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Flux of Nutrient Leaching from Ultisol of Pineapple Plantation Ameliorated with FABA and Compost and Its Implications on Fertilizer Management

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ABSTRACT

Ultisol is a weathered tropical soil order with low fertility status. It is also prone to nutrient leaching processes. Plantation area of PT. Great Giant Pineapple (PT GGP), grown in Ultisol, has been intensively cultivated for decades in rotation with banana and cassava. This study aims to evaluate the effects of FABA+compost amendment on nutrient leaching from the Ultisol in the PT GGP area and its implications for fertilizer management. A nutrient-leaching simulation was conducted using percolation experiments. Soil samples were taken from the 0-20 cm layer from pineapple-cultivated field plots 9 months after treatment application or 1 month before the plant regenerative-phase forcing step. Percolations were performed every 7 days with 170 mL Aquadest at 0.75 kg^{-1} soil for a 35-day experimental period, equivalent to the monthly average rainfall during the six wet months in the study area. The amelioration significantly reduced soil nutrient leaching, as indicated by t_{max}, total flux, and flux proportion. The band application of 25 t ha^{-1} FABA + compost gave the best results. The NO_3 and K leaching flux proportions, however, were still high. It is suggested that controlled-release fertilizers be considered to reduce nutrient leaching flux.

Keywords: Fertilizer management, flux proportion, percolation, total flux, t_{max}

INTRODUCTION

PT. Great Giant Pineapple is an Indonesian agro-industrial company engaged in the third-largest pineapple plantation and canning in the world. Started operations in 1979, PT GGP now manages a total plantation area of ±32,000 ha in the Central Lampung Regency, Lampung Province, Indonesia, with an effective pineapple cultivation area of ±25,000 ha, after being cultivated for the last 45 years, apart from the high precipitation rate, the soil physical, chemical, and biological properties of PT GGP plantation area have been declining, particularly for the soil organic matter content, due to the intensive use of inorganic fertilizers for cultivating pineapple in rotation with banana and cassava (Ramadhani et al., 2020). The ameliorants and basal soil fertilizers used for pineapple cultivation until 5 months after planting (MAP) age in PT GGP consisted of 50 t ha^{-1} compost, 3 t ha^{-1} dolomite, and inorganic fertilizers equal to 236, 304, 46, and 27 kg ha^{-1} N, K_2O, P_2O_5, and MgO, respectively. Then, from ages 6 to 9 MAP, the plants were given N and K foliar fertilizers every 21 days, and continued at 15 and 45 days after the forcing step was performed at 10 MAP. Efforts to improve the soil using various organic materials have been undertaken; however, satisfactory results have not yet been achieved. It was, among other things, due to the residence or decomposition time of the applied organic materials being shorter than the pineapple cultivation age. Exploration and development of other types of soil ameliorants are needed to address problems related to low soil organic matter content and high nutrient leaching fluxes.

The plantation area of PT GGP is dominated by Ultisol, a naturally acidic, highly weathered soil. The highly weathered nature of the soil can also be attributed to high rainfall in the area, which leaches some basic cations (Carnice & Lina, 2021). In general, this soil is prone to erosion (Meli et al., 2018).

It has an Al saturation of >60% (Gama et al., 2022), with low levels of organic matter, available P, and cation exchange capacity (CEC) (Ramadhani & Nuraini, 2018). Low pH and CEC, as well as high Al saturation, result in low nutrient availability and are the main soil chemical limiting factors for plant growth on Ultisol (Hale et al., 2020).

Soils with low levels of organic matter and CEC have a low ability to retain water and nutrients, thereby intensifying nutrient leaching in Ultisols (Sahfitra, 2023). Apart from that, high rainfall intensity accelerates eluviation of the soil clay fraction, which then illuviates into the deeper soil layers. Hence, the topsoil of Ultisol, as the main plant root zone, is dominated by the sand fraction, leading to the sandy textural class (Suseno et al., 2018). This condition will further lead to significant inefficiency in fertilizer application.

For the plantation area of PT GGP under pineapple cultivation, the amelioration of coal ash in the form of FABA (fly ash-bottom ash) and compost combination to specifically increase soil water and nutrient holding capacity is currently in the field trial stage. This management option is expected to reduce nutrient leaching flux, thereby increasing soil and crop productivity through greater water and fertilizer use efficiency.

FABA is waste produced from the burning process of coal at high temperatures. FABA produced at the steam power plants (SPP) consists of 80-90% fly ash and 10-20% bottom ash (Faoziah et al., 2022), which is abundant in Indonesia and has not been widely used in agriculture as an ameliorant. It is because FABA was previously categorized as a hazardous and toxic waste material. Based on the Government of Indonesia Regulation No. 22 of 2021, FABA from SPP activities has now been reclassified as non-hazardous, non-toxic waste.

FABA is alkaline in reaction (pH 8-12) with a main composition of 52% SiO_2, 31.9% Al_2O_3, 4.89% Fe_2O_2, 4.66% MgO, and 2.68% CaO (Khasanah & Budiono, 2022). FABA has the potential to be used as an ameliorant to reduce soil acidity (Alterary & Marei, 2021). It contains remarkable amounts of macronutrients (K, Ca, and Mg) and micronutrients (Fe, Cu, Zn, and Mn), making it useful for supporting plant growth (Damayanti, 2018) as a natural fertilizer.

Application of compost, the results of microbial decomposition on organic material under aerobic conditions (Cooper et al., 2020), improves soil biological, chemical, and physical properties by increasing soil organic matter content, porosity and aggregate stability, water and nutrient holding capacity, and reducing soil bulk density (Ho et al., 2022). Compost plays an essential role in increasing soil CEC, providing macronutrients (N, P, K, Ca, Mg, and S) and micronutrients (Fe, Mn, Zn, Cu, Mo, Co, and B), as well as supporting soil pH buffering capacity and increasing crop production (Yuniarti et al., 2020). Besides improving soil quality, the use of organic ameliorants is renewable, *in situ*, relatively inexpensive, and environmentally friendly (Prasetyo et al., 2018).

An ameliorant formulated from FABA and organic waste was reported to significantly increase soil pH, available P, and CEC in an Ultisol (Ilham et al., 2021). According to Faoziah et al. (2022), application of FABA and compost can generally improve the chemical properties of a sandy soil by increasing soil organic C, total N, available P, and base cations levels. Application of either compost or compost+FABA+lignite increased soil organic C, pH, total N, K, S, Ca, Mg, base saturation, and Zn, and reduced Al saturation in the Ultisol of the PT GGP plantation area (Fajarindo et al., 2024). However, the effectiveness of FABA and compost combination application on soil nutrients leaching flux has not been studied in the plantation area of PT GGP. In this study, a nutrient leaching simulation based on monthly-average rainfall intensity in the study area was conducted using percolation experiments on soil samples from field plots treated with FABA+compost. This study aims to evaluate the effects of FABA and compost amendments on macro- and micronutrient leaching fluxes from an Ultisol in the PT GGP pineapple plantation area and their implications for fertilizer management.

MATERIALS AND METHODS

Soil Samples Collection

Composite soil samples derived from 5 sub-samples were taken from each field experimental plot treated with FABA+compost amelioration for use in the percolation experiment. The soil samples for the percolation experiment were collected 9 months after the amelioration treatment (MAA) was applied in the field plots (August 2023) or 1 month before the pineapple cultivation step, when forcing the plant's generative phase was performed (September 2023). The field experiment was conducted on the limed, basal-fertilized, and pineapple-planted area of PT GGP, located in the Central Lampung Regency, Lampung Province, Indonesia, and began in November 2022.

The field experiment was done according to a Completely Randomized Design with 1 factor of 6 levels, namely (1) None (without application of either FABA or compost), (2) application of 50 t ha^{-1}

compost (CS 50), (3) 50 t ha^{-1} FABA+compost (FCS 50), (4) 25 t ha^{-1} FABA+ compost (FCB 25), (5) 15 t ha^{-1} FABA+compost (FCB 15), and (6) 5 t ha^{-1} FABA+compost (FCB 5), with three replications per treatment, resulted in 18 experimental units. The ratio of FABA and compost used was 25:75, while that of fly ash and bottom ash was 7:1. The symbols F, C, S, and B indicate FABA, compost, spread-application, and band-application, respectively. The compost was made from the solid waste from the bromelain extraction process for pineapple fruits. The CS 50 treatment is the original standard operating procedure for soil amelioration at PT GGP.

Percolation Experiment

Soil nutrient leaching assessment was conducted through percolation experiments using soil samples collected from each field experimental plot treated with FABA+compost amelioration. Soil samples at the 0-20 cm depth, each weighing 0.75 kg on an oven-dry basis, were placed into the nutrient leaching installation sets. Each treated soil sample was placed above 100 g of sterile sand, then covered with another 100 g of sterile sand in the percolation set. Then, aquadest was added as percolation water.

The amount of percolation water added to each percolation set was equal to the monthly average of the six wet-month rainfalls in the PT GGP area. It was 278 mm, which was equal to 2780 m^3 or 2780 x 10^3 dm^3 per 30 days per 1 ha or 10,000 m^2 area. For the nutrient leaching simulation using a 0.75 kg soil sample, the percolation water volume was calculated based on the weight of 1 ha of soil at a 20 cm depth. With a soil bulk density of 1.43 kg dm^{-3}, it was equal to $0.75 \text{ kg} \times 1 / (10{,}000 \text{ m}^2 \times 0.2 \text{ m} \times 1.43 \times 10^3 \text{ kg m}^{-3}) \times 2780 \times 10^3 \text{ dm}^3$ per 30 d = 0.729 dm^3 or 729 mL per 30 d. For practical reasons, percolations were done every 7 days for 5 periods or 35 days. The percolation water given was then 35 d/30 d × 729 mL = 851 mL per 35 d or 170 mL per 7 d. This amount of percolation water has exceeded the soil's field capacity, allowing leaching to occur and allowing leachates containing leached soil nutrients to be collected for laboratory analysis.

Laboratory Analysis

Laboratory analysis was conducted on the soil samples before leaching, using routine soil analysis methods, as well as on soil nutrient concentrations in the leachates. Soil nutrient analysis in the leachates was conducted for NO_3^- and P concentrations using a spectrophotometer, K concentration using a flame photometer, and Ca, Mg, Fe, Mn, Cu, and Zn concentrations using an atomic absorption spectrophotometer.

Data Analysis

Data analysis included fitting logarithmic curves and determining the best-fit equations that show the relationships between the nutrient leaching time (*t*, d; X-axis) and the leached nutrient concentration (*C*, mg L^{-1}; Y-axis) for the five leaching periods. The leached nutrient flux for each leaching period (*F*, mg. $7d^{-1}$) was calculated as the collected leachate volume (*L*) x leached nutrient concentration (*C*, mg L^{-1}). To calculate the total leaching flux (*TF*, mg) of each soil nutrient, an integral operation was applied to the corresponding equation from t=0 to $t=t_{max}$, yielding the area under the curve, which was interpreted as an estimate of the total flux (*TF*) of soil nutrient leaching over 35 days. The calculation was done by using the Wolfram Alpha application available on the homepage at https://wolframalpha.com. The t_{max} value represents the time required for the leaching process to stop and is obtained when the curve crosses the X-axis, or at C=0. The ratio between *TF* and the initial concentration of each nutrient before the soil sample was percolated was designated as the soil nutrient leaching flux proportion. Then, analysis of variance (ANOVA) and Duncan Multiple Range Test (DMRT) were conducted at the 5% significance level to evaluate the treatment effects on the total flux (TF) of leached soil nutrients.

RESULTS AND DISCUSSION

Soil Chemical Properties before the Leaching Process

The Ultisol at the study site has a sandy clay textural class, with proportions of 59% sand, 5.2% silt, and 35.8% clay (Putri, 2023). It is related to the soil parent material. Based on the geological map of the Menggala sheet at scale 1:250,000, the geological formation of the study area is Qpt (Terbanggi Formation), consisting of sandstone with claystone intercalations. Ultisols form from acidic parent materials such as sand, granite, or tuff, which tend to yield soils with a high sand fraction (Sahfitri & Prijono, 2021).

The results of soil analysis conducted before the leaching process (Table 1) showed that soil pH-H_2O was classified as acid to very acid with very high Al saturation. Soil organic C levels were low to moderate. Application of compost increased soil organic C by releasing organic C (Banamtuan,

Table 1. Average soil chemical properties of the Ultisol of the PT GGP plantation area before the leaching process.

Soil Properties*	Treatment***					
	None	CS 50	FCS 50	FCB 25	FCB 15	FCB 5
pH H_2O	4.18 va	4.47 a	4.62 a	4.69 a	4.50 a	4.20 va
Organic C (%)	1.82 l	2.16 m	2.56 m	2.59 m	2.19 m	2.08 m
Total N (%)	0.14 l	0.11 l	0.10 l	0.13 l	0.10 l	0.13 l
NO_3 (ppm)**	381.99 h	412.85 h	419.05 h	420.16 h	366.08 h	333.41 h
Available P (ppm)	13.95 h	24.04 vh	32.38 vh	30.05 vh	22.64 vh	14.72 h
Exch. K (ppm)	7.28 vl	7.93 vl	9.13 vl	8.24 vl	8.11 vl	7.34 vl
Exch. Ca (ppm)	15.26 vl	21.63 vl	31.27 vl	28.91 vl	21.51 vl	18.08 vl
Exch. Mg (ppm)	5.02 vl	9.49 vl	9.26 vl	8.9 vl	6.9 vl	5.72 vl
Fe (ppm)	1.06 vl	1.19 vl	0.98 vl	1.10 vl	1.04 vl	0.98 vl
Mn (ppm)	2.86 vl	5.83 vl	7.06 vl	5.74 vl	4.28 vl	3.32 vl
Cu (ppm)	0.70 vl	0.84 vl	0.76 vl	0.79 vl	0.93 vl	1.28 vl
Zn (ppm)	1.97 l	3.30 l	3.80 l	3.76 l	2.98 l	2.47 l
CEC (cmol$_c$.kg^{-1})	6.43 l	7.97 l	8.84 l	9.44 l	8.92 l	8.19 l
Base saturation (%)	5.66 vl	14.60 vl	18.53 vl	15.96 vl	11.47 vl	6.34 vl
Al saturation (%)	68.42 vh	59.72 vh	58.58 vh	55.99 vh	62.12 vh	72.47 vh

*According to the assessment criteria for the results of soil chemical analysis (Balai Penelitian Tanah 2009): va = very acid, a = acid, vl = very low, l = low, m = medium, vh = very high; ** According to the criteria of Bagshaw et al. (2010); *** CS 50 (50 t ha^{-1} compost), FCS 50 (50 t ha^{-1} FABA+compost), FCB 25 (25 t ha^{-1} FABA+compost), FCB 15 (15 t ha^{-1} FABA+compost), and FCB 5 (5 t ha^{-1} FABA+compost); S = spread application, B= band application. FABA: Compost = 25:75, FA: BA= 7:1.

2023). Compost contains fulvic acid and humic acid. Humic acid contains 40-80% C (Abel et al., 2021). Soil NO_3 levels were relatively high, while available P levels were high to very high. The application of organic materials increased the availability of soil N and P, either directly through the mineralization of organic materials that resulted in the release of NH_4^+, NO_3^-, and PO_4^{3-}, or indirectly through the role of organic acids in forming chelates with Al and Fe, thereby reducing P adsorption and increasing P availability (Enita et al., 2020). Soil CEC was relatively low with very low levels of exchangeable base cations and base saturation.

Soil Nutrient Leaching Time

The logarithmic equations of the relationship between the leaching time (*t*) and the total leached nutrient flux (*F*) with the highest t_{max} value are given in Table 2. All equations in Table 2 have R^2 values of 0.90-0.99, indicating that all equations formed have good regression coefficients. In general, the amelioration of FABA and compost combination significantly affected the duration of nutrient leaching. The longest time required for the nutrient leaching process to stop (t_{max}) was achieved in the FCB 25 treatment for NO_3^-, P, Ca, and Mg, in the FCB 50 treatment for K, and in the FCB 5, FCB 15, CS 50, and FCB 5 treatments for Fe, Mn, Cu, and Zn, respectively.

A higher t_{max} value indicated a higher soil capacity to retain water and nutrients as affected by the treatment. Compost amendment increases soil negative charge (CEC) by deprotonating phenolic (R-OH) and carboxylic (R-COOH) functional groups on soil organic colloids, yielding negatively charged phenolic (R-O$^-$) and carboxylate (R-COO$^-$) reactive sites (Kusumarini et al., 2020). In addition, FABA amelioration increases soil pH and, subsequently, CEC by deprotonating reactive sites on variable-charge soil clay colloids that dominate Ultisols (Ilham et al., 2021). However, the highest t_{max} value or the longest leaching time needed does not necessarily indicate the highest total and proportion of the nutrient leaching flux. Therefore, it is necessary to determine the total flux and the proportion of nutrient-leaching flux for each treatment level.

Total Nutrient Leaching Flux

The treatment evaluated significantly affected the total leaching flux of soil macro- and micronutrients, except for Cu (Table 3). The lowest total leaching flux of NO_3 was observed in the FCB 25

Table 2. Logarithmic curve equations of the relationship between leaching time (t, X-axis) and leached nutrient flux (F, Y-axis) with the highest t_{max} and/or the lowest TF.

Treatment*	Curve equation	t_{max} (d)	Total flux (*TF*, mg)	Curve equation	t_{max} (d)	Total flux (*TF*, mg)
	NO_3			P		
FCB 25	Y = -5.305 ln(X) + 20.60	48.56	231.73	Y = -0.156 ln(X) + 0.63	56.16	7.98
	K			Ca		
FCS 50	Y = -0.2 ln(X) + 0.80	54.46	9.89	Y = -0.186 ln(X) + 0.72	47.98	8.02
FCB 25	Y = -0.193 ln(X) + 0.75	47.89	8.30	Y = -0.154 ln(X) + 0.61	53.09	7.41
	Mg					
FCB 25	Y = -0.051 ln(X) + 0.21	55,67	2,58			
	Fe			Mn		
FCB 15	Y = -0.004 ln(X) + 0.01	27.79	0.09	Y = -0.036 ln(X) + 0.14	46.47	1.50
FCB 5	Y = -0.003 ln(X) + 0.01	44.70	0.12	Y = -0.038 ln(X) + 0.14	40.13	1.34
	Cu			Zn		
CS 50	Y = -0.004 ln(X) + 0.02	55.98	0.20	Y = -0.017 ln(X) + 0.06	37.46	0.56
FCB 5	Y = -0.004 ln(X) + 0.01	43.59	0.16	Y = -0.02 ln(X) + 0.08	53.78	0.98

*see Table 1

Table 3. Effect of FABA+compost amelioration on the total leached nutrient flux.

Treatment**	Total leached nutrient flux*								
	mg kg^{-1}								
	NO_3	P	K	Ca	Mg	Fe	Mn	Cu	Zn
None	359.09 a	10.82 a	11.23 a	9.13 a	4.71 a	0.29 a	1.58 a	0.20	0.95 a
CS 50	341.59 a	8.61 bc	11.57 a	8.21 b	4.21 a	0.13 b	1.43 ab	0.20	0.56 b
FCS 50	286.75 b	8.04 c	9.89 b	8.02 b	3.20 b	0.12 b	1.35 b	0.17	0.51 b
FCB 25	231.73 c	7.98 c	8.30 d	7.41 c	2.58 c	0.11 b	1.37 b	0.15	0.54 b
FCB 15	234.32 c	8.58 bc	9.32 bc	7.34 c	2.99 bc	0.09 b	1.50 b	0.16	0.55 b
FCB 5	267.14 b	9.23 b	8.90 cd	8.37 b	4.66 a	0.12 b	1.35 b	0.16	0.98 a
p value	0.0001	0.0001	0.0001	0.001	0.0001	0.009	0.014	0.51	0.0001

*Numbers followed by different letters in the same column are significantly different at 5% test level; **see Table 1

treatment, which was not significantly different from that in the FCB 15 treatment. In both treatments, the total leaching flux of NO_3 was higher than that of the other nutrients. It is because inorganic N species in soil solution are predominantly present as nitrate (NO_3^-), which has a low affinity for negatively charged soil clay and organic colloids (Siswanto, 2018). In the soil system, nitrate is mobile because of its low interaction with soil colloids, which are predominantly negatively charged. Therefore, it readily dissolves in soil solution and is leached from the soil system (Thakur & Kumar, 2020). Compost amelioration increased the organic matter content of a sandy soil and increased its capacity to retain water (Faoziah et al., 2022). The application of fly ash could also increase the soil's water-holding capacity due to its fine texture and high specific surface area (Jeyaraj & Sankararajan, 2024). Thus, nitrate leaching would be slower in FABA+compost-ameliorated soils compared to the control soil.

The amelioration treatment significantly affected the total P leaching flux, with the lowest flux observed in the FCB 25, which was not significantly different from that of the FCS 50 treatment. Compared to NO_3^-, the total P leaching flux was lower. Soil P loss through leaching is lower than by other processes, such as runoff and erosion (Asbur et al., 2023). Low soil P leaching flux is related to the solubility of soil P compounds, which is generally very low. In acid soil, phosphate is relatively immobile because it forms complexes with

Table 4. Effect of FABA+compost amelioration on the proportion of nutrient leaching flux.

Treatment*	Proportion of leached nutrient flux								
	%								
	NO_3	P	K	Ca	Mg	Fe	Mn	Cu	Zn
None	94.00	77.60	154.21	59.82	93.72	27.28	55.46	27.90	48.08
CS 50	82.74	35.80	145.92	31.97	44.41	11.25	24.58	24.32	16.93
FCS 50	68.43	24.82	108.40	25.64	34.57	12.23	19.17	22.58	13.39
FCB 25	55.15	26.55	100.73	25.85	29.04	9.29	23.87	18.51	14.27
FCB 15	64.01	37.87	115.00	34.11	43.24	9.03	35.00	17.56	18.28
FCB 5	80.12	62.69	121.34	46.26	81.47	12.21	40.50	12.11	39.59
Average**	70.09	37.54	118.28	32.77	46.55	10.80	28.62	19.01	20.49

*see Table 1; ** Proportion of the leached nutrient flux in the None treatment was not included in the calculation

Al and Fe, which are insoluble in soil (Septiawan et al., 2020).

The amelioration treatment significantly reduced the total K leaching flux; the lowest value was observed in the FCB 25 treatment. The combined application of fly ash and compost increased the pH and CEC of an acidic soil (Bhavya et al., 2022). The mobility of K ions in soil is lower than that of nitrate but higher than that of phosphates. Soil cation exchange complexes tend to retain divalent cations (Ca^{2+} and Mg^{2+}) more strongly than monovalent ones. It causes monovalent cations such as K^+ to become more easily exchanged and released into the soil solution (Fitratian, 2019), and then leached.

The amelioration treatment significantly affected the total Ca leaching flux; the lowest flux was observed in the FCB 15 treatment, which was not significantly different from that in the FCB 25 treatment. The lowest total Mg leaching flux was achieved in the FCB 25 treatment. The application of FABA and compost was reported to increase soil CEC and retention capacity for K, Ca, Mg, and water (Rakhmania et al., 2017).

The amelioration treatment significantly affected the total leaching flux of micronutrients Fe, Mn, and Zn. The lowest Fe level was observed in the FCB 15 treatment, which was not significantly different from the other treatments except the control. The lowest levels of Mn and Zn were observed in the FCB 50 treatment, which was not significantly different from the other treatments except the control. The total leaching flux of Mn was higher than that of Fe and Zn. The leaching of soil micronutrients follows the sequence Mn > Zn > Fe > Cu (Thakur & Kumar, 2020). In acidic conditions, soil Mn oxides dissolve, releasing Mn^{2+} into the soil solution and making it more easily leachable from the soil (Li et al., 2021).

Proportion of Nutrient Leaching Flux

The proportion of leached nutrient flux relative to the initial levels before the leaching process is given in Table 4. Generally, the lowest proportions of leached macronutrients were observed in the FCS 50 and FCB 25 treatments, whereas for micronutrients, the lowest proportions were observed in the FCB 15 treatment. The average proportions of leached NO_3 and K (70.09% and 118.28%, respectively) were still high and higher than those of P, Ca, Mg, Fe, Mn, Cu, and Zn. Nitrate is readily leached from soil because it has a weak affinity for soil colloids (Han et al., 2020). For K, this could be caused by dissolution of K from the total K in KCl-fertilized soil due to percolation, representing precipitation. The dissolved K will then leach from the soil. When the K concentration in soil solution decreases due to leaching, adsorbed K is desorbed and released into the soil solution, which can then be leached from the soil (Singh et al., 2020).

Implications for Fertilizer Management

In general, the highest t_{max}, the lowest total leaching flux, and the lowest leaching flux proportion of the soil macro- and micro-nutrients were obtained in the FCB 25 treatment, even though the total flux and flux proportion of NO_3 and K were still high. The proportion of K leaching flux was even >100%. It indicates a remarkable loss of soil N and K. Accordingly, from the fertilizer management point of view, more attention should be paid to improve the efficiency of soil-based fertilizer application. Since the initial soil-available K concentration was very low (Table 1), it can be predicted that the loss of soil K was predominantly from the soil fertilizers applied before planting pineapple. Given the high leaching flux of soil NO_3, even though its initial concentration was very high (Table 1), alternative soil N fertilizer management options should also be considered. In this case, the use of controlled-release soil N and K fertilizers is suggested. Since pineapple cultivation in rotation with banana and cassava in PT GGP generates a large amount of biomass waste, producing biochar from it is worth considering. The biochar produced will then be used as a nutrient carrier for formulating biochar-based controlled-release fertilizers.

CONCLUSIONS

Amelioration of FABA and compost combination in the Ultisol of the PT GGP pineapple plantation area reduced soil macro- and micronutrient leaching fluxes, as indicated by t_{max}, total leaching flux, and the proportion of nutrient leaching flux. In general, the longest nutrient leaching time (t_{max}) and the lowest total and proportion of nutrient leaching flux were obtained in the band-application of 25 t ha^{-1} FABA+compost treatment. The total and proportion of NO_3 and K leaching flux after 35 days of percolation were still high. As an implication for fertilizer management, consider using controlled-release fertilizers to reduce soil nutrient loss from leaching.

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