organic fertilizers, and Ultisol.

Introduction

Mung bean (*Vigna radiata*) and edamame (*Glycine max*) are agricultural commodities with significant economic and nutritional value, making them essential in modern agricultural systems. Both are functional foods that positively impact health and nutritional adequacy (Anugrahtama et al., 2020). Mung bean is a rich source of plant-based protein, micronutrients like folate, magnesium, and B vitamins, and is high in fiber and low in fat. Edamame, the young soybean pods, is rich in omega-3 fatty acids, protein, and fiber. These crops adapt well to challenging conditions, enhancing food security. However, production in Indonesia has declined, with mung bean falling from 379,928 tons in 2022 to 350,017 tons in 2023, and edamame decreasing between 2018 and 2021 (Directorate General of Food Crops, 2024). This decline is due to reduced productivity and underutilized land.

In Bangka Belitung, a province in Indonesia, the development of mung bean and edamame is further challenged by the soil conditions, which are dominated by Ultisol. Ultisols are characterized by low fertility, with deficiencies in macronutrients such as phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) (Maulana et al., 2020). Additionally, these soils have a low pH, ranging from 5 to 3.1, making the soil acidic and limiting nutrient availability for crops (Karnilawati et al., 2022). To improve soil fertility, liming is commonly applied, which raises the pH, enhances calcium and magnesium levels, and reduces aluminum toxicity, thereby improving nutrient absorption (Fahrunsyah et al., 2023; Firdany et al., 2021). Despite the potential for expanding cultivation, the dominance of Ultisol in areas like Bangka Belitung remains a significant constraint.

Ultisols are characterized by significant challenges, particularly their low pH, which requires regular amendments to improve soil quality and enhance crop growth. Traditionally, agricultural lime (calcium carbonate) has been used to raise soil pH. However, Bangka Belitung faces a scarcity of natural limestone sources and lacks factories for producing commercial lime, leading to an increased demand and potential shortages of agricultural lime. A viable solution to this issue is the utilization of gypsum waste from the tin smelting process at PT. Timah Metallurgical Unit in Muntok, Bangka Belitung. This gypsum waste ($CaSO_4$) is produced through the sulfurization of tin ore and whiting, a process known as desulfurization, and shares a similar molecular structure to agricultural lime (Barroso et al 2023; Aakriti et al., 2023). As such, gypsum waste can serve as a sustainable and effective alternative to agricultural lime, offering a feasible method to improve soil pH and fertility in Ultisols.

In addition to pH amendments, organic fertilizers provide a sustainable solution for improving the fertility of Ultisols. These fertilizers enhance soil structure, water retention, and nutrient availability, making them ideal for boosting crop yields in nutrient-poor soils (Tian et al., 2025). Local resources, such as cow and chicken manure, are rich in nitrogen, phosphorus, and potassium, essential nutrients that promote plant growth (Liu et al., 2021). Utilizing these resources not only reduces livestock waste but also improves soil health and reduces reliance on harmful chemical fertilizers. Organic matter can also complement agricultural lime by further increasing soil pH and enhancing soil fertility (Pramono & Dedi, 2023). Additionally, organic fertilizers improve the physical, chemical, and biological properties of the soil, significantly boosting crop productivity and quality (Mufriah & Sulistiani, 2020). Together, these approaches offer a comprehensive and sustainable solution for enhancing the productivity of Ultisols.

This study aims to evaluate whether the use of gypsum waste can serve as a substitute for agricultural lime and to assess its impact when combined with cow and chicken manure on the production of mung bean and edamame. The research will investigate the effectiveness of gypsum waste, derived from the tin smelting process, in improving soil pH and fertility, and how its combination with organic fertilizers can enhance crop yields. By exploring this alternative, the study seeks to provide a sustainable solution to soil pH management in Ultisol lands, offering insights into potential improvements in crop production and soil health.

Results

Gypsum waste and organic fertilizer effect on mung beans growth and productivity

The results of the analysis of variance for mung beans revealed that the interaction between different types of calcite sources and organic fertilization significantly affected growth and yield, particularly in terms of plant height, number of leaves, and percentage of filled pods. Similarly, the analysis of variance for edamame plants indicated that the interaction between calcite sources and organic fertilization had a significant impact on plant height, weight of filled pods, and overall bean yield (Table 3). These findings underscore the importance of combining appropriate calcite sources with organic fertilizers to optimize growth and yield parameters for both mung bean and edamame.

The combination of agricultural calcite and chicken manure (P2K2) resulted in the highest plant height, measuring 24.91 cm, although it was not significantly different from the treatments of P3K2, P2K1, and P1K2. The highest number of leaves, 34.67 units, was observed in the P2K2 treatment, though it was not significantly different from P1K2, P3K2, P1K3, and P2K3. Additionally, P2K2 showed the highest percentage of flowers transitioning into pods (94%), although this was not significantly different from other treatments. The highest percentage of filled pods (94.67%) was found in the P2K2 treatment, which was significantly different from P1K1, P1K2, and P1K3, but not significantly different from the other treatments (Table 4). Furthermore, P2K2 produced the highest weight of filled pods (68.91 g), the lowest weight of empty pods (2.09 g), the highest bean yield (47.08 g/plant), and the highest weight of 100 seeds (5.40 g). However, these parameters did not show significant differences between the P2K2 treatment and the other treatments and control treatment (without calcite and gypsum waste)(Table 5).

Gypsum waste and organic fertilizer effect on edamame growth and productivity

On the other hand, edamame exhibited slightly different growth and yield responses compared to mung beans. The combination of agricultural calcite and cow manure (P2K3) resulted in the highest plant height (19.80 cm), which was significantly different from the P1K1 treatment, but not significantly different from the other treatments. The P2K2 treatment tended to produce the highest number of leaves (25.47 units), although this was not significantly different from other treatments. The application of gypsum waste combined with commercial compost yielded the highest values for the percentage of flowers becoming pods (94%) and the percentage of filled pods (94%), but these results were not significantly different from the other treatments (Table 6). The treatment of agricultural calcite combined with cow manure (P2K3) also showed the highest weight of filled pods (99.81 g), although it was not significantly different from the P1K3, P2K1, and P3K3 treatments. The best treatment for the weight of empty pods was P3K1, which gave the lowest value (0.92 g), though it was not significantly different from other treatments. For bean yield, the P2K3 treatment produced the highest result (27.33 g), significantly differing from P1K2, P2K2, and P3K2, but not from the other treatments. Additionally, P2K3 tended to yield the heaviest weight of 100 beans (67.27 g), although there was no significant difference compared to other treatments and control treatment (without calcite and gypsum waste)(Table 7).

Discussion

The application of different calcite sources and organic fertilizers significantly affected several growth and yield parameters of mung bean and edamame. Specifically, different calcite sources and organic fertilizers had a notable impact on plant height, number of leaves, and percentage of filled pods in mung beans. In contrast, for edamame, significant effects were observed in plant height, weight of filled pods, and bean yield. These findings demonstrate that the combination of different calcite sources and organic fertilizers can influence various growth and yield parameters for both mung bean and edamame (Table 3). The application of agricultural calcite and gypsum waste as calcite sources can increase soil pH, improve the availability of calcium (Ca), magnesium (Mg), and base saturation, and reduce exchangeable aluminum (Al-dd) (Krisnawati & Bowo, 2019). The increase in calcium, a key component of the chlorophyll molecule, plays a critical role in photosynthesis. Furthermore, the liming process helps decrease the content of heavy metals that bind essential nutrients, thereby enhancing the availability of vital nutrients for plant growth (Wahyuningsih, 2017).

The application of organic fertilizers shows good compatibility with calcite sources, further enhancing the availability of essential nutrients for plant growth and yield. Organic fertilizers not only improve nutrient levels but also positively affect the physical and chemical properties of the soil, as well as its microbial communities (Saragih & Sitanggang, 2021). The biological role of organic materials, as an energy and nutrient source for soil microorganisms, enhances microbial activity, which in turn benefits nutrient provision to plants. Marlina et al. (2015) highlighted that the use of organic fertilizers is effective in promoting plant growth and improving yields. The combination of calcite sources, which improve environmental conditions for plant growth, and organic fertilizers, which provide vital nutrients for both plants and soil organisms, makes this treatment combination ideal for enhancing the growth and yield of mung bean and edamame.

The effect of calcite sources and organic fertilizers on the growth and yield of mung bean revealed that the combination of agricultural calcite and chicken manure (P2K2) yielded the highest results across all observed parameters. However, the application of gypsum waste showed similar effects, though not significantly different from the agricultural calcite treatment (Table 4 and 5). The superior performance of agricultural calcite can be attributed to its intended use as an agricultural product, while gypsum waste, though containing calcite, is a byproduct of the tin ore smelting process and not originally designed for agricultural purposes. Despite this, the results of this research indicate that gypsum waste can serve as a viable alternative to commercial agricultural lime for mung bean cultivation. The

Table 1. Soil physical and chemical quality analysis of soil from Regional Technical Implementation Unit – Agricultural Seed Centre (UPTD Balai Benih Pertanian) Air Pelempang.

No	Parameter	Unit	Result	Criteria
1	pH H_2O	-	5.7	Slightly Acid
2	KCl	-	4.4	Acid
3	C Organik	%	1.27	Low
4	N-Total	%	0.10	Low
5	C/N Ratio	-	13	Medium
6	P_2O_5 available	mg/kg	7.36	Low
7	P_2O_5 potential	mg/100g	7.58	Very low
8	K_2O potential	mg/100g	12.17	Low
9	K^+	cmol(+)/kg	0.15	Low
10	Na^+	cmol(+)/kg	<0.029	Very low
11	Ca^{2+}	cmol(+)/kg	1.74	Very low
12	Mg^{2+}	cmol(+)/kg	0.60	Low
13	KTK	cmol(+)/kg	8.23	Low
14	Base saturation	%	30	Low
15	AI^{3+}	cmol(+)/kg	<0.04	-
16	H^+	cmol(+)/kg	0.21	-
17	Nikel (Ni)	mg/kg	<9.00	Normal
18	Timbal (Pb)	mg/kg	<8.00	Normal
19	Kadmium (cd)	mg/kg	<5.00	Critical threshold
20	Arsen (As)	mg/kg	<2.60	Normal
21	Raksa (Hg)	mg/kg	<1.40	Critical threshold
22	Krom (Cr)	mg/kg	<1,00	Normal

Notes: Soil analysis conducted in ICBB laboratory, PT. Biodiversitas Bioteknologi Indonesia. The soil criteria were determined based on the Soil Research Center, 2009.

Table 2. Heavy metal content analysis in gypsum waste.

No	Parameter	Unit	Result	Threshold Standard (SNI 482:2018)
1	Water content	%	16.11	Did not meet the standard
2	Timbal (Pb)	mg/kg	< 8.00	Met the standard
3	Nickel (Ni)	mg/kg	< 9.00	-
4	Cadmium (Cd)	mg/kg	< 1.00	Met the standard
5	Arsenic (As)	mg/kg	< 2.60	Met the standard
6	Cromium (Cr)	mg/kg	< 0.10	-
7	Mercury (Hg)	mg/kg	< 0.56	Met the standard

Notes: The analysis of heavy metal content in gypsum waste was conducted at the ICBB Laboratory. PT. Biodiversitas Bioteknologi Indonesia. The heavy metal criteria refer to the Indonesia National Standardization Board for agricultural lime SNI 482:2018.

Table 3. Analysis of variance from combination of different calcite sources and organic fertilizer on growth and yield parameters of mung bean and edamame plant.

No	Paramater	Mung bean		KK	Edamame		CV (%)
		F-hit	Pr>F		F-hit	Pr>F	
1	Plant height (cm)	**5.98***	<0.01	7.23	**2.45***	0.05	6.99
2	Number of leaves (Helai)	**5.06***	<0.01	10.69	2.11ns	0.09	12.30
3	Flowers becoming pods (%)	2.37ns	0.07	6.42	0.44ns	0.88	3.84
4	Percentage of filled pods (%)	**2.73***	0.04	2.68	0.59ns	0.77	4.31
5	Weight of filled pods (g)	0.66ns	0.72	13.48	**2.95***	0.03	14.14
6	Weight of empty pods (g)	2.20ns	0.09	35.93	0.20ns	0.99	15.85
7	Seed yield (g/plant)	0.76ns	0.80	14.34	**2.72***	0.04	16.88
8	Weight 100 beans (g)	1.92ns	0.13	9.80	1.36ns	0.28	11.58

Note: Pr>F = Probability value. * = significantly different, ns = Not significantly different, CV = Coefficient of Variation.

Table 4. Interaction of different calcite sources and organic fertilizer on the parameters of plant height, number of leaves, percentage of flowers becoming pods and percentage of filled pods of mung beans.

No	Treatment	Parameters			
		Plant height (cm)	Number of leaves (units)	Flowers becoming pods (%)	Filled pods (%)
1	P1K1	19.13 c	26.20 cd	78.33	87.33 c
2	P1K2	23.63 ab	30.60 a	92.00	89.33 bc
3	P1K3	19.28 c	31.07 abc	86.33	89.33 bc
4	P2K1	20.42 a	26.33 cd	90.33	91.67 abc
5	P2K2	**24.91 a**	**34.67 a**	**94.00**	**94.67 a**
6	P2K3	20.36 c	30.53 abcd	86.33	93.67 a
7	P3K1	21.45 bc	27.87 bcd	82.33	90.00 abc
8	P3K2	24.73 a	33.47 ab	91.00	92.33 ab
9	P3K3	21.42 bc	24.60 d	85.67	91.33 abc

notes: P1K1 (without calcite source + commercial compost fertilizer), P1K2 (without calcite source + chicken manure fertilizer), P1K3 (without calcite source + cow manure fertilizer), P2K1 (agricultural calcite source + commercial compost fertilizer), P2K2 (agricultural calcite source + chicken manure fertilizer), P2K3 (agricultural calcite source + cow manure fertilizer), P3K1 (gypsum waste + commercial compost fertilizer), P3K2 (gypsum waste + chicken manure fertilizer), P3K3 (gypsum waste + cow manure fertilizer). Numbers followed by the same letter in the same column were not significantly different according to the DMRT test at 95 % significant level.

Table 5. Interaction of different calcite sources and organic fertilizer on the yield parameters of mung bean.

No	Treatment	Parameter			
		Weight of filled pods (g)	Weight of empty pods (g)	Seed yield (g/plant)	Weight of 100 beans (g)
1	P1K1	57.59	5.28	39.41	4.30
2	P1K2	61.28	3.27	40.50	4.60
3	P1K3	58.11	4.41	40.33	4.67
4	P2K1	64.60	2.80	44.84	4.93
5	P2K2	68.91	2.09	47.08	5.40
6	P2K3	66.39	2.19	45.47	4.43
7	P3K1	59.48	3.23	41.57	4.57
8	P3K2	63.34	4.15	44.02	5.30
9	P3K3	59.31	4.33	42.74	4.73

notes: P1K1 (without calcite source + commercial compost fertilizer), P1K2 (without calcite source + chicken manure fertilizer), P1K3 (without calcite source + cow manure fertilizer), P2K1 (agricultural calcite source + commercial compost fertilizer), P2K2 (agricultural calcite source + chicken manure fertilizer), P2K3 (agricultural calcite source + cow manure fertilizer), P3K1 (gypsum waste + commercial compost fertilizer), P3K2 (gypsum waste + chicken manure fertilizer), P3K3 (gypsum waste + cow manure fertilizer).

Table 6. Interaction of different calcite sources and organic fertilizer on the parameters of plant height, number of leaves, percentage of flowers becoming pods and percentage of filled pods of edamame.

No	Treatment	Parameters			
		Plant height (cm)	Number of leaves (units)	Flowers becoming pods (%)	Filled pods (%)
1	P1K1	15.76 b	17.93	89.33	89.33
2	P1K2	17.34 ab	21.40	92.67	92.68
3	P1K3	18.55 ab	16.67	92.67	93.33
4	P2K1	17.30 ab	20.20	89.67	89.68
5	P2K2	19.47 a	25.47	91.33	90.33
6	P2K3	19.80 a	23.27	92.33	93.33
7	P3K1	18.35 ab	22.53	94.00	94.00
8	P3K2	17.37 ab	21.27	93.00	93.00
9	P3K3	19.61 a	21.73	91.67	92.68

notes: P1K1 (without calcite source + commercial compost fertilizer), P1K2 (without calcite source + chicken manure fertilizer), P1K3 (without calcite source + cow manure fertilizer), P2K1 (agricultural calcite source + commercial compost fertilizer), P2K2 (agricultural calcite source + chicken manure fertilizer), P2K3 (agricultural calcite source + cow manure fertilizer), P3K1 (gypsum waste + commercial compost fertilizer), P3K2 (gypsum waste + chicken manure fertilizer), P3K3 (gypsum waste + cow manure fertilizer). Numbers followed by the same letter in the same column were not significantly different according to the DMRT test at 95 % significant level.

Table 7. Interaction of different calcite sources and organic fertilizer on the yield parameters of edamame.

No	treatment	Parameter			
		Weight of filled pods (g)	Weight of empty pods (g)	Seed yield (g/plant)	Weight of 100 beans (g)
1	P1K1	78.20 bc	1.43	26.89 ab	63.90
2	P1K2	69.86 c	1.49	19.33 cd	58.07
3	P1K3	89.67 abc	1.83	25.07 abc	59.00
4	P2K1	84.60 abc	1.84	25.82 abc	62.43
5	P2K2	77.91 bc	1.85	17.22 d	57.00
6	P2K3	99.81 a	1.51	27.33 a	67.27
7	P3K1	74.40 c	0.92	23.21 abcd	59.72
8	P3K2	76.08 bc	1.67	19.56 bcd	51.67
9	P3K3	95.83 ab	1.72	25.00 abc	64.27

notes: P1K1 (without calcite source + commercial compost fertilizer), P1K2 (without calcite source + chicken manure fertilizer), P1K3 (without calcite source + cow manure fertilizer), P2K1 (agricultural calcite source + commercial compost fertilizer), P2K2 (agricultural calcite source + chicken manure fertilizer), P2K3 (agricultural calcite source + cow manure fertilizer), P3K1 (gypsum waste + commercial compost fertilizer), P3K2 (gypsum waste + chicken manure fertilizer), P3K3 (gypsum waste + cow manure fertilizer). Numbers followed by the same letter in the same column were not significantly different according to the DMRT test at 95 % significant level.

application of calcite-containing materials, such as agricultural lime, has been shown to boost crop yields by increasing nutrient availability, allowing plants to absorb essential nutrients like calcium (Ca), magnesium (Mg), nitrogen (N), phosphorus (P), and potassium (K), which were less available before the liming process (Prastia & Fikriman, 2018). Agricultural calcite also supports plant growth during the production phase, including pod filling, number of pods, and overall plant yield (Hanan et al., 2017). Calcite liming is especially important for acidic soils, such as Ultisols, where the calcium in calcite plays a crucial role in apical growth, enhancing cell division from the growth period through to flower formation (Zahanis et al., 2020). Additionally, calcite application has been shown to increase the number of pods, seed weight per plant, and overall plant dry weight (Irwan & Nurmala, 2018).

The application of organic fertilizers, particularly chicken manure, significantly increased the production of mung beans. The ability of chicken manure to enhance plant productivity is closely linked to its nutrient content. Compared to commercial compost and cow manure, chicken manure has higher levels of nitrogen (N) and potassium (K), making it a more effective fertilizer for increasing crop production (Latuamury, 2015). According to Alibasyah (2016), macronutrients such as nitrogen (N), phosphorus (P), and potassium (K) play essential roles in plant growth. Nitrogen is crucial for leaf growth and the formation of stems and branches, while phosphorus supports seed and root development, and potassium is vital for flower and pod formation (Stephanie et al., 2015). Thus, the high nutrient content in chicken manure directly contributes to improved mung bean growth and yield.

Edamame exhibited a slightly different response compared to mung bean, with agricultural calcite and cow manure fertilizer showing the best effects on several growth and yield parameters (Table 3).

Agricultural calcite provided the best results for several growth parameters in edamame, aligning with the findings of Koesrini et al. (2015), who reported that the application of agricultural lime significantly increased soil pH, reduced aluminum saturation, and enhanced growth factors such as plant height, number of leaves, stem weight, and root growth. Roma et al. (2023) also stated that agricultural lime application to edamame soybean plants can promote plant growth and increase seed yield. Nuraini et al. (2021) further confirmed that agricultural lime raised soil pH, improving soil quality for edamame growth. Additionally, cow manure fertilizer demonstrated good compatibility with calcite sources in edamame cultivation. Sofyan et al. (2022) noted that, in conjunction with agricultural lime, cow manure fertilizer supplies essential nutrients that enhance plant growth, including plant height, pod quantity, and seed weight. Cow manure, with its high fiber content, improves water retention in the soil and contains cellulose, which undergoes decomposition, providing further benefits to soil structure. Sugirno (2021) highlighted that cow manure fertilizer positively influences root growth due to its phosphorus content, which plays a crucial role in cell division and root development.

An interesting discovery in this research was the ability of gypsum waste to show no significant difference compared to agricultural calcite in both mung bean and edamame cultivation. While gypsum waste produced slightly lower results than agricultural calcite, it was particularly notable in the weight of filled pods parameter for mung bean, where gypsum waste demonstrated similar effects to agricultural calcite. In contrast, treatments without calcite sources resulted in the lowest values, significantly different from the calcite treatments. This finding indicates that gypsum waste can serve as an alternative to agricultural calcite. Gypsum waste contains calcium (Ca) like agricultural calcite, and based on heavy metal analysis, it meets the Indonesian National Standard (SNI 482:2018) for agricultural lime, making it safe for agricultural applications. Furthermore, gypsum waste combined with chicken manure fertilizer produced similar results to agricultural calcite in mung bean cultivation, while gypsum waste combined with cow manure fertilizer showed comparable effects to agricultural calcite in edamame cultivation across several parameters.

Material and Methods

Study site

The field trial was conducted at the Regional Technical Implementation Unit – Agricultural Seed Centre in Air Pelempang, Bangka Regency, from April to July 2024. Soil physical and chemical properties were analyzed to assess fertility criteria, with the results compared to the soil fertility standards based on Balittanah (2009) (Table 1). The soil in the study area is acidic, with a low pH, which limits the availability of essential nutrients. Consequently, the soil exhibits low levels of NPK, significantly reducing its fertility and limiting plant productivity. These factors emphasize the need for soil amendments to enhance nutrient availability and support crop growth.

Material Used

The materials used in this study included mung bean seeds (cultivar Vima 3), edamame seeds (cultivar Ryoko 75), commercial agricultural calcite ($CaCO_3$), gypsum waste obtained from the Metallurgical Unit in Muntok, cow manure, chicken manure, and commercial compost. To ensure its safety for agricultural use, the gypsum waste was analyzed for heavy metal contamination. The results of this analysis were compared to the Indonesia National Standard for agricultural lime (SNI 482:2018) (Table 2). The heavy metal content in the gypsum waste complied with the SNI 482:2018 standard, indicating that it is a safe and viable alternative to commercial agricultural lime. This makes gypsum waste a potential and effective soil amendment for improving soil fertility in agricultural applications.

Experimental design

This research employed a split-plot randomized block design with three replications, consisting of main plot and subplot treatments. The main plot treatments included P1 (without calcite source), P2 (agricultural calcite source), and P3 (gypsum waste). The subplot treatments consisted of K1 (commercial compost), K2 (chicken manure), and K3 (cow manure). In total, there were 27 experimental units, each consisting of 10 plants, with 5 sample plants selected per unit. This resulted in a total of 270 plants and 135 plant samples, prepared in two sets for mung bean and edamame.

Parameter Response and Statistical Analysis

The observed parameters included plant height (cm), number of leaves (units), percentage of flowers becoming pods (%), weight of filled pods (g), weight of empty pods (g), percentage of filled pods (%), bean yield (g/plant), and weight of 100 seeds (g). Data analysis was conducted separately for mung bean and edamame. Analysis of variance (ANOVA) was performed at a 95% significance level, followed by Duncan's Multiple Range Test (DMRT) at the same significance level.

Conclusion

The combination between agricultural calcite and chicken manure fertilizer was the best combination for mung bean cultivation in ultisol soil, while agricultural calcite and cow manure fertilizer was the best combination for edamame cultivation in Ultisolsl. Gypsum waste had potential as a substitute material for commercial agricultural calcite but it needed to be combined with chicken manure fertilizer for mung bean cultivation and it needed to be combined with cow manure fertilizer for edamame cultivation.

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Statement of Contributions

DP participated in conceptualization, methodology, validation, data curation, writing the original draft, visualization, and project administration; TL and K contributed to data curation and supervision; D and NH were involved in investigation and data curation; and DDMA contributed to writing, editing and administration.

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