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Improving Maize Yield, Biomass, and Selected Chemical Properties of an Acid Soil Using Transformed Chicken Dung

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ABSTRACT

Ultisols and Oxisols are acidic soils with high concentrations of Al (Aluminium) and Fe (Iron), making them unsuitable for agriculture without intervention, which contributes to Brunei's low agricultural self-sufficiency. Sustainable agro-waste management can enhance soil quality and crop productivity. With the increasing number of poultry farms, better management of chicken dung produced is crucial for maintaining soil fertility and enhancing maize production. This study aimed to improve selected soil chemical properties, maize yield, and above-ground biomass of maize plants by repurposing chicken dung as an organic amendment (OA). A field trial was conducted using a Random Complete Block Design with five treatments: (T1) chemical fertiliser only; (T2) 100% OA + chemical fertiliser; (T3) 75% OA + chemical fertiliser (T3); (T4) 50% OA + chemical fertiliser; and (T5) 25% OA + chemical fertiliser. Maize yield (test crop), maize plants' above-ground biomass, and soil samples were collected and analysed using standard procedures. Results suggest that the OA treatments enhanced maize fresh cob yield and maize plants' above-ground biomass compared with chemical fertiliser alone by 89.42% and 50.95%. Moreover, the OA increased soil exchangeable Al^{3+} and H^+, whereas soil nitrate, P, and Na^+ decreased. However, no significant differences were observed in soil pH, total organic carbon, total N, K, NH_4^+, Mg, and Ca^{2+}. Further field trials may reveal the long-term soil, maize fresh cob yield, and above-ground maize plants' biomass improvements. This study provides a novel approach to restoring Brunei's degraded agricultural soil by integrating organic amendments and promoting sustainable waste management.

Keywords: Crop productivity, low pH soils, organic amendment, soil quality

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INTRODUCTION

Soil serves as a medium for several purposes, including building construction, agroforestry, and animal and crop production. However, the natural state does not guarantee the best ecological functions for these purposes. In the case of agriculture, the tropics primarily have Ultisols and Oxisols (von Uexküll & Mutert, 1995), which are highly acidic with pH values below 5.5. Thus, they are relatively unfavourable or infertile for production agriculture without suitable intervention, such as applying lime, organic matter, and chemical fertilisers. Because Ultisols and Oxisols have high concentrations of Al and Fe, they are noted for causing nutrient imbalances such as low P in addition to reducing critical biological activities and microbial communities (Agegnehu et al., 2019; Osman, 2018).

The traditional practice of liming and the use of chemical fertilisers may enhance soil acidification and further deteriorate soil health (Cai et al., 2019). Additionally, these traditional practices are deemed uneconomical and unsustainable for the environment because, for example, the liming effect is temporary; thus, compelling farmers to apply significant amounts of lime every growing season, and this practice is expensive, time-consuming, and laborious. Although agricultural lime is easy to handle, over-liming has its risks, and such risks are listed as follows: (i) further increased soil pH causing a decrease in solubility of nutrients, (ii) molybdenum toxicity, (iii) micronutrient deficiency, and (iv) disruption of soil structure by reducing the stability and drainage, and (v) liming effect is temporary (Osman, 2018; Weil & Brady, 2016). Moreover, excessive application of chemical fertilisers high in P and N causes environmental issues such as the eutrophication of water bodies.

The use of manure as an ingredient for organic fertilisers or soil amendments is suggested to be more sustainable for soil productivity and management, food production, cost-effective, and can increase crop yield by improving soil fertility compared with synthetic fertilisers such as compound N-P-K (nitrogen-phosphorous-potassium) or straight N, P, and K fertilisers (Ali et al., 2023; Zhang et al., 2020). It is worth stressing that the excessive use of chemical fertilisers for improving soil productivity decreases soil pH and worsens the initial problem. In comparison with plants treated with chemical fertiliser only, combining organic soil amendments and chemical fertilisers enhances soil chemical properties, nutrient uptake, and crop yield (Ali et al., 2023). A study by Cai et al. (2019) revealed that manure positively impacted maize yields more than synthetic fertilisers. In addition, the study demonstrated that manure and interactive manure with synthetic fertiliser application could prevent soil acidification, other to increasing soil pH and improving soil structure. The production of organic fertilisers or soil amendments from poultry manure suggests the possibility of slow-release properties causing long-term improvement of soil and crop productivity (Purnomo et al., 2017). The timely release of nutrients prevents nutrient loss; therefore, the plants can receive sufficient nutrients to enhance their growth, which can be translated into the crop yield. Similarly, the application of chemical fertilisers amended with organic amendments showed significant improvement in maize yield (Ch'ng et al., 2017). The study further revealed minimal N loss between the plant-soil system, an improvement in soil pH, nutrient availability, and a reduction of Al and Fe, leading to an improvement of nutrient uptake in the rooting zone of the maize plants. Adebayo et al. (2017) reported that the growth of *M. oleifera* was significant when poultry manure, cow dung manure, organo-minerals, and NPK were applied. Nonetheless, using poultry manure was superior in terms of providing optimum crop growth qualities, which translates into increasing crop yield. Furthermore, the biochemical transformation of poultry wastes offers benefits, particularly in nutrient recycling and application to agricultural soils, and this approach reduces environmental degradation (Ali et al., 2023; Dróżdż et al., 2020; Obi et al., 2016) because poultry waste has a variety of naturally occurring beneficial microorganisms that contribute positively to ecological nutrient cycles, such as recycling C, N, P, and other elements present in the poultry by-product (Williams, 2013).

In Brunei, there has been a yearly increase in the broiler and egg industry. The annual increase is the main reason for attaining 100% SSL in the broiler sector, 100% SSL in the egg sector, 94.60% SSL in the day-old chicks' sector, and 80.10% SSL in the fertilised eggs sector in Brunei (Department of Agriculture and Agri-food, 2023). In return, these sectors generate more waste, which could cause environmental problems, such as increasing waste received by Brunie's landfills. Nonetheless, biodegradable wastes such as chicken dung have valuable nutrients that could be recycled, thus regenerating agricultural wastes into beneficial by-products that can improve Brunei soils' physical, chemical, and biological properties. The broiler and egg wastes can be turned into organic fertilisers or soil amendments through composting or co-composting of the wastes. Several studies have provided results on using organic amendments in improving soils' chemical, physical, and biological properties in a manner that translates into increased yield of crops (Dróżdż et al., 2020; Gržinić et al., 2023; Mironiuk et al., 2023).

Higher crop yield not only enhances food production but also provides raw materials for animal feed, supporting the livestock and poultry industry. Despite its potential, this approach has yet to gain widespread adoption in Brunei. At the same time, this approach enables effective and efficient waste management and utilisation, a practice that has yet to gain full traction in Brunei. To this end, regenerating poultry manure into value-added products such as organic amendments will support waste and soil management in Brunei and simultaneously improve the crop industry's sufficiency rate. Therefore, this study aimed to improve selected chemical properties of soil, maize yield, and above-ground maize plants' biomass production using transformed organic amendment from chicken dung.

MATERIALS AND METHODS

Soil and Organic Amendment Characterisation

The area used in this study is located at Hasmit Enterprise, Kampung Batong, Brunei (4.83788° N, 114.82173° E). Soil from the area was collected at 0-20 cm using an auger. The sampling area was 22 m x 71 m, and 10 soil samples were randomly taken. Afterwards, the soil samples were air-dried, ground, and sieved to pass a 2-mm sieve, after which they were analysed for pH and electrical conductivity (EC) using a pH and electrical conductivity meter (Ohaus, AQUASEARCHER™ AB33M1 Bench Meter) (FAO, 2021a, 2021c). Organic matter and total organic carbon were determined using the Walkley-Black method (FAO, 2019). The soil total P, K, Mg, and Ca were extracted using the aqua regia method (Moursy et al., 2020), where 20 mL of aqua regia (1:3 of HCl: HNO_3) was used to digest 2 g of the soil. Afterwards, the concentration of extracted K, Mg, and Ca was determined using an atomic absorption spectrophotometry (AAS) (AA-7000, Shimadzu), and total P following the molybdenum blue method in conjunction with ultraviolet-visible spectrophotometry (UV-Vis) (Cary 60 UV-Vis Spectrophotometer, Agilent). Similarly, the soil available P and exchangeable base cations such as K, Mg, Ca, and Na were extracted using the Mehlich 1 extraction method (Tan, 2005). Thereafter, the extractants were analysed using AAS for the exchangeable cations and UV-vis for available P, after the blue colour was developed by following the method described by Murphy and Riley (1962). The soil total N and exchangeable NH_4^+ were determined using the Kjeldahl method (FAO, 2021b; Lee et al., 2017) (Vapodest 450, Gerhardt), and exchangeable NO_3^- was determined following the sodium salicylate method (Monteiro et al., 2003) using a UV-Vis Spectrophotometer (UV-2700, UV-VIS Spectrophotometer, Shimadzu). The soil exchangeable acidity, Al^{+3}, and H^+ were extracted using 1 M KCl, after which they were determined using the acid-base titration with 0.01 M NaOH and 0.01 M HCl (Rowell, 1994).

The organic amendment was produced by mixing 25 kg of dried chicken dung with 1.25 kg of corn feed, 0.5 L of molasses, and 5% chicken manure slurry, following the procedure of Omar et al. (2021) with slight modification. The chicken manure slurry was made by mixing fresh chicken manure with water, which was a source of microbes. The corn feed was added to provide energy for the microbes, and the molasses provided carbohydrates, for example, glucose. For the first four weeks, the amendment was turned once every week. The corn feed and molasses were topped up during the first turning only to provide sufficient nutrients for the microbes. Seven boxes as replicates of the co-composting process were produced to ensure repeatability and error minimisation. The co-composting process lasted for 50 days, and the ambient and compost temperatures were monitored every 48 hours (7 AM and 5 PM) using a digital thermometer. The organic amendment produced was analysed for pH, electrical conductivity, organic matter, and total organic carbon following the procedures cited previously. Aqua regia was used to extract P, K, Mg, and Ca, after which AAS was used to analyse the concentration of K, Mg, and Ca, whereas P was analysed using the molybdenum blue method. The Kjeldahl method was used to determine total N.

Field Trial

A field experiment was conducted at Hasmit Enterprise, Kampung Batong, Brunei. The test crop used for this study was maize because of its sensitivity to low pH soils with high Al and Fe ions but low in organic matter. Land preparation was done in stages following standard procedures. Firstly, the land used was cleared by removing weeds manually, after which it was harrowed three times, such that the soil broke up for even seedbed establishment. The experimental field was designed with three blocks in a Randomised Complete Block Design. Each block had five plots to accommodate the treatments used in this field trial (five treatments x three blocks). Thus, a total of 15 plots were constructed, and the size of each plot was 3.2 m (width) x 5.6 m (length), where a total of 56 maize seeds were planted per plot. The Dolomite application was performed a day for equilibration before the organic amendment was broadcast. The dolomite applied was based on the rate of 6 t ha^{-1} as recommended by the *Jabatan Pertanian & Agrimakanan* (2023). The organic amendment was evenly applied to each plot according to its designated treatments. A total of five treatments were evaluated in triplicate (Table 1). The organic amendments applied were based on the rates of 5 t ha^{-1} (based on a planting density of 27,777 plants ha^{-1}) (Johan et al., 2021). The organic amendment rate was varied as 100%, 75%, 50%, and 25% of the recommended 5 t ha^{-1}. Chemical fertilisers N-P-K (15-15-15) were applied at a rate of 60 kg N ha^{-1} (Omar et al., 2020). The fertiliser was broadcast in two equal splits: (500 g NPK) and (500 g NPK) at 10 and 28 days after sowing (DAS), respectively. The treatments evaluated are presented in Table 1.

Standard procedures were used to monitor the maize plants until they were harvested at 73 DAS. The maize fresh cobs and shoots (leaves and stems) were harvested by cutting the stems at 0.1 mm from the soil surface. This was followed by collecting soil samples in each plot at 0 -20 cm. After harvesting, the cobs, leaves, stems, and soil were collected and processed for laboratory analysis. To assess total above-ground fresh biomass, the cobs, leaves, and stems were separated and weighed accordingly. The prepared soils were analysed for pH, EC, organic matter, total organic carbon, exchangeable acidity, Al^{3+}, H^{+}, P, and base cations (K, Mg, Ca, and Na), and total N, P, K, Mg, and Ca using the method previously cited.

Table 1
Description of treatments, rate of organic amendment, chemical fertiliser, and dolomite used

Treatments Code	Description	Organic Amendment rate	Chemical Fertiliser Rate	Dolomite Rate
T1	Soil + chemical fertiliser + dolomite	-	1 kg	10.75 kg
T2	Soil + 100% organic amendment + chemical fertiliser + dolomite	9 kg	1 kg	10.75 kg
T3	Soil + 75% organic amendment + chemical fertiliser + dolomite	6.75 kg	1 kg	10.75 kg
T4	Soil + 50% organic amendment + chemical fertiliser + dolomite	4.5 kg	1 kg	10.75 kg
T5	Soil + 25 % organic amendment + chemical fertiliser + dolomite	2.25 kg	1 kg	g

Statistical Analysis

Analysis of variance (ANOVA) was used to identify the treatment effect, and Tukey's HSD test was used to differentiate the treatment means at $p \leq 0.05$. This statistical analysis was performed using the Statistical Analysis System (SAS) On Demand for Academics (Version 9.4).

RESULTS AND DISCUSSION

Characteristics of the Soil and Organic Amendment

The soil collected from Hasmit Enterprise was analysed for its selected chemical properties. Table 2 presents the selected chemical properties of the soil before planting. The soil had a low pH value of 5.1 with high exchangeable acidity. This indicates it is a strongly acidic soil (USDA NRCS, 1998). A reason for this result is that 1 mole of Al^{3+} can release three moles of H^+ during aluminium hydrolysis in water, whereas in the case of Fe^{2+}, it releases two moles of H^+ during its hydrolysis in the soil. These chemical reactions contribute to the acidity of the soil (Weil & Brady, 2016). The low P is related to its fixation by the Al and Fe ions. Fixation of P by these acidic ions leads to the formation of insoluble phosphate, and this process makes P unavailable for plants. Meanwhile, the soil also showed low EC, indicating there are insufficient nutrients available in the soil, partly because of leaching and weathering. As the exchangeable basic cations, such as K, Ca, Mg, and Na, are leached out of the soil profile, they are replaced by acidic cations, Al^{3+}, Fe^{2+}, and H^+ in the soil to further make the soil acidic if no intervention, such as liming or application of organic amendment or soil conditioners, is practised. Although the total soil nutrients were relatively high, they are not plant-available due to fixation or adsorption to the soil's colloids. Furthermore, the nitrogen profile also reveals there were more NH_4^+ than NO_3^- due to suppression of nitrification, which is expected from acid soil due to reduced activity of nitrifying bacteria and archaea in acid or low pH soils (Ni et al., 2023).

The organic amendment produced from the chicken was analysed for its selected chemical properties, and the results indicate it is of good quality (Table 3). The high pH of the organic amendment suggests that it is neutral and has a liming effect on the

Table 2
Selected chemical properties of the soil before conducting the field trial

Variables	Value Obtained ± SD
pH in water	5.10 ± 0.03
Electrical conductivity (mS cm^{-1})	0.0061 ± 0.0004
Exchangeable Acidity (cmol kg^{-1})	1.57 ± 0.12
Exchangeable Al^{3+} (cmol kg^{-1})	0.18 ± 0.02
Exchangeable H^{+} (cmol kg^{-1})	1.39 ± 0.10
Total organic carbon (%)	2.17 ± 0.039
Organic matter (%)	3.74 ± 0.12
Total N (%)	0.23 ± 0.01
Total P (ppm)	7468.90 ± 104.26
Total K (ppm)	7150.35 ± 41.79
Total Ca (ppm)	763.33 ± 102.14
Total Mg (ppm)	722.09 ± 40.90
Available P (ppm)	2.03 ± 0.72
Available K^{+} (cmol kg^{-1})	39.62 ± 1.91
Exchangeable NH_4^{+} (ppm)	16.62 ± 1.57
Available NO_3^{-} (ppm)	1.93 ± 0.19
Exchangeable Ca^{2+} (cmol kg^{-1})	0.094 ± 0.003
Exchangeable Mg^{2+} (cmol kg^{-1})	1.39 ± 0.12
Exchangeable Na^{+} (cmol kg^{-1})	0.08 ± 0.00

Table 3
Selected chemical properties of the organic amendment produced from chicken dung

Variables	Organic Amendment ± SE
pH in water	7.19 ± 0.05
Electrical conductivity (mS cm^{-1})	8.99 ± 0.07
Total organic carbon (%)	34.24 ± 0.44
Organic matter (%)	59.02 ± 0.76
Total N (%)	4.29 ± 0.05
Total P (ppm)	8701.43 ± 184.14
Total K (ppm)	59987.50 ± 764.13
Total Mg (ppm)	2708 ± 0.58
Total Ca (ppm)	78708.33 ± 441.00

soil because of the presence of basic cations such as K, Mg, and Ca. Based on its EC, the organic amendment may be rich in dissolved salt, translating into high levels of plant-available nutrients that are non-toxic to plants. The organic amendment shows a high level of total organic carbon and organic matter, implying that it comprises highly decomposed organic by-products, which can improve soil structure, water retention, nutrient reservoir for essential nutrients, and biological activities, including beneficial microorganisms. The overall total nutrient content of organic amendment possesses substantial quantities of N, P, K, Mg, and Ca, resulting from the diverse nutrient sources from the raw materials used. To conclude, the results obtained demonstrate that the organic amendment was mature and stable for use (Ch'ng et al., 2013; Omar et al., 2021).

Selected Soil Chemical Properties, Maize Yield, and Above-ground Biomass

The soil pH at the end of the field trial showed differences between T1, T3, and T5, but T3 and T5 (Organic amendment with chemical fertiliser) decreased the soil pH compared with the treatment with chemical fertiliser only (T1). Nitrification and ammonification cause H^+ production and the presence of organic acid from mineralisation, one of the major contributors to soil acidification and low buffering capacity. This is consistent with the findings of Dușa et al. (2023) that different combinations of organic amendment and chemical fertiliser caused a decrease in soil pH during autumn. Similar to the finding of Angelova et al. (2013), compost caused a slight decrease in pH because of nitrification and mineralisation of organic materials to produce organic acids. Zaki et al. (2018) explained that there was a decline in the pH of the soil with N-P-K fertiliser, compost cover crop, and straw mulch was because of nitrification to nitrates, decomposition of residues in the straw mulch treatment, and acidification through nitrogen-fixation in the rooting zones of legumes. A study conducted by Chong et al. (2022) resulted in reduced soil pH between the experiment's incubation times; however, the pH increased from day 60 of incubation. The decrease in soil pH was due to high soil buffering capacity; nevertheless, soil pH increases because of the constant dissolution of calcium silicate. It is also true that long-term application of organic amendment can improve the overall soil pH in acid soil (Cai et al., 2019; Ch'ng et al., 2017). The fact that the soil's electrical conductivity, regardless of treatments were similar suggests that the relatively high electrical conductivity of the organic amendment did not have adverse effects on the soil and the maize plants because the soil's electrical conductivity was below the threshold of >2.0 mS cm^{-1} (Ch'ng et al., 2017; Chong et al., 2022; Johan et al., 2021).

The high exchangeable acidity, Al^{3+}, and H^+ are highly related to the changes in soil pH because of the negative correlation between soil pH, exchangeable acidity, Al^{3+}, and H^+ (Dai et al., 2021). The organic amendment influenced the soil exchangeable acidity and Al^{3+}. There was a reduction of soil exchangeable acidity and Al^{3+} in the plot with

T2 but an increase in T3, T4, and T5 (Table 3). The reduction of the soil exchangeable acidity and Al^{3+} in the plot with T2 is related to the protonation and proton (H^+) exchange between the organic amendment and the soil, precipitation of soluble Al and Fe ions, and using organic amendment with high concentrations of base cations (K, Mg, Ca, and Na) (Ch'ng et al., 2017; Dai et al., 2021; Rusli et al., 2022). Nevertheless, an increase in soil exchangeable acidity can be caused by the release of H^+ from the decomposition of organic matter (Agegnehu et al., 2019), which is highly available in the organic amendment. Similarly, the increase in soil acidity was caused by the liming effect of the organic amendment, thus enabling the replacement of acidic cations onto the soil colloid and release into the soil solution (Toluwase Oreoluwa et al., 2020). This study suggests that long-term application of organic amendment with the aid of any liming materials can minimise the slow liming effect of organic amendment only during the first cycle of planting, and application of the organic amendment for three to five planting cycles could provide sufficient organic matter to buffer the soil pH (Ali et al., 2023; Ch'ng et al., 2017).

There were no differences between T1 (chemical fertiliser only) and T2, T3, T4, and T5 (organic amendment with chemical fertiliser) for the soil total organic carbon and organic matter, total N, ammoniacal-N, and nitrate-N, and because of the soil's natural characteristics, applying dolomite was essential during the first planting stage. However, this may have caused a priming effect, which further mineralises the organic matter and reduces the total organic carbon in the soil, a practice that also leads to a reduction in soil nitrogen (Sae-Tun et al., 2024). A study by Ali et al. (2023) revealed similar results. They reported no differences among treatments because of the low N in the organic amendment. However, the residual effect of the organic amendment during the two cropping cycles improved soil total C, available nitrate, ammoniacal-N, and CEC, and reduced exchangeable acidity and Al^{3+}. The high content of the organic matter in organic amendment enables better retention of organic N by slowly mineralising the soil organic N to soil inorganic N for efficient plant uptake (Omar et al., 2020), suggesting that using organic amendment has a greater long-term effect without inducing nutrient loss (Diacono & Montemurro, 2010).

The overall results for total and available nutrients of the soil indicate that organic amendment improved some of the selected chemical properties of the soil. The organic amendment did not influence the soil K and Mg. Although the organic amendment showed a high total K value, the supplied K appears to be fixed due to the initial conditions of the acid soil. Several factors may influence K fixation in the soil such as: (1) the nature of the soil colloids, (2) the levels of previous potassium additions and removals, (3) wetting and drying, (4) freezing and thawing, and (5) the presence of excess lime (influence of pH) (Weil & Brady, 2016). A study conducted by Roy et al. (2023) indicates that the rate of K fixation increased with higher K application rates but decreased as fixation sites became more saturated. This is because K fixation occurs when the concentration of K in the

Table 4
Treatments effects on the selected chemical properties of the soil after the field trial

Treatments	pH in Water	EC (mS cm^{-1})	cmol kg^{-1}		
			Exch. Acidity	Exch. Al^{3+}	Exch. H^+
T1	$5.49^a \pm 0.04$	$0.020^a \pm 0.0009$	$0.56^c \pm 0.08$	$0.045^{bc} \pm 0.02$	$0.51^c \pm 0.06$
T2	$5.12^{ab} \pm 0.04$	$0.017^a \pm 0.0013$	$0.58^c \pm 0.02$	$0.035^c \pm 0.02$	$0.54^c \pm 0.00$
T3	$4.97^b \pm 0.07$	$0.021^a \pm 0.0023$	$0.88^b \pm 0.07$	$0.08^{ab} \pm 0.01$	$0.80^b \pm 0.06$
T4	$5.07^{ab} \pm 0.19$	$0.016^a \pm 0.0005$	$1.04^{ab} \pm 0.01$	$0.11^a \pm 0.02$	$0.92^{ab} \pm 0.08$
T5	$4.74^b \pm 0.06$	$0.022^a \pm 0.0010$	$1.08^a \pm 0.11$	$0.10^a \pm 0.02$	$0.98^a \pm 0.09$

Treatments	TOC (%)	OM (%)	Total N (%)	Exch. NH_4^+ (ppm)	Available NO_3^- (ppm)
T1	$2.10^a \pm 0.04$	$3.62^a \pm 0.07$	$0.23^a \pm 0.009$	$27.69^a \pm 5.54$	$8.26^a \pm 2.27$
T2	$2.23^a \pm 0.08$	$3.84^a \pm 0.10$	$0.22^a \pm 0.015$	$18.83^a \pm 3.32$	$4.97^a \pm 0.98$
T3	$2.34^a \pm 0.06$	$4.03^a \pm 0.13$	$0.23^a \pm 0.005$	$52.06^{a+} \pm 18.83$	$5.11^a \pm 0.49$
T4	$2.07^a \pm 0.14$	$3.56^a \pm 0.13$	$0.22^a \pm 0.010$	$26.58^a \pm 4.60$	$4.11^a \pm 0.15$
T5	$2.51^a \pm 0.19$	$4.32^a \pm 0.32$	$0.26^a \pm 0.001$	$27.69^a \pm 3.32$	$8.15^a \pm 0.83$

Note. Means within the column with different letter(s) indicate significant differences between treatments by Tukey's HSD test at $p \leq 0.05$

soil solution rises; therefore, soils with higher native K content fix less K compared with soils with lower K content. However, there was a significant difference in the soil total and available P, total Ca, and exchangeable Na. As for soil total P, substantial differences were caused by the treatments, where T3 caused the highest total P concentration, whereas T2 and T1 had the lowest soil total P concentration. For soil available P, there were significant differences in the plots with T1 (Chemical fertiliser only), T2, T3, T4, and T5 (Organic amendment with chemical fertiliser), and T3, T4, and T5 (organic amendment with chemical fertiliser), with T3 plot having the highest concentration of available P and the T1 plot having the lowest concentration. Significant differences existed in the total Ca of the plot with chemical fertiliser (T1) and the soil with the organic amendment with chemical fertiliser (T2 and T5). The plot with T5 had the highest concentration of total Ca, but those with T2 and T1 had similar concentrations. However, the soil exchangeable Ca was not significantly affected by the treatment differences. The soil exchangeable Na showed significant differences among the treatments. As shown in Table 5, the T5 plot had the highest Na concentration, followed by T2, T1, T3, and T4 plots. Although chemical fertiliser treatment had the highest soil nutrient availability in some variables, the surge in the availability of these base cations was due to the inherent high content of the base cations in the organic amendment (Table 2). This is because chemical fertilisers are more soluble, making it easier for plant uptake (Zaki et al., 2018); at the same time, nutrients are prone to leaching from the soil (Cai et al., 2019). However, the co-application of organic amendment and chemical fertiliser can prevent nutrients from leaching. It has been demonstrated co-application of organic amendment and inorganic fertiliser can retain ammoniacal-N because of the high content of cations such as K, Ca, and Mg, the ability of organic matter to adsorb ammoniacal-N, and the high CEC of the compost is retained by clay minerals (Omar et al., 2021). Co-application of organic amendment and chemical fertilisers and/or lime increased the soil available P because organic matter mineralisation releases organic acids, which have a high affinity for Al and Fe ions because of their highly negatively charged sites. This reaction decreases P fixation; at the same time, the organic amendment is a good source of available P because of a higher P concentration than needed for mineralisation (Fekadu et al., 2018; Rusli et al., 2022). The overall characteristics of the organic amendment, which include the decomposition of organic matter and the release of humic substances to the soil, have a positive effect on the soil's exchangeable basic cations and can influence soil health and aggregate stability (Rusli et al., 2022). As dolomite was initially applied during the land preparation, and with the addition of organic amendment and chemical fertiliser, this also increased the soil total Ca (Islam et al., 2021).

Table 5
Effects of treatments on the soil Total P, K, Ca, and Mg after the field trial

Treatments	ppm			
	Total P	**Total K**	**Total Ca**	**Total Mg**
T1	$67.84^{ab} \pm 11.67$	$628.75^{a} \pm 187.75$	$518.75^{b} \pm 18.85$	$542.70^{a} \pm 86.62$
T2	$62.83^{b} \pm 10.45$	$668.44^{a} \pm 1.81$	$612.50^{b} \pm 37.50$	$401.69^{a} \pm 70.94$
T3	$120.41^{a} \pm 5.89$	$717.38^{a} \pm 130.74$	$754.17^{b} \pm 117.33$	$502.25^{a} \pm 83.00$
T4	$82.75^{ab} \pm 3.46$	$660.38^{a} \pm 27.38$	$870^{ab} \pm 94.19$	$476.21^{a} \pm 40.12$
T5	$90.91^{ab} \pm 8.59$	$494.76^{a} \pm 62.13$	$1233.30^{a} \pm 158.33$	$304.69^{a} \pm 40.69$

Note. Means within the column with different letter(s) indicate significant differences between treatments by Tukey's HSD test at $p \leq 0.05$

The overall finding suggests that increasing the rate of organic amendment did not result in a proportional increase in total above-ground maize biomass. However, there were differences in the maize fresh cobs' weight. Treatments 2 caused the highest fresh cob yield, followed by T4, T3, T5, and T1 (Table 6), suggesting that the combined use of the organic amendment and inorganic fertiliser was more effective than using the inorganic fertiliser only. The study conducted by Omar et al. (2020) revealed similar results where the co-application of chemical fertiliser and organic amendment, and additional clinoptilolite zeolite improved the maize yield because of the mineralisation of organic N to inorganic forms, beneficial for maize uptake. This is also consistent with the findings of Islam et al. (2021), who reported that co-application of lime and organic amendment increased crop yield, nutrient uptake, and soil nutrient availability. Similarly, Cai et al. (2019) suggest that the application of manure has a major role in improving the soil environment for regulating crop growth, especially nutrient availability and the community of soil microbes. Zaki et al. (2018) demonstrated that compost and mulch can increase plant height, cob weight, and biomass. In a related study, the organic amendment and inorganic fertiliser enhance physiological processes in plants, which include effective translocation of nutrients for grain formation and improvement in the stomata conductance and photosynthesis rate of the crop (Ali et al., 2023); these physiological processes enhance the overall crop development and growth.

An improvement in the soil nutrient availability in the plots with the organic amendment caused the overall improvement in the maize plants' growth and development. Table 7 shows that the fresh weight of the maize plants' leaves

Table 6
Effects of treatments on the soil available P and exchangeable K, Ca, and Na after the field trial

Treatments	ppm				
	Available P	Exchangeable K	Exchangeable Ca	Exchangeable Mg	Exchangeable Na
T1	$6.54^{b} \pm 1.02$	$60.62^{a} \pm 9.03$	$490.80^{a} \pm 60.08$	$111.81^{a} \pm 4.34$	$39.16^{bc} \pm 0.61$
T2	$7.55^{b} \pm 0.49$	$70.93^{a} \pm 1.86$	$349.48^{a} \pm 110.79$	$111.96^{a} \pm 1.39$	$43.27^{b} \pm 1.10$
T3	$17.29^{a} \pm 1.82$	$75.95^{a} \pm 13.32$	$340.96^{a} \pm 68.74$	$106.88^{a} \pm 1.30$	$39.29^{bc} \pm 1.35$
T4	$7.37^{b} \pm 0.14$	$56.46^{a} \pm 5.20$	$314.91^{a} \pm 36.25$	$113.64^{a} \pm 1.35$	$34.25^{c} \pm 1.04$
T5	$10.09^{b} \pm 2.32$	$63.49^{a} \pm 3.96$	$199.99^{a} \pm 12.09$	$111.36^{a} \pm 2.15$	$50.90^{a} \pm 2.60$

Note. Means within the column with different letter(s) indicate significant differences between treatments by Tukey's HSD test at $p \leq 0.05$

Table 7
Effects of the chemical fertiliser and different amounts of organic amendments on maize fresh cob yield and above-ground biomass of maize plants

Treatments	Fresh Weight (kg/plot)			
	Cob	Leaves	Stem	Total Weight (leaves + stem)
T1	$0.83^{c} \pm 0.09$	$1.10^{b} \pm 0.12$	$2.27^{b} \pm 0.43$	$3.37^{b} \pm 0.54$
T2	$7.85^{a} \pm 0.45$	$1.45^{ab} \pm 0.25$	$3.95^{ab} \pm 0.25$	$5.40^{ab} \pm 0.50$
T3	$4.20^{bc} \pm 1.25$	$1.65^{ab} \pm 0.05$	$4.07^{a} \pm 0.19$	$5.67^{a} \pm 0.24$
T4	$5.55^{ab} \pm 0.65$	$1.93^{a} \pm 0.03$	$4.93^{a} \pm 0.54$	$6.87^{a} \pm 0.57$
T5	$2.33^{bc} \pm 0.32$	$1.70^{ab} \pm 0.15$	$3.77^{ab} \pm 0.27$	$5.47^{ab} \pm 0.33$

Note. Means within the column with different letter(s) indicate significant differences between treatments by Tukey's HSD test at $p \leq 0.05$

significantly differed for T4 (50% organic amendment with chemical fertiliser) and T1 (Chemical fertiliser only). The fresh weight of the leaves of the maize plants was higher with T4 (1.93 kg/plot) than the other treatments, and T1 had the lowest fresh weight of leaves (1.10 kg/plot). Similarly, the fresh weight of the stem and the total weight of the maize plant (Leaves + stem) were significant for T1 (Chemical fertiliser only), T3, and T4 (Organic amendment with chemical fertiliser). The mineralisation of organic matter to inorganic forms amplified the soil nutrient availability for plant uptake and other effects of compost, such as improved microbial activity (Saleem et al., 2017). Treating the soil with the organic amendment populates the soil with beneficial microbes, which is valuable for crop growth. A study by Su et al. (2022) showed the presence of microbes beneficial for tomato growth and positively correlated with the shoot and total dry weight of the tomato. The organic amendment may also have improved the physical structures of the treated soil, enabling better water and nutrient absorption, improving root penetration and aeration, and thus, better growth and development of the maize plant (Ch'ng et al., 2014; Yaqoob et al., 2020).

CONCLUSION

The overall study demonstrated that the co-application of organic amendment and chemical fertiliser can improve some of the chemical properties of the acid soil in the present study. The organic amendment significantly increases soil total and available P, total Ca, and exchangeable Na. Moreover, the approach improves maize fresh cob yield and above-ground biomass of the maize plants. This study suggests organic amendment regains soil health and alleviates P fixation in acid soils that translates into enhanced growth and development of maize plants. The outcome of this present study provides an opportunity to improve the Brunei soil condition of low P availability, crop production, and effective poultry waste management and utilisation. However, this study is limited by one planting cycle, which may restrict the research findings. This limitation does not diminish the study's overall result. Still, it opens the way for to improving the research, such as conducting two planting cycles to understand the residual effect and assess the sustainability of the amendment and the uptake of P in plants.

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