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Utilizing Coal ash and Lignite Enriched-Compost to Improve Chemical Properties of Ultisols

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ABSTRACT

Continuous monoculture activities can cause soil degradation, leading to low pH, organic matter content, and nutrient deficiencies in Ultisols. Compost has been used to improve soil fertility. Unfortunately, its effectiveness has been limited due to rapid decomposition in the humid tropic area. This study investigated the effect of adding coal ash (fly ash and bottom ash or abbr. as FABA) and lignite to compost on the chemical properties of degraded Ultisols planted with pineapple. The study was conducted at Pineapple plantation in Central Lampung using a split-plot design. The application technique (row or spread) was the main plot and three treatments as subplots were 100% compost (K), 75% compost + 25% FABA (KF), and 70% compost + 20% FABA + 10% lignite (KFL). Each treatment was applied at a dose of 50 Mg ha^{-1}. The results showed that adding FABA and lignite to compost effectively increased the organic carbon, pH, base saturation, exchangeable calcium, -magnesium, -sodium, and zinc, decreasing the aluminum saturation of Ultisols. The application of ameliorants in rows technique was more effective than those of spreading. These findings suggest that FABA and lignite-enriched compost in row application can effectively improve the chemical properties of degraded Ultisols.

Keywords: Coal ash, compost, lignite, soil degradation, ultisols

INTRODUCTION

Agricultural cultivation of Ultisols faces significant challenges because Ultisols are highly developed soils, which results in high acidity and low nutrient content (Buol et al., 2011). According to Prasetyo and Suriadikarta (2006), Ultisols are characterized by the translocation and accumulation of clay in the B horizon, resulting in low pH, available phosphorus (P), base saturation, and high Al^{3+} and Fe^{3+} content. This accumulation restricts water absorption and increases soil erosion rates. Long-term intensive monoculture activities exacerbate soil degradation and reduce productivity (Osman, 2014).

Studies by Cahyono et al. (2019, 2020a, 2020b) revealed that Ultisols in pineapple plantations in Central Lampung have a pH range of 3.97-4.76, low soil organic carbon, nutrient content, and high Al^{3+} and Fe^{3+} content. In response to soil degradation, ameliorants such as organic matter (Agustini et al., 2017; Suwardi, 2021), coal ash (Nurmegawati et al., 2019; Ilham et al., 2020; Rais et al., 2021), lignite (Ram et al., 2007), and lime (Havlin et al., 2017; Cahyono et al., 2019; Cahyono et al., 2020a) are commonly used. These ameliorants can improve the soil quality and productivity of Ultisols.

Organic matter is crucial in improving soil quality because it acts as a pH buffer and has high nutrient content (Sanjaya et al., 2016; Havlin et al., 2017; Cahyono et al., 2020b). However, applying organic matter (OM) to soil has limitations due to the rapid decomposition of OM in the tropical humid area. Ramadhani et al. (2022) showed that applying OM in cow manure compost and liquid pineapple waste can decrease soil organic C by 23% 60 days after planting. In a report by Nurmegawati et al. (2019), the application of cow manure compost at a dose of 10 Mg ha^{-1} resulted in a lower soil pH of 4.45 compared to its control of 4.57 at the harvest. The rapid decrease of soil organic carbon content showed that it is necessary to enrich organic matter or compost with other soil ameliorants, such as coal ash and lignite.

Coal ash, a byproduct of coal combustion in power plants, consists of fly ash (FA) and bottom ash (BA), also known as FABA. FABA is alkaline and can effectively increase the Ultisols' pH, as Bauddh et al. (2020) and Iskandar et al. (2009) that shows coal ash could increase soil pH because it has high pH about 8.0 – 11.00. Utami et al. (2019) stated that using 10% fly ash + 10% banana stalk +20% poultry manure has pH of 8.52. Hamanaka et al. (2022) also state that applying 5% fly ash can reduce the Al content to 5.4 ppm compared to the control of 34.1 ppm. On the other hand, fly ash can increase available P with additions of phosphate solubilizing fungi and biocom about 388.91% - 396.36% on peat soils of Central Kalimantan (Ichriani et al., 2022). FABA combined with oil palm empty fruit bunch compost at rates of 10 Mg ha^{-1} and 20 tons ha^{-1} fly ash also increased the available P content in the soil by 5.19 ppm compared to the control of 3.2 ppm (Mashfufah and Prasetya, 2019). Furthermore, FABA has a high solubility of K, Ca, Mg, Na, and nutrient content for plants (Iskandar et al., 2008; Faoziah et al., 2022).

Lignite, also known as brown coal, is the lowest grade of coal characterized by its low-calorie value, soft structure, and high moisture content. Lignite has a high humic acid content, making it an effective tool for increasing the organic matter content of soil and improving its quality (Sao et al., 2010; Saha et al., 2016; Huculak-M^{1}czka et al., 2018). Incorporating FABA and lignite into the compost can enhance its effectiveness in improving soil quality and productivity.

This study aims to evaluate the effect of adding FABA and lignite to compost on the chemical properties of degraded Ultisols in pineapple plantations.

MATERIALS AND METHODS

Study Site

This research was conducted from September 2021 to April 2022 (7 months) at the pineapple plantation of Great Giant Pineapple Company (PT. GGP) on 4°48'12,89" S 105°10'28,52" E to 4°48'10,76" S 105°10'31,04" E and 4°48'13,22" S 105°10'28,92" E to 4°48'11,20" S 105°10'31,48" E (Figure 1). Production of compost, compost+FABA, and compost+FABA+lignite was carried out in a compost plant utilizing all materials produced by PT. GGP. Fine compost was made from cow manure,

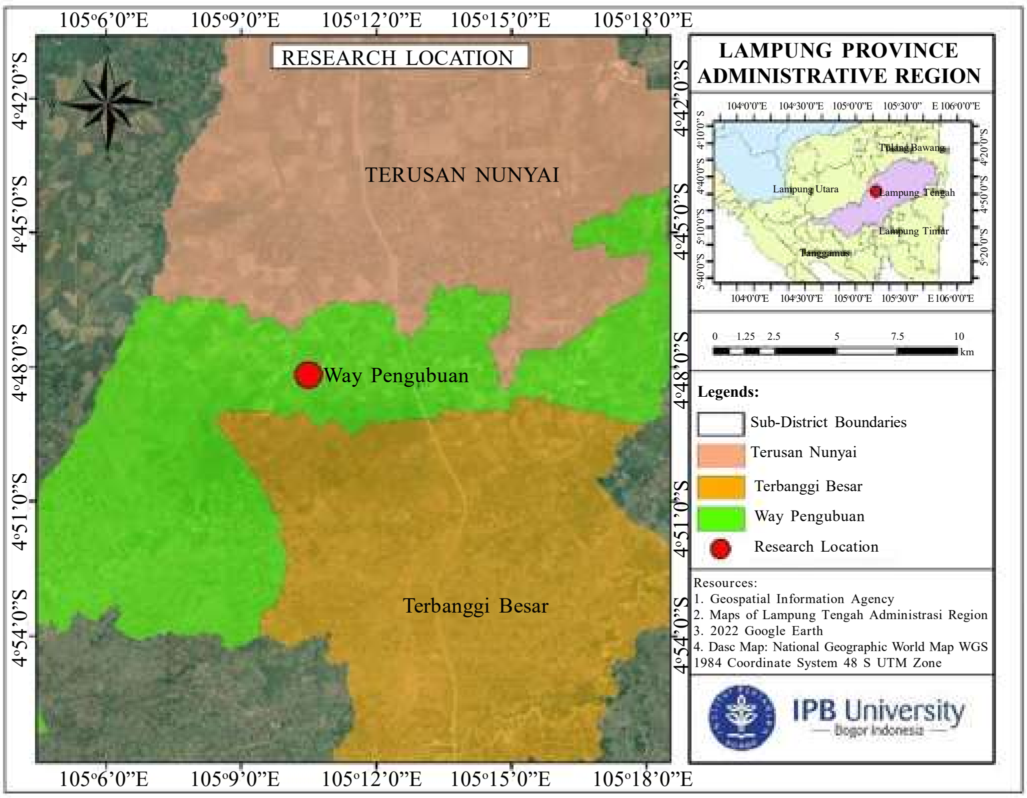

Figure 1. Research Location at Block 86-A.

Figure 2. The appearance of the Experimental Field.

waste of bromelain extraction, and chopped bamboo mixed and put through a composting process. FABA was produced from coal combustion in a power plant, and lignite was taken from a power plant. Then, compost, FABA, and lignite were mixed at the compost plant of PT. GGP within a week before application.

Management Practices

A split-plot design in a randomized block design was employed, with main plots and subplots. The main plot consisted of two ameliorant application techniques, i.e., spread (S) and row (R). The subplots included three ameliorant types: 100% compost (K), 75% compost + 25% FABA (KF), and 70% compost + 20% FABA + 10% lignite (KFL), with the ratio of fly ash (FA) and bottom ash (BA), set at 6:1. The BA and lignite used were sieved and sized under 10 mm. The experiment was conducted with four replications for each treatment, with ameliorants applied at 50 Mg ha^{-1}.

The research area was prepared by making a 12 × 4m plot followed by tillage. Before flattening, ameliorants were applied using a spread technique (treatment S). Plant lanes were created continuously by adding diammonium phosphate (DAP) fertilizers, potassium sulfate (K_2SO_4), and borax, followed by bifent G pesticides. After fertilizers were applied, ameliorants that used row techniques (treatment R) were applied, and continuously test plants planted. Spread and row treatments were applied within 24 hours. Pineapple (*Ananas comosus*) clone GP-3 large class sucker seedlings were utilized with a spacing of 50 × 27.5 cm. Watering was conducted before reaching the permanent wilting point, and foliar fertilizer with composition and doses referred to PT. GGP procedure was applied every 20 days after three months old. The study results were compared with the standard cultivation results of the plantation. The experimental field is shown in Figure 2.

Soil Analysis

Soil chemical analysis was conducted at the Soil Laboratory of Plantation using soil analysis procedures developed by Eviati and Sulaeman (2009). Soil samples were collected at the beginning of the study and 5 months after planting (MAP), compositely from five points in each plot using a soil auger with a depth of 0-25 cm. The parameters

Table 1. Characteristics of the soil and ameliorants used in the experiment.

Parameters	Unit	Soil	Level*	K	KF	KFL
pH H_2O	-	4.50	Acid	7.43	8.89	8.13
Organic Carbon	%	1.25	Low	15.40	15.12	17.48
Al Saturation	%	32.40	High	-	-	-
Total N	%	0.13	Low	1.30	1.13	1.13
Available P	ppm	22.02	Very High	110.19	40.51	53.94
Exchangeable-K	cmol(+)kg^{-1}	0.22	Low	25.76	46.19	42.57
Exchangeable-Ca	cmol(+)kg^{-1}	1.96	Very Low	40.15	102.80	99.61
Exchangeable-Mg	cmol(+)kg^{-1}	0.55	Low	22.12	45.81	43.55
Exchangeable-Na	cmol(+)kg^{-1}	0.04	Very Low	-	-	-
Cation exchange capacity	cmol(+)kg^{-1}	7.77	Low	-	-	-
Base Saturation	%	35.64	Low	-	-	-
Cu	ppm	0.55	Moderate	31.70	37.00	35.80
Zn	ppm	2.60	Moderate	301.70	218.20	199.30
B	ppm	1.26	-	-	226.30	205.90
S	ppm	13.28	-	-	5,931.00	3,707.00

Note: *Based on the criteria of soil characteristics proposed by Eviati and Sulaeman (2009); K: compost; KF: compost+FABA; KFL: compost+FABA+lignite.

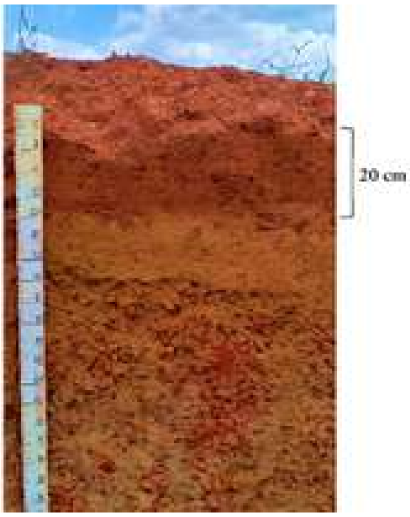

Figure 3. Soil profile at research location Block 86-A.

observed were organic C (Walkley & Black), soil pH (pH meter), Al saturation (KCl 1N-Volumetry), nitrogen (N)-total (Kjeldahl), available P (Bray I), microelements Zn, Cu, B, and S (DTPA-AAS), cation exchange capacity (CEC) (Ammonium acetate pH 7-Volumetry), and base cations (Ammonium acetate pH 7-AAS). The data obtained were subjected to the Tukey test at the 5% significance level.

RESULTS AND DISCUSSION

Characteristics of Ultisols

The location used in this study was previously planted with cassava (*Manihot esculenta*). Table 1 shows the soil analysis results used to determine the soil characteristics. According to Eviati and Sulaeman (2009), the soil used was acid, high Al saturation, and very high Fe levels. The soil also had low organic C, total N, exchangeable-K, exchangeable-Mg, CEC, base saturation, and deficient levels of exchangeable-Ca and exchangeable-Na. The levels of Zn and Cu were sufficient, and Mn was moderate.

The soil condition described in Table 1 was caused by the long-term monoculture since 1979 (GGF, 2022), which decreased soil OM and humus content and reduced crop production. Figure 3 shows the soil profile at the research location.

Effect of the Treatments on the Organic C, Total N, Available P, and S Content

Applying ameliorant in the forms of K in rows technique (K-R) and KFL in rows technique (KFL-R) increased the organic C, Total N, and S content (Table 2). Soil organic C content increased because the compost contained higher organic C than the KFL. Cahyono et al. (2020b) reported that applying OM in the form of compost consisting of cow manure, waste of bromelain extraction, and chopped bamboo at a dose of 50 tons ha^{-1} increased the organic C content by up to 50% compared to non-compost at the four MAP in pineapple plantation's Ultisol.

The application of K-R increased the highest soil N content compared to other treatments, despite no significant differences observed except with the control (Table 2). Increased soil N can be attributed to the increased soil OM (Tisdale et al*.,* 1985; Havlin et al*.,* 2017). The compost contains the highest organic C content compared to other treatments that give more N sources for N-breaking microbes. Moreover, the increased soil pH resulting from ameliorant application provides a more favorable environment for N-breaking microbes to carry out

Table 2. Effect of the treatments on the soil's Organic C, Total N, Available P, and S content.

Treatment	Organic C	Total N	Available P	S
	-------- %	--------	-------- ppm	--------
K-R	1.87 a	0.16 a	26.33 a	7.01 ab
K-S	1.45 b	0.13 ab	21.82 a	3.62 b
KF-R	1.48 ab	0.11 ab	28.15 a	6.37 ab
KF-S	1.45 ab	0.11 ab	24.17 a	3.12 b
KFL-R	1.62 ab	0.12 ab	37.32 a	5.19 ab
KFL-S	1.49 ab	0.13 ab	33.06 a	2.47 b
CONTROL	1.23 b	0.10 b	35.97 a	3.63 b

Note: Results that do not share a letter differ significantly; K: Compost; KF: Compost+FABA; KFL: Compost+FABA+Lignite; R: Row; S: Spread.

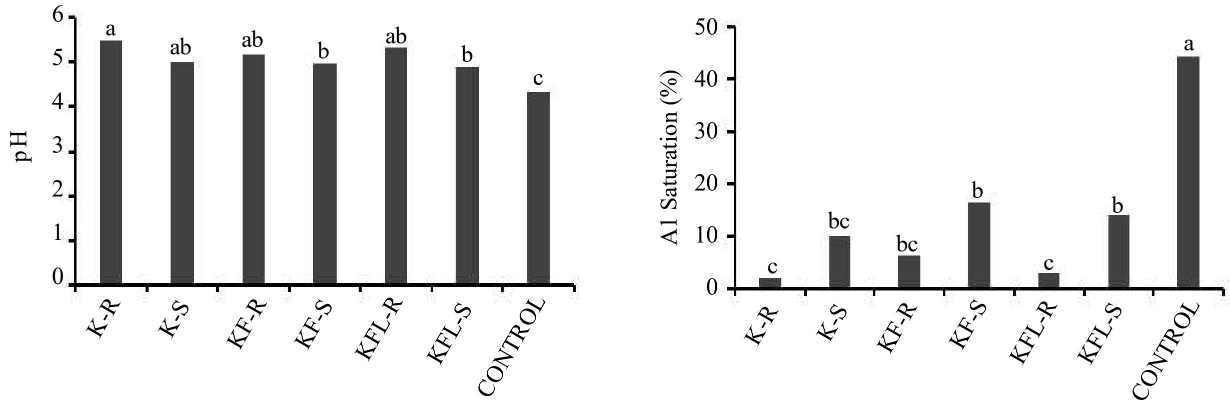

Figure 4. The effect between ameliorant types and application techniques on soil acidity. K: Compost; KF: Compost+FABA; KFL: Compost+FABA+Lignite; R: Row; S: Spread.

their activities, as the optimum pH range for microbial activity is 5-7 (Havlin et al., 2017). Additionally, the FABA contributed also to the increased N content by retaining water, resulting in a 9% increase in soil moisture content, which enhanced microbial activity and the decomposition process of ameliorants (Havlin et al., 2017; Song et al., 2020).

Available P did not significantly increase by ameliorants applied, despite visual observations indicating the highest P availability for the KFL-R treatment (Table 2). P availability is affected by soil acidity, as in acid soils, P is usually bonded to Al^{3+} and Fe^{3+}, making it unavailable to plants (Havlin et al., 2017). The insignificant effect of ameliorant application on available P in the soil can be attributed to the application of compost and lignite, as organic matter releases P into the soil by forming protective groups for phosphate ions, reducing P fixation, and making it easier for plants to absorb. Organic matter also acts as new adsorption sites for P, leading to competition between the groups for releasing and adsorbing P in the soil (Tisdale et al., 1985; Nuryani et al., 2006).

Table 2 shows that the K-R application results in higher soil S content than the KFL-R due to the increase in pH and application of organic matter. Organic matter in the soil can increase the potential sorption of S^{2-}. However, the potential of S^{2-} sorption decreases with increasing soil pH and will be minimum at soil pH >6.0 (Havlin et al., 2017).

Effect of the Treatments on the Characteristics of Sorption Complex

The application of KFL-R reduced the Ultisols acidity, characterized by increasing soil pH and decreasing Al saturation at 5 MAP, even though the soil is still in the acidic category (Table 3). The decreased soil acidity is due to the liming effect given by FABA, which has a high Ca and Mg (Iskandar et al., 2008; Fan et al., 2019) and can replace Al^{3+} thereby reducing Al contents (Tisdale et al., 1985; Foth & Ellis, 1997; Havlin et al., 2017). The decrease of soil acidity in the KFL-R application is still lower

Table 3. Effect of the treatments on the characteristics of sorption complex.

Treatment	pH	CEC	K	Ca	Mg	Na	BS	Al saturation
		-------------------- cmol(+)kg^{-1} --------------------					-------- % --------	
K-R	5.47 a	11.82 ab	0.53 a	3.84 a	2.02 a	0.030 c	54.32 a	2.16 c
K-S	4.99 ab	11.19 ab	0.44 ab	2.36 b	1.28 ab	0.027 cd	36.34 bc	9.95 bc
KF-R	5.18 ab	11.93 a	0.26 ab	3.04 ab	1.20 ab	0.042 ab	38.04 bc	6.38 bc
KF-S	4.95 b	11.27 ab	0.23 b	2.35 bc	0.83 b	0.036 bc	30.59 c	16.41 b
KFL-R	5.32 ab	12.09 a	0.25 b	3.49 ab	1.34 ab	0.049 a	42.51 b	3.02 c
KFL-S	4.89 b	11.38 ab	0.26 b	2.36 b	0.91 b	0.039 b	31.49 c	14.08 b
CONTROL	4.32 c	10.24 b	0.22 b	0.91 c	0.54 b	0.021 d	16.49 d	44.45 a

Note: Results that do not share a letter differ significantly; K: Compost; KF: Compost+FABA; KFL: Compost+FABA+Lignite; R: Row; S: Spread.

than that observed in the compost application in a row technique (K-R) due to its pH buffer ability (Havlin et al., 2017). However, the KFL-R application is preferred because it contains more Ca from FABA, which can hold soil pH, reduce the compost dose used, and reduce coal combustion waste in the power plant environment. The increased soil pH and the decreased Al saturation in the soil treated with KFL in a row technique were better than those of the spread technique, as the concentration of KFL application was focused on the rhizosphere, leading to higher content in the soil. These effects are shown in Figure 4.

Table 3 presents the impact of KFL-R application on the CEC of Ultisols, which increased by 12.09 cmol(+)kg^{-1}. Applying the KFL-R is comparable to the KF in a row technique (KF-R). The rise in CEC is attributed to the enhanced soil pH and the organic matter content in the ameliorants (Table 3). Organic matter increases the negative charge of the soil, derived from carboxyl (R-COOH) and phenolic (6-C aromatic rings with OH) groups, resulting in an increase in absorption sites for base cations (Foth, 1990; Suwardi, 2021).

Increasing CEC in the KFL-R application also increased base saturation of about 42.51%, lower than the K-R application of about 54.32%. According to Mengel et al. (2001) and Havlin et al. (2017), increased base saturation leads to more absorption of base cations (K^+, Ca^{2+}, Mg^{2+}, and Na^+) by the soil compared to acid cations (H^+, Al^{3+}, and Fe^{3+}), as shown in Table 3. Iskandar et al. (2008) confirmed that coal fly ash has high K, Ca, Mg, and Na solubility, and it is demonstrated in Table 3 that applying KFL increases the base saturation in the soil.

Table 3 shows that the K-R application increased soil potassium by 0.53 cmol(+)kg^{-1} at 5 MAP, higher than the other treatments. This effect was due to the increased soil pH, which reduced Al saturation and Al^{3+} competition for K^+ (Havlin et al., 2017). The Ca content in the soil also increased, which has the same pattern as the decreased Al saturation and the increase in pH also CEC by the KFL-R application, even though those were lower than the K-R application. Ameliorants applied in the rows technique showed higher Ca than those spread techniques. The decomposition of OM in the soil produces acids like malonic, oxalic, and tartaric, which generate organic anions. These anions can bind Al ions in soil solution, reducing Al saturation. However, soil pH below 5.6-4.0 can limit the availability of Ca to plants (Tisdale et al., 1985).

The increased Mg and Na in the soil through the KFL-R application also impacts the soil pH. Mg and Na are base cations that increase pH by replacing acid cations in the soils. Mg availability is usually about 4-20% of the CEC content (Tisdale et al., 1985). The increased base cations (K^+, Ca^{2+}, Mg^{2+}, and Na^+) in the soil are also due to the ability of FABA-treated soil to retain water, preventing base cations from leaching quickly (Havlin et al., 2017; Song et al., 2020). The reduction in Na^+ content in the K by spreading (K-S) and KF by spreading (KF-S) application is due to the ease of Na^+ cations being lost due to leaching (Havlin et al., 2017).

Table 4. Effect of the treatments on the micronutrients.

Treatment	Cu	Zn	B
	ppm		
K-R	0.76 a	8.65 a	1.26 ab
K-S	0.80 a	6.28 b	0.83 b
KF-R	0.56 b	4.22 bc	1.89 a
KF-S	0.56 b	3.56 c	1.32 a
KFL-R	0.60 b	4.65 bc	2.05 a
KFL-S	0.70 ab	5.73 bc	1.45 a
CONTROL	0.83 a	6.58 ab	0.37 b

Note: Results that do not share a letter differ significantly; K: Compost; KF: Compost + FABA; KFL: Compost + FABA + Lignite; R: Row; S: Spread.

Effect of the Treatments on the Micronutrients of Ultisols

Applied Ameliorants did not affect Fe and Mn but affected Cu, Zn, and B, as shown in Table 4. Table 4 shows that applying ameliorants through the rowing technique reduces the Cu contents in the soil due to the resulting increased soil pH (Havlin et al., 2017). The Cu content in the soil is lower in row applications than in spread applications, which is directly related to the increased soil pH, as shown in Table 3. The application of the KF shows lower Cu content than those of compost and KFL applications due to the higher organic matter content in K and KFL. Carboxyl and phenolic groups in soil organic matter form a negative charge, binding Cu^{2+} more strongly than other metal ions (Foth, 1990; Havlin et al., 2017), and the higher Zn content in compost lead to the increased Zn content in the K-R application. In line with the lower OM content, applying the KF in a spread technique reduced the Zn content in the soil.

Table 4 shows that applying the KFL-R resulted in the highest B content due to increased soil organic matter. On the other hand, B availability decreased at higher soil pH, especially at excessive pH >6.5 (Havlin et al., 2017). KFL has higher B than compost caused by its pH was lower than compost treatment, as shown in Table 3, even though compost has a higher organic matter than KFL. Increased pH on the soil led to B adsorption on freshly precipitated by $Al(OH)_3$.

Row application of ameliorants is more effective than spread. The effectiveness of row application is proven by the same pattern in Table 2 (organic C and S), Table 3 (pH, CEC, Ca, Mg, Na, BS, and Al saturation), and Table 4 (Cu and B). Row application has given more ameliorants at the rhizosphere than spread, increasing crop nutrients and reducing its leaching by rainfall.

CONCLUSIONS

Compost application increased organic C, pH, total N, K, S, Ca, Mg, base saturation, Zn, and reduced Al saturation in Ultisol. The increase in the chemical properties of Ultisol applied by the compost is not significantly different from KFL. The ameliorant applied by the row was better than the spread. Ameliorant application in the form of KFL is recommended because it can reduce the compost dose and the accumulation of FABA in the power plant environment.

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