Maize nutrient translocation on artisanal gold mining soil ameliorated with EFB compost, clay and lime

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ABSTRACT (IN ENGLISH)

Artisanal gold mining generally produces coarse-textured soils with low nutrient absorption capacity, which limits plant growth and productivity. Soil reclamation in these conditions necessitates not only improved soil quality but also effective nutrient uptake and allocation within the plant. This study aims to evaluate the effect of oil palm empty fruit bunch (EFB) compost, clay soil, and lime used as soil conditioners on the concentration of N, P, and K in various maize organs planted on soil formerly used for artisanal gold mining. The study was conducted in experimental pots using a completely randomized factorial design (CRF) with three factors: A) EFB compost at 6, 12, and 18 t ha^{-1}; B) clay at 10 and 20%; and C) lime at 0.5 and 1.0 t ha^{-1}. After harvest, maize plants were separated into roots, stems, leaves, and grain, and tissue concentrations of N, P, and K were determined. The results showed clear organ-specific patterns of nutrient accumulation. The highest N concentration was found in the grain (1.95%), the highest P in the roots (0.37%), and the highest K in the leaves (3.07%), all under treatment A3B1C1 (18 t ha^{-1} of EFB compost, 10% clay, and 0.5 t ha^{-1} of lime). The findings suggest that using EFB compost, clay soil, and lime together can effectively improve nutrient availability, uptake, and partitioning in maize grown on post-gold mining soil. This strategy has the potential to support the productive reuse of degraded artisanal gold mining land.

Keywords: clay soil, EFB compost, lime, maize, post artisanal gold mining soil

ABSTRAK (IN INDONESIAN)

Tanah bekas tambang emas artisanal umumnya memiliki tekstur berpasir dengan kapasitas retensi hara yang rendah, sehingga kurang mendukung pertumbuhan tanaman. Oleh karena itu, reklamasi lahan tidak hanya memerlukan perbaikan sifat tanah, tetapi juga peningkatan serapan dan distribusi hara di dalam tanaman. Penelitian ini bertujuan untuk mengevaluasi pengaruh kompos tandan kosong kelapa sawit (TKKS), tanah ber-liat, dan kapur yang digunakan sebagai pembenah tanah terhadap konsentrasi N, P dan K pada berbagai organ tanaman jagung yang ditanam pada tanah bekas tambang emas artisanal. Penelitian dilakukan dengan percobaan pot menggunakan rancangan acak lengkap faktorial dengan tiga faktor, yaitu A) kompos TKKS dosis 6, 12, dan 18 t ha^{-1}; B) tanah berliat 10% dan 20%; serta C) kapur 0.5 dan 1.0 t ha^{-1}. Setelah panen, tanaman jagung dipisahkan menjadi akar, batang, daun, dan biji, kemudian dianalisis konsentrasi N, P, dan K jaringannya. Hasil penelitian menunjukkan bahwa akumulasi hara mengikuti pola spesifik organ tanaman. Konsentrasi N tertinggi ditemukan pada biji (1.95%), konsentrasi P tertinggi pada akar (0.37%), dan konsentrasi K tertinggi pada daun (3.07%), seluruhnya pada perlakuan A3B1C1 (12 t ha^{-1} kompos TKKS dan 1.0 t ha^{-1} kapur). Temuan ini menunjukkan bahwa ameliorasi terpadu dengan kompos TKKS, tanah berliat, dan kapur efektif memperbaiki ketersediaan, serapan, dan distribusi hara pada jagung di tanah bekas tambang emas. Strategi ini berpotensi mendukung pemanfaatan kembali lahan tambang emas artisanal secara lebih produktif dan berkelanjutan.

Kata kunci: tanah berklei, kompos TKKS, kapur, jagung, bekas tambang emas artisanal

INTRODUCTION

Artisanal gold mining has far-reaching environmental consequences, including severe landscape disturbance and the formation of soils that are physically fragile, chemically degraded, and biologically impoverished. Following topsoil removal or intense substrate mixing, the residual material is commonly coarse-textured, weakly structured, low in organic matter, low in cation exchange capacity, and poorly able to retain nutrients and support crop establishment (Timsina *et al.*, 2022 ; Eludoyin *et al.*, 2017). This issue is particularly relevant when researchers use maize as a test crop to evaluate nutrient translocation in reclaimed soils. Maize is a crop that requires many nutrients, such as nitrogen, phosphorus, and potassium, in the right balance during its vegetative and reproductive growth (Rawal *et al.*, 2022; Ciampitti *et al.*, 2013; Kuunya *et al.*, 2025). In reclaimed mining soils, maize performance reflects soil quality and productivity. Its response to soil amendments can indicate whether reclamation has improved nutrient availability. It can also indicate whether reclamation has improved soil–plant nutrient dynamics (Hu *et al.*, 2021; Zhang *et al.*, 2025; Fang *et al.*, 2025; Kumari and Maiti, 2022).

Among the amendments available for post-mining soil rehabilitation, oil palm empty fruit bunch compost is especially promising because it supplies organic matter and nutrients while improving cation exchange capacity, pH, and biological activity (Neswati *et al*. 2022; Saidy *et al.*, 2025). The effectiveness of this method can be further enhanced by two factors. First, the addition of clay soil, which improves nutrient retention through colloidal charge. Second, the addition of lime, which reduces acidity and increases the availability of phosphorus. Previous studies have demonstrated that EFB-based amendments and related organic materials can enhance nutrient availability, reduce acidity, and improve crop performance in degraded soils (Saidy *et al.*, 2024; Dejene *et al.*, 2023). However, there has been limited research on how these combined ameliorants affect nutrient levels in specific maize organs under artisanal ex-gold mining conditions.

The effects of EFB compost, clay soil, and lime on N, P, and K concentrations in maize roots, stems, leaves, and grain grown in soil from an artisanal ex-gold mining area are investigated in this study. The study aims to clarify how reclamation treatments influence not only soil nutrient availability but also nutrient uptake, translocation, and partitioning within the plant by focusing on organ-specific nutrient concentrations. This perspective is essential for developing reclamation strategies, which must be both agronomically effective and physiologically meaningful. This is essential for the sustainable reuse of post-mining land.

MATERIALS AND METHODS

Study site

This research was conducted from January to July 2025. Maize cultivation was carried out on land belonging to the Bunga Tanjung agricultural group, which was supervised by the Kuantan Singingi Regency Agricultural Crop Service, Riau.

Experimental Design

The study was conducted using experimental pots to evaluate land reclamation strategies for former artisanal gold mines. The soil used in this study was collected from a land typology H of gold mine located along the Singingi River, Riau Province, as previously characterized by Okalia *et al.* (2025). The experiment was designed using a completely randomized factorial (CRF) design, consisting of three factors (A, B, and C) at various levels, each replicated three times. Three ameliorants were used: A (EFB compost), B (clay soil), and C (lime). EFB compost (A) was applied at doses of 6, 12, and 18 t ha^{-1} (144, 288, and 432 g pot^{-1}), clay soil (B) at 10% and 20% (4.8 and 9.6 kg pot^{-1}), and lime (C) at 0.5 and 1.0 t ha^{-1} (12 and 24 g pot^{-1}), respectively. The clay soil used in this study belongs to the Ultisol order, with a clay content of 40%, and the lime used is $CaCO_3$. Maize grains of Pioneer P32 were planted at a distance of 70 cm apart in a 50 x 50 cm pot (equivalent to 48 kg of dry soil weight) and fertilized with 3.1 g of N, 1 g of P_2O_5, and 1.3 g of K_2O pot^{-1}.

Research procedure

After harvesting maize biomass (100 days after planting), plant tissue samples were obtained by separating roots, stems, leaves, and grain. The samples were dried in an oven at 70°C, and their dry weights were measured. Next, the dried samples were ground using a mechanical grinder equipped with a 0.5-mm mesh filter. The macro-nutrients nitrogen (N), phosphorus (P), and potassium (K) were determined using the wet combustion method with H_2SO_4 and H_2O_2. Total N concentration was measured using the Kjeldahl method, P using a spectrophotometer at a wavelength of 693 nm, and K concentration was measured using an atomic absorption spectrophotometer (AAS). All chemical analysis methods refer to (Eviati *et al.* 2023).

Statistical Analysis

The collected data were analyzed using Analysis of Variance (ANOVA) to detect significant differences between treatment groups at a 5% significance level. If significant differences were detected ($p < 0.05$), post-hoc analysis was conducted. Tukey's test was used to identify the specific treatment combinations responsible for the differences. Pearson correlation analysis was performed to assess relationships among nutrient concentrations in maize organs, and visualized as a heatmap. RStudio 4.5.2 was used for all data analysis, and the results were presented in both tabular and graphical formats in Origin Pro Learning Edition.

RESULTS AND DISCUSSION

Effects of EFB Compost, Clay Soil, and Lime on N, P, and K Nutrient Concentration in Maize Roots

The effect of EFB compost, clay soil, and lime significantly increased the nutrient concentration of N, P, and K in maize roots. Based on the results of the Tukey 5% post-hoc test, there was an EFB compost, clay soil and lime interaction (AxBxC) in the N and P nutrient concentration in maize roots as shown in Table 1.

(Insert Table 1 here)

Treatment A3B2C2 had the highest nitrogen concentration at 0.72%, while A1B1C1 had the lowest at 0.27%, which is a difference of 0.45%. The study revealed an intriguing finding, treatments A3B2C2, A3B1C1, and A3B1C2 with a high EFB compost dose (A3) increased nitrogen (N) concentration. Moreover, the combination of high EFB compost (A3) with different clay soils (B1 and B2) and lime doses (C1 and C2) further increased nitrogen availability. The root nitrogen concentration of soil from reclaimed mine sites treated with soil amendments in this study was approximately 0.27–0.72%; however, it can vary depending on soil type. This is consistent with the study by Castellano *et al.* (2021) , which examined root nitrogen concentration in maize across several soil types. The lowest root nitrogen concentration was around 0.70%. The average whole-root nitrogen concentration increased with nitrogen fertilization rate 1.1% for zero N, 1.2% for middle N, and 1.3% for excess N.

Table 1 shows that the highest P concentration (0.37%) was found in A3B1C1, while the lowest (0.14%) was in A1B1C1, resulting in a 0.23% difference. The results of the study indicate that a combination of high dose EFB compost, clay soil, and lime at optimal doses improves phosphorus availability by increasing soil pH and phosphate solubility. Castaned *et al.* (2018) reported P nutrient concentration in corn roots is influenced by the availability of P in the soil.

Furthermore, regarding potassium concentration in maize roots, based on the results of the Tukey 5% post-hoc test, the concentration of the K nutrient was influenced by the interactions between the treatments of EFB compost (A) and clay (B), EFB compost (A) and lime (C), and clay (B) and lime (C) (Figure 1).

(Insert Figure 1 here)

In the AxB interaction (Figure 1a), treatments A3B1 and A3B2 resulted in the highest potassium concentration, which was not significantly different at 1.31%. Figure 1a shows an inverse relationship in treatment A1B1 (6 t ha^{-1} EFB compost and 10% clay soil), where the potassium concentration was the lowest at 0.41%. Figure 1b also illustrates an AxC interaction; treatment A3C2 resulted in a potassium concentration of 1.32%, which was not significantly different from A3C1 (18 t ha^{-1} EFB compost and 0.5 t ha^{-1} lime), with a concentration of 1.31%. This suggests that increasing the lime dose from 0.5 t ha^{-1} (C1) to 1 t ha^{-1} (C2) does not lead to a significant change in soil potassium concentration. Treatment A1C1 showed the lowest potassium concentration, at 0.44%. In Figure 1c, the BxC interaction is shown; B2C2 exhibits a potassium concentration of 1.06%, slightly higher than that of B1C2 (0.88%). This indicates that AxB and AXC have higher K concentration than BxC. Amri (2018) reported that potassium supply from EFB compost, and the lime-regulated soil chemistry work together to improve potassium uptake.

Effects of EFB Compost, Clay Soil, and Lime on N, P, and K Concentration in Maize Stems

Soil amelioration significantly affected all parameters, N, P, and K, in maize stems (Figure 2 and Table 2). Based on Figure 2a, for the EFB compost and clay interaction (AxB), treatment A3B1 showed the highest nitrogen concentration at 0.29%, followed by treatment A3B1 at 0.25%. There was an interaction between EFB compost (A) and clay soil (B) and EFB compost (A) and lime (C) in terms of N concentration in stems (Figure 2).

(Insert Figure 2 here)

Based on Figure 2a, for the AxB interaction, treatment A3B1 showed the highest nitrogen concentration at 0.29%, followed by treatment A3B1 at 0.25%. Increasing the compost application rate from 6 t ha^{-1} (A1) to 18 t ha^{-1} (A3) resulted in a significant increase in nitrogen concentration, with a difference of 0.13% between A1B1 (0.16%) and A3B1 (0.29%). The A3B1 treatment yielded the highest nitrogen concentration, while in A1B1 it was 0.16%, the lowest

Figure 2b shows that the AxC interaction, the A3C1 treatment (18 t ha^{-1} EFB compost and 0.5 t ha^{-1} lime) yielded the highest nitrogen concentration, at 0.29%, followed by A2C1 with a concentration of 0.27%. The addition of lime (C1) increased the nitrogen availability required by maize plants; however, the change from C1 to C2 (1.0 t ha^{-1} of lime) did not show a significant difference in N concentration. In A1C1, the N concentration was recorded at 0.17%, which was lower than in A3C1, indicating that a higher compost dose combined with a 0.5 t ha^{-1} lime dose was more effective in increasing nitrogen availability. In addition, compared to the nitrogen concentration in the roots, the nitrogen concentration in the stems is lower (see Table 1). In maize, the distribution of nitrogen among roots, stems, leaves, and grain is dynamic and influenced by nutrients and management (Duan *et al.* 2023). Furthermore, the P and K concentration of maize stems is significantly influenced by the interaction AxBxC shown in Table2.

(Insert Table 2 here)

Table 2 shows that the effect of the AxBxC interaction P and K concentration in maize stems. The highest P concentration was observed in treatment A2B2C1, at 0.22%, while the lowest was in treatments A3B2C1 and A2B2C2, both at 0.05%, with a 0.17% difference. The phosphorus concentration in the roots is approximately 0.05-0.22%, which is lower than the phosphorus concentration in the roots, which ranges from approximately 0.14-0.37%. Holz *et al.* (2024) stated that the distribution of phosphorus within plants is such that only about 60% of the absorbed P reaches the upper parts of the plant, while approximately 40% remains in the growing root tips of both lateral and primary roots. This suggests that the root growth zone has a very high phosphorus requirement. For potassium, the highest concentration was recorded in A3B2C2 (1.93%), not different from A3B1C1. While the lowest was observed in A1B1C1, the difference in potassium concentration between treatments ranged from 0.17% to 1.21%. In contrast to the phosphorus concentration, the potassium concentration in the corn stalk (0.72-1.93%) is higher than that in the roots, which is only

0.41-1.31%. Daher *et al.* (2010) and Ozpinar (2016) reported that potassium concentration in maize stems is generally higher than in roots, indicating greater potassium accumulation in aboveground tissues than in belowground tissues.

Effects of EFB Compost, Clay Soil, and Lime on N, P, and K Concentration in Maize Leaves

Amelioration of EFB compost, clay soil, and lime significantly affected the nutrient concentration of N, P, and K in leaves. The effects of EFB (A) and clay soil (B) on the nitrogen concentration of maize leaves are shown in Table 3.

(Insert Table 3 here)

According to Table 3, the increase in leaf nitrogen concentration with higher EFB compost rates suggests that the amount of compost applied was the main factor controlling nitrogen availability in maize. Treatment A3 (18 t ha^{-1}) led to the highest N value (0.73%), indicating that increasing the compost supply resulted in greater organic N, enhancing nutrient mineralization, retention, and uptake. Recent studies also indicate that the addition of compost and other organic matter to soil significantly increases the concentration of nitrogen (N) in maize, enhances its uptake, and improves its overall nutrient efficiency. This enhancement is achieved by improving the chemical properties of the soil and supporting more sustained N release (Nigussie *et al.*, 2021; Toth dan Toth, 2024; Wang *et al.*, 2024). By contrast, clay had a relatively small effect, as B2 (20% clay) increased leaf N only slightly compared with B1 (10% clay). This indicates that clay mainly improved the medium's capacity to retain water and available N rather than acting as a major source of N itself. Recent findings suggest that the positive effects of soil amendments on maize are most evident when they enhance nutrient conservation and root zone conditions. However, leaf nitrogen (N) levels remain a reliable indicator of enhanced physiological N status (Brodowska dan Wyszkowski, 2022; Liang *et al.*, 2024).

Furthermore, AxBxC interactions occurred in the P and K parameters in maize leaves. For P concentration, treatment A3B1C1 yielded the highest, at 0.27%, followed by A3B2C1 at 0.27%. The

EFB compost, clay soil and lime interaction (AxBxC) on P, and K concentration in maize leaves is shown in Table 4.

(Insert Table 4 here)

Table 4 shows the effect of the AxBxC interaction on the phosphorus (P) and potassium (K) concentration of maize leaves. Treatment A3B1C1 had the highest phosphorus concentration, at 0.27%, while A1B1C1 had the lowest, at 0.12%, showing a 0.15% difference. For potassium, the highest concentration was recorded in A3B1C1 (3.07%), while the lowest potassium concentration was observed in A1B1C1 (1.13%). The difference in potassium concentration between treatments ranged from 0.04 % to 1.94%.

The relationship between EFB, clay soil, and lime with P and K concentrations in maize leaves lies in their complementary roles. These roles improve nutrient availability and uptake. P and K are gradually released by EFB while soil organic matter and cation exchange capacity are increased; nutrients are retained by clay colloids and leaching is reduced; and soil pH is raised, acidity is reduced, and P availability is increased by lime. Together, these factors create a more favorable root environment. Thus, higher P and K concentrations in maize leaf tissue reflect improved nutrient release, retention, and translocation within the plant (Adu *et al.*, 2022; Saidy *et al.*, 2024; Blankson *et al.*, 2025).

Effects of EFB Compost, Clay Soil, and Lime on N, P, and K Concentration in Maize Grain

Soil amelioration of former artisanal mining sites significantly affects the N, P, and K concentration of maize grain. Parameters showing EFB compost, clay soil, and lime interaction (AxBxC) were found in the N and P concentration. Treatment A3B1C1 had the highest N concentration at 1.95%, which was not significantly different from A3B1C2, A3B2C1, and A3B2C2. Treatment A1B1C1 had the lowest N concentration (0.78%), indicating that a low compost dose is insufficient to provide optimal nitrogen. The EFB compost, clay soil, and lime interaction (AxBxC) of N and P nutrient concentration in the grain are shown in Table 5.

(Insert Table 5 here)

Based on Table 5, the phosphorus concentration of maize grain followed a pattern similar to nitrogen, with treatment A3B1C1 recording the highest value (0.35%), although it was not significantly different from A3B1C2, A3B2C1, and A3B2C2. This suggests that the highest compost dose, combined with either 10% or 20% clay soil and lime rates of 0.5 or 1.0 t ha^{-1}, created similarly favorable conditions for P uptake and its subsequent translocation to the grain during grain development. In maize, grain P concentration reflects not only the amount of available P in the soil but also the plant's capacity to absorb, remobilize, and allocate P to reproductive organs during grain filling. The role of EFB compost in this process is likely related to its contribution to organic matter and nutrient supply, while clay soil enhances P retention and lime improves P availability by reducing soil acidity and limiting P fixation. Studies have shown that the combined use of compost and lime can improve soil pH, available P, cation exchange capacity, and grain yield in maize, while integrated organic amendments can also increase nutrient uptake and transfer into economically important tissues (Dawid, 2021; Dejene *et al.*, 2023; Matheus *et al.*, 2023). In contrast, the lowest grain P concentration was found in A1B1C1 (0.23%), indicating that the lowest compost dose was insufficient to support optimum phosphorus accumulation in the grain.

The interaction between EFB compost (A) and clay soil (B) actually affects K concentration. The EFB compost (A) and clay soil interaction (B) on K concentration in maize grain is shown in Figure 3.

(Insert Figure 3 here)

Figure 3 shows that the interaction between EFB compost and clay soil significantly increased potassium concentration in maize. The highest value was recorded in A3B2 (0.50%), although it did not differ significantly from A3B1, A2B2, and A2B1, indicating that moderate to high compost rates under clay soil conditions were sufficient to stabilize K availability and support similar plant uptake. This effect likely arose from the complementary roles of both factors: EFB compost increased exchangeable K and soil organic matter, whereas clay enhanced K retention through its colloidal surface and reduced leaching losses. Consequently, the lower K concentration in A1B1 (0.40%)

suggests that the lowest compost rate could not maintain adequate K supply, while the 0.10% increase between A1B1 and A3B1 confirms that raising the compost rate from 6 to 18 t ha^{-1} significantly improved potassium status in maize by increasing available K and preserving it in plant-accessible form (El-awady and El-naqma, 2023; Hakimi *et al.,* 2024; Bao *et al.,* 2024; Teressa *et al.,* 2024; Khairo *et al.,* 2025).

Relationships of Nutrient Concentrations Among Maize Organs After Harvest

The results indicate element-specific nutrient accumulation patterns in maize organs after harvest. Nitrogen (N) reached the highest concentration in the grains (1.95%) under treatment A3B1C1, phosphorus (P) was highest in the roots (0.37%), and potassium (K) peaked in the leaves (3.07%). The correlation results are presented as a heatmap (Figure 4), in which Pearson correlation coefficients (r) indicate the strength and direction of relationships among maize organs.

(Insert Figure 4 here)

The correlation heatmap (Figure 4) illustrates that leaf and stem N are highly correlated with grain N (r = 0.96-0.86), indicating efficient remobilization to reproductive organs. Root P shows moderate correlations with leaf and grain P (r = 0.84-0.88), while stem and leaf K positively correlate with grain K (r = 0.82-0.91). During the reproductive phase, nitrogen (N) and phosphorus (P) are actively translocated to the reproductive organs, contributing significantly to the nutrient content of maize grain (Ray *et al.*, 2020). A portion of P and K remains retained in roots and leaves for metabolic functions (Yuhui *et al.,* 2019; Sun *et al.,* 2023). These findings highlight that integrated soil amendments not only enhance nutrient availability but also support optimal nutrient allocation to grains, improving maize productivity on post artisanal gold mining soils.

CONCLUSIONS

Nitrogen, phosphorus, and potassium exhibited distinct organ specific translocation patterns in maize, with the highest accumulation concentrations recorded in the grain (1.95% N), roots (0.37% P), and leaves (3.07% K), respectively, under treatment A3B1C1. The application of 18 t ha^{-1} EFB compost combined with 10% clay soil and 0.5 t ha^{-1} lime represented the most effective amelioration strategy for improving nutrient availability, uptake, and partitioning in maize grown on post artisanal gold mining soil.

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TABLES, AND FIGURES

Table 1. Effect of the EFB compost and clay soil interaction (AxBxC) on the N, and P nutrient concentration in maize roots

Treatment	N concentration %	P concentration (%)
A1B1C1 (6 t ha^{-1} EFB compost, 10% clay soil, 0.5 t ha^{-1} lime)	0.27 ± 0.001 ^{h}	0.14 ± 0.028 ^{e}
A1B1C2 (6 t ha^{-1} EFB compost, 10% clay soil, 1.0 t ha^{-1} lime)	0.47 ± 0.019 ^{fg}	0.18 ± 0.020 ^{de}
A1B2C1 (6 t ha^{-1} EFB compost, 20% clay soil, 0.5 t ha^{-1} lime)	0.42 ± 0.036 ^{g}	0.25 ± 0.023 ^{c}
A1B2C2 (6 t ha^{-1} EFB compost, 20% clay soil, 1.0 t ha^{-1} lime)	0.55 ± 0.035 ^{cd}	0.23 ± 0.023 ^{cd}

Treatment	N concentration %	P concentration (%)
A2B1C1 (12 t ha^{-1} EFB compost, 10% clay soil, 0.5 t ha^{-1} lime)	0.67 ± 0.044 ^{ab}	0.25 ± 0.005 ^{c}
A2B1C2 (12 t ha^{-1} EFB compost, 10% clay soil, 1.0 t ha^{-1} lime)	0.64 ± 0.003 ^{bc}	0.24 ± 0.001 ^{c}
A2B2C1 (12 t ha^{-1} EFB compost, 20% clay soil, 0.5 t ha^{-1} lime)	0.60 ± 0.023 ^{cd}	0.25 ± 0.024 ^{c}
A2B2C2 (12 t ha^{-1} EFB compost, 20% clay soil, 1.0 t ha^{-1} lime)	0.52 ± 0.029 ^{ef}	0.24 ± 0.016 ^{c}
A3B1C1 (18 t ha^{-1} EFB compost, 10% clay soil, 0.5 t ha^{-1} lime)	0.65 ± 0.022 ^{abc}	0.37 ± 0.005 ^{a}
A3B1C2 (18 t ha^{-1} EFB compost, 10% clay soil, 1.0 t ha^{-1} lime)	0.67 ± 0.022 ^{abc}	0.32 ± 0.018 ^{b}
A3B2C1 (18 t ha^{-1} EFB compost, 20% clay soil, 0.5 t ha^{-1} lime)	0.52 ± 0.022 ^{ef}	0.24 ± 0.009 ^{c}
A3B2C2 (18 t ha^{-1} EFB compost, 20% clay soil, 1.0 t ha^{-1} lime)	0.72 ± 0.006 ^{a}	0.34 ± 0.002 ^{ab}

Note: Numbers followed by the same letter in the same column are not significantly different according to Tukey's test at the 5% level.

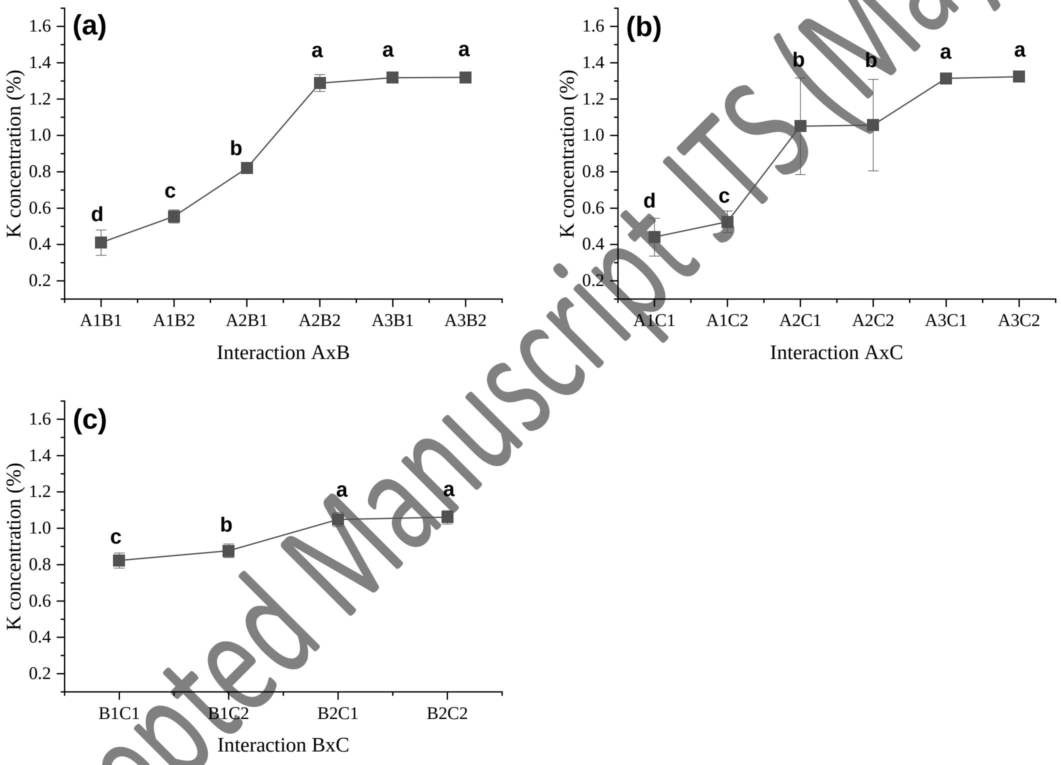

Figure 1. The effect of EFB compost (A) x clay soil (B) (1a), EFB compost (A) x lime (C) (1b), and clay soil (B) x lime (C) (1c) interactions on the K concentration in maize roots. Means above a bar of each sample, superscripted with different lowercase letters, are significantly different according to the Tukey test ($p<0.05$). Notes : A1: 6 t ha^{-1}, A2: 12 t ha^{-1} and A3: 18 t ha^{-1} of EFB compost; B1: 10% and B2: 20% clay; C1: 0.5 t ha^{-1} and C2: 1.0 t ha^{-1} of lime.

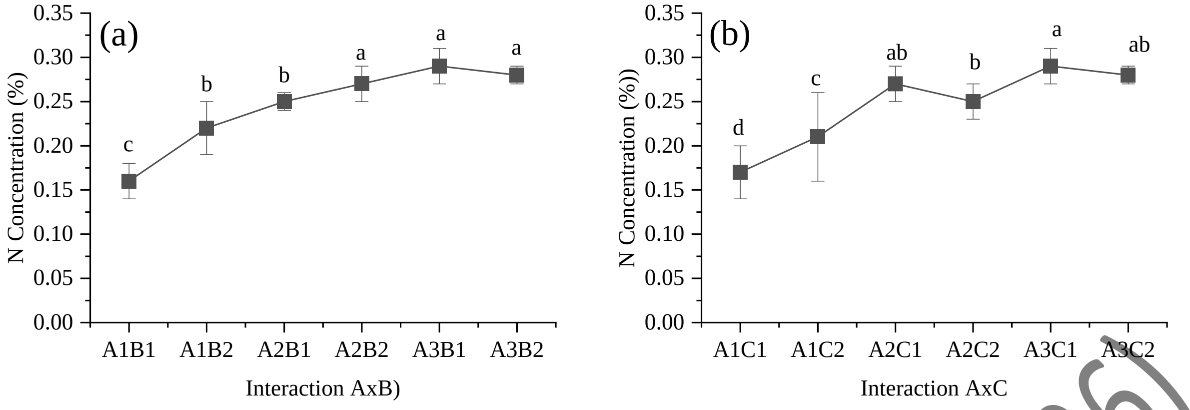

Figure 2. Effect of the EFB compost (A) x clay soil (B) (2a) and EFB compost (A) x lime (C) (2b) interactions on nitrogen concentration in maize stems. Means above a bar of each sample, superscripted with different lowercase letters, are significantly different according to the Tukey test ($p<0.05$). Note : A1: 6 t ha^{-1}, A2: 12 t ha^{-1} and A3: 18 t ha^{-1} of EFB compost; B1: 10% and B2: 20% clay; C1: 0.5 t ha^{-1} and C2: 1.0 t ha^{-1} of lime.

Table 2. Effect of the EFB compost, clay soil, and lime interaction (AxBxC) on the P and K nutrient concentration in maize stems

Treatment	P concentration (%)	K concentration (%)
A1B1C1 (6 t ha^{-1} EFB compost, 10% clay soil, 0.5 t ha^{-1} lime)	0.17 ± 0.0019 ^{d}	0.72 ± 0.026 ^{f}
A1B1C2 (6 t ha^{-1} EFB compost, 10% clay soil, 1.0 t ha^{-1} lime)	0.18 ± 0.0010 ^{cd}	0.77 ± 0.035 ^{f}
A1B2C1 (6 t ha^{-1} EFB compost, 20% clay soil, 0.5 t ha^{-1} lime)	0.07 ± 0.0017 ^{g}	1.02 ± 0.032 ^{de}
A1B2C2 (6 t ha^{-1} EFB compost, 20% clay soil, 1.0 t ha^{-1} lime)	0.18 ± 0.0060 ^{bc}	1.08 ± 0.031 ^{d}
A2B1C1 (12 t ha^{-1} EFB compost, 10% clay soil, 0.5 t ha^{-1} lime)	0.19 ± 0.0035 ^{b}	0.99 ± 0.015 ^{e}
A2B1C2 (12 t ha^{-1} EFB compost, 10% clay soil , 1.0 t ha^{-1} lime)	0.09 ± 0.0035 ^{e}	1.26 ± 0.016 ^{c}
A2B2C1 (12 t ha^{-1} EFB compost, 20% claysoil, 0.5 t ha^{-1} lime)	0.22 ± 0.0017 ^{a}	1.36 ± 0.030 ^{b}
A2B2C2 (12 t ha^{-1} EFB compost, 20% clay soil, 1.0 t ha^{-1} lime)	0.05 ± 0.0071 ^{h}	1.38 ± 0.039 ^{b}
A3B1C1 (18 t ha^{-1} EFB compost, 10% clay soil, 0.5 t ha^{-1} lime)	0.07 ± 0.0025 ^{g}	1.92 ± 0.028 ^{a}
A3B1C2 (18 t ha^{-1} EFB compost, 10% clay soil, 1.0 t ha^{-1} lime)	0.08 ± 0.0030 ^{ef}	1.89 ± 0.029 ^{a}
A3B2C1 (18 t ha^{-1} EFB compost, 20% clay soil, 0.5 t ha^{-1} lime)	0.05 ± 0.0026 ^{h}	1.91 ± 0.034 ^{a}
A3B2C2 (18 t ha^{-1} EFB compost, 20% clay soil, 1.0 t ha^{-1} lime)	0.08 ± 0.0040 f^{g}	1.93 ± 0.018 ^{a}

Note: Numbers followed by the same letter in the same column are not significantly different according to Tukey's test at the 5% level.

Table 3. Effects of EFB compost (A) and clay soil (B) on the nitrogen concentration of maize leaves

Factor	Treatment level	N concentration (%)
EFB (A)	A1 (6 t ha^{-1})	0.59±0.03 ^{c}
	A2 (12 t ha^{-1})	0.65±0.04 ^{b}
	A3 (18 t ha^{-1})	0.73±0.04 ^{a}
Clay soil (B)	B1 (10%)	0.64±0.07 ^{b}
	B2 (20%)	0.67±0.07 ^{a}

Note: Numbers followed by the same letter in the same column are not significantly different according to Tukey's test at the 5% level.

Table 4. Effect of EFB compost, clay soil, and lime interactions (AxBxC) on P, and K nutrient concentration in maize leaves

Treatment	P concentration (%)	K concentration (%)
A1B1C1 (6 t ha^{-1} EFB compost, 10% clay soil , 0.5 t ha^{-1} lime)	0.12 ± 0.007 ^{c}	1.13 ± 0.06 ^{f}
A1B1C2 (6 t ha^{-1} EFB compost, 10% clay soil, 1.0 t ha^{-1} lime)	0.13 ± 0.007 ^{c}	1.37± 0.05 ^{f}
A1B2C1 (6 t ha^{-1} EFB compost, 20% clay soil, 0.5 t ha^{-1} lime)	0.13 ± 0.022 ^{c}	1.64 ± 0.06 ^{e}
A1B2C2 (6 t ha^{-1} EFB compost, 20% clay soil, 1.0 t ha^{-1} lime)	0.23 ± 0.034 ^{ab}	1.92 ± 0.01 ^{d}
A2B1C1 (12 t ha^{-1} EFB compost, 10% clay soil, 0.5 t ha^{-1} lime)	0.13 ± 0.003 ^{c}	2.66 ± 0.08 ^{bc}
A2B1C2 (12 t ha^{-1} EFB compost, 10% clay soil, 1.0 t ha^{-1} lime)	0.17 ± 0.027 ^{bc}	2.09 ± 0.08 ^{d}
A2B2C1 (12 t ha^{-1} EFB compost, 20% clay soil, 0.5 t ha^{-1} lime)	0.21 ± 0.020 ^{ab}	2.71 ± 0.01 ^{b}
A2B2C2 (12 t ha^{-1} EFB compost, 20% clay soil, 1.0 t ha^{-1} lime)	0.22 ± 0.035 ^{ab}	2.42 ± 0.09 ^{c}
A3B1C1 (18 t ha^{-1} EFB compost, 10% clay soil, 0.5 t ha^{-1} lime)	0.27 ± 0.010 ^{a}	3.07± 0.12 ^{a}
A3B1C2 (18 t ha^{-1} EFB compost, 10% clay soil, 1.0 t ha^{-1} lime)	0.21 ± 0.016 ^{ab}	2.53± 0.10 ^{bc}
A3B2C1 (18 t ha^{-1} EFB compost, 20% clay soil, 0.5 t ha^{-1} lime)	0.27 ± 0.024 ^{a}	2.55 ± 0.11 ^{cd}
A3B2C2 (18 t ha^{-1} EFB compost, 20% clay soil, 1.0 t ha^{-1} lime)	0.26 ± 0.049 ^{a}	3.03 ± 0.07 ^{a}

Note: Numbers followed by the same letter in the same column are not significantly different according to Tukey's test at the 5% level.

Table 5. Effect of EFB compost, clay soil, and lime interactions (AxBxC) on N and P nutrient concentration in maize grain

Treatment	N concentration (%)	P concentration (%)
A1B1C1 (6 t ha^{-1} EFB compost, 10% clay soil, 0.5 t ha^{-1} lime)	0.78 ± 0.02 ^{f}	0.23 ± 0.010 ^{e}
A1B1C2 (6 t ha^{-1} EFB compost, 10% clay soil, 1.0 t ha^{-1} lime)	1.08 ± 0.02 ^{e}	0.23± 0.005 ^{de}
A1B2C1 (6 t ha^{-1} EFB compost, 20% clay soil, 0.5 t ha^{-1} lime)	1.25 ± 0.02 ^{d}	0.26 ± 0.017 ^{cd}
A1B2C2 (6 t ha^{-1} EFB compost, 20% clay soil , 1.0 t ha^{-1} lime)	1.23 ± 0.01 ^{d}	0.27 ± 0.003 ^{c}
A2B1C1 (12 t ha^{-1} EFB compost, 10% clays oil, 0.5 t ha^{-1} lime)	1.30 ± 0.02 ^{cd}	0.28 ± 0.007 ^{c}

Treatment	N concentration (%)	P concentration (%)
A2B1C2 (12 t ha^{-1} EFB compost, 10% clay soil, 1.0 t ha^{-1} lime)	1.36 ± 0.01^{c}	0.35 ± 0.009^{a}
A2B2C1 (12 t ha^{-1} EFB compost, 20% clay soil, 0.5 t ha^{-1} lime)	1.36 ± 0.01^{c}	0.35 ± 0.012^{ab}
A2B2C2 (12 t ha^{-1} EFB compost, 20% clay soil, 1.0 t ha^{-1} lime)	1.59 ± 0.01^{b}	0.32 ± 0.012^{b}
A3B1C1 (18 t ha^{-1} EFB compost, 10% clay soil, 0.5 t ha^{-1} lime)	1.95 ± 0.05^{a}	0.35 ± 0.006^{ab}
A3B1C2 (18 t ha^{-1} EFB compost, 10% clay soil, 1.0 t ha^{-1} lime)	1.89 ± 0.07^{a}	0.35 ± 0.007^{a}
A3B2C1 (18 t ha^{-1} EFB compost, 20% clay soil, 0.5 t ha^{-1} lime)	1.91 ± 0.02^{a}	0.35 ± 0.015^{ab}
A3B2C2 (18 t ha^{-1} EFB compost, 20% clay soil, 1.0 t ha^{-1} lime)	1.94 ± 0.03^{a}	0.35 ± 0.009^{a}

Note: Numbers followed by the same letter in the same column are not significantly different according to Tukey's test at the 5% level.

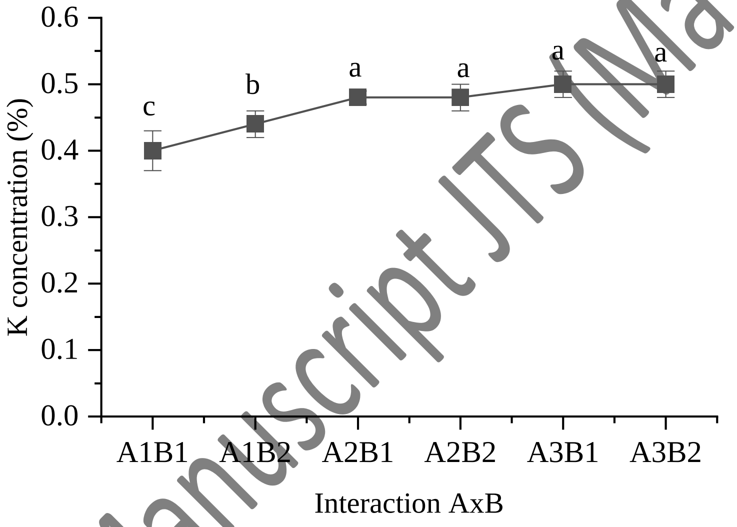

Figure 3. Effect of the EFB compost (A) x clay soil (B) interaction on K concentration in grain. Means above a bar of each sample, superscripted with different lowercase letters, are significantly different according to the Tukey test ($p<0.05$). Note : A1: 6 t ha^{-1}, A2: 12 t ha^{-1} and A3: 18 t ha^{-1} of EFB compost; B1: 10% and B2: 20% clay.

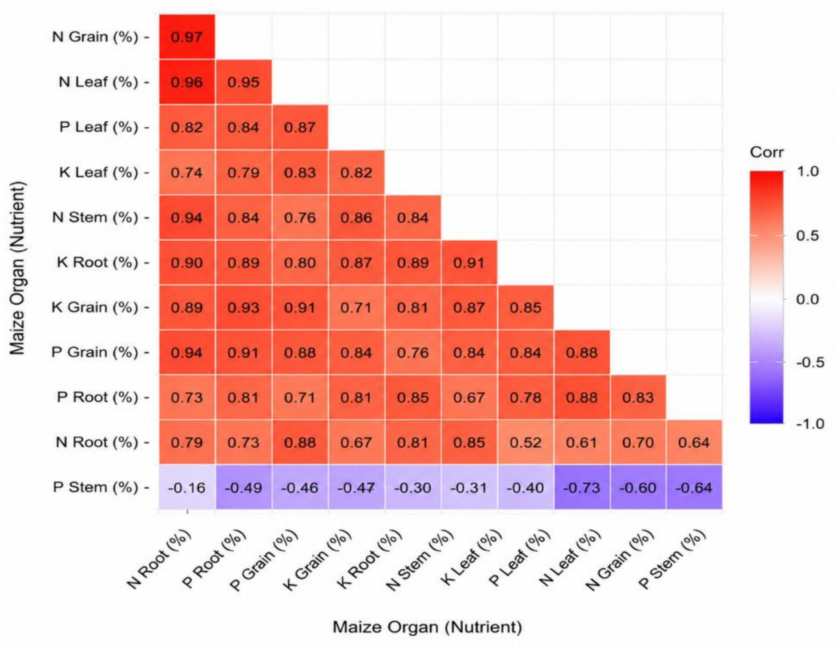

Figure 4. Heatmap of Pearson correlation coefficients (r) among N, P, and K concentrations in maize organs after harvest.