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# The Use of Bicomat and Tithonia Compost on Chemical Properties of Post-Mining Group-C Soil After Bok Choy Cultivation

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**Abstract**

In mining areas, improper soil management frequently leads to soil degradation and the depletion or loss of N, P, and K nutrients. Bicomat is known as an effective amendment for improving physical properties in the short term, whereas its effects on chemical properties generally become evident only in the long term. The purpose of this study was to determine the effect of combining Bicomat and *Tithonia* compost on the chemical properties of Group-C post-mining soil after planting mustard greens. This study was conducted from October to December 2024 at the Science Technopark of Tribhuwana Tunggadewi University, Malang City, at an altitude of approximately 450 meters above sea level. The study employed a non-factorial Randomized Block Design (RBD) with 8 treatments and 3 replications. The tested treatments consisted of: KT1 (Non-Mining Soil Control), KT2 (Group-C Mining Soil Control), T1P1B1 (Soil 1, 200 g fertilizer, 10 t ha$^{-1}$ Bicomat), T1P1B2 (Soil 1, 200 g fertilizer, 20 t ha$^{-1}$ Bicomat), T1P2B2 (Soil 1, 300 g fertilizer, 20 t ha$^{-1}$ Bicomat), T2P1B1 (Soil 2, 200 g fertilizer, 10 t ha$^{-1}$ Bicomat), T2P1B2 (Soil 2, 200 g fertilizer, 20 t ha$^{-1}$ Bicomat), and T2P2B2 (Soil 2, 300 g fertilizer, 20 t ha$^{-1}$ Bicomat). The results showed that the combination of Bicomat and compost had a significant effect on improving the chemical properties of the Group-C post-mining soil. The best results for nitrogen, phosphorus, and potassium were obtained from treatment T1P2B2, while treatments T1P1B1 and T2P1B1 yielded the best results for organic C.

## 1. Introduction

Soil functions as a medium for plant growth and as a source of nutrients. It provides water and various essential macro- and micronutrients (Khalil et al., 2015). The ability of the soil to provide nutrients is influenced by soil organic matter (SOM) and the soil moisture level (Bashir et al., 2021). Based on its organic matter content, soil is generally divided into two categories: mineral soil and organic/peat soil. Mineral soil originating from former mining sites has a rough and loose texture, with low air absorption capacity and minimal nutrient and organic matter content (Hartati and Sudarmadji, 2016).

According to Government Regulation No. 37 of 1960, mining materials in Indonesia are divided into three groups: Group A (strategic mining materials such as petroleum, natural gas, coal, nickel, and tin), Group B (vital mining materials such as copper, gold, and iron), and Group C (non-strategic and non-vital mining materials such as phosphate, gemstones, bentonite, quartz sand, granite, sand, limestone, and marble). Consequently, soils resulting from such extraction activities are generally unsuitable as plant growth media.

In mining areas, improper soil management frequently leads to soil degradation and the depletion or loss of N, P, and K nutrients (Peñaranda et al., 2023). As a result, mining activities alter the physical and chemical properties

of the soil; the pH becomes acidic, and organic carbon (organic-C) and N, P, and K nutrients decrease or disappear entirely (Amalia et al., 2021). Chemically, soil functions as a reservoir and supplier of nutrients (simple organic and inorganic compounds, and essential elements such as N, P, K, Ca, and Mg) (Delgado et al., 2017; Gerke, 2022). Biologically, it functions as a habitat for soil biota (Blume et al., 2016), which actively participates in the provision of nutrients.

Bicomat is a humic acid-coated biochar product that combines the benefits of both materials into a soil amendment, developed by Hamzah et al. (2021). Bicomat is known as an effective amendment for improving physical properties in the short term, whereas its effects on chemical properties generally become evident only in the long term (Hamzah et al., 2023). Compost is organic matter that has undergone decomposition by microorganisms, converting it into a form essential for plants (Sánchez et al., 2017). When applied together, these two materials can enhance soil fertility in both the short and long term. Previous research demonstrated that applying a Bicomat dose of 30 t $ha^{-1}$ increased the fresh weight of plants by 64.6% compared to the control treatment and reduced lead (Pb) uptake by plants by 40.04% to 87.28% (Hamzah et al., 2022). The inclusion of biochar in Bicomat aims to remediate heavy metals and improve physical properties, while compost contributes to the improvement of soil chemical properties (Hamzah et al., 2021).

Currently, research on Bicomat primarily focuses on its ability to reduce heavy metals and increase plant productivity; however, the impact of its application on soil chemical properties has not been widely studied. Evaluating soil chemical properties after the cultivation period is essential to determine the buffering capacity and nutrient stability provided by Bicomat and *Tithonia* compost. Bok choy (*Brassica rapa* L.) was utilized in this study to create a dynamic soil-plant interaction. By analyzing the soil after the planting season, this research provides insights into how the amendments sustain nutrient availability and chemical balance in post-mining soil, despite being subjected to intensive nutrient uptake by short-rotation crops. The purpose of this study was to determine the effect of the combination of Bicomat and *Tithonia* compost on the chemical properties of Group-C post-mining soil compared to agricultural soil.

## 2. Research Methods

### 2.1. Research Location

The research was conducted from October to December 2024 at the Science Technopark of Tribhuwana Tunggadewi University, Malang City at an elevation of ± 450 m above sea level. The materials used in this study included Post-mining Group-C soil in Lawang District, East Java, Indonesia, (coordinates: Lat -7.833473°, Long 112.681558°), and agricultural soil in Science Technopark, Tribhuwana Tunggadewi University, Malang City. Bicomat (Biochar-coated humate) was produced by the Faculty of Agriculture, Tribhuwana Tunggadewi University, Malang. *Tithonia diversifolia* compost was produced by the soil science and agronomy laboratory, Tribhuwana Tunggadewi University.

### 2.2. Research Implementation

The study used a non-factorial Randomized Block Design (RBD) with three replications and eight treatments, as described in Table 1.

Table 1. Description of research treatment

| No | Treatment | Description |
|---|---|---|
| 1 | KT 1 | Soil 1 Control (Agriculture soil no treatment) |
| 2 | KT 2 | Soil 2 Control (Post-mining C soil no treatment) |
| 3 | T1P1B1 | Soil 1 with Tithonia fertilizer 200 g+ Bicomat 10t $ha^{-1}$ |
| 4 | T1P1B2 | Soil 1 with Tithonia fertilizer 200 g+ Bicomat 20 t $ha^{-1}$ |
| 5 | T1P2B2 | Soil 1 with Tithonia fertilizer 300 g+ Bicomat 20 t $ha^{-1}$ |
| 6 | T2P1B1 | Soil 2 with Tithonia fertilizer 200 g+ Bicomat 10 t $ha^{-1}$ |
| 7 | T2P1B2 | Soil 2 with Tithonia fertilizer 200 g+ Bicomat 20 t $ha^{-1}$ |
| 8 | T2P2B2 | Soil 2 with Tithonia fertilizer 300 g+ Bicomat 20 t $ha^{-1}$ |

Soil samples from the former Group-C mining site and agricultural soil were collected at a depth of 10 cm. Furthermore, the soil was ground through a 2 mm sieve and weighed 4 kg each. Tithonia compost and Bicomat were added to the soil while stirring until homogeneous. The soil mixed with fertilizer and Bicomat was incubated for 7 days and its moisture was maintained. Green variety bok choy seeds were sown for 2 weeks before transplanting. At the time of transplanting, 150 kg $ha^{-1}$ N, 150 kg $ha^{-1}$ $P_2O_5$, and 100 kg $ha^{-1}$ $K_2O$ were applied as basic fertilizer. The chemical properties of the soil and the materials used are presented in Table 2.

2.3. Data Analysis

Observation of soil chemical properties was conducted after harvesting (4 weeks after planting/WAP) including: pH $H_2O$, total N, total P, total K, organic-C, and soil pH. Data were analyzed using analysis of variance (ANOVA). When significant differences among treatments were observed, Tukey's Honestly Significant Difference (HSD) test was performed at the 5% significance level.

Table 2. Characteristics of chemical properties in research materials

| Characteristic | Agricultural Soil | Post-mining C soil* | Titonia compost | Bicomat** |
|---|---|---|---|---|
| pH | 5.88 | 5.66 | 8.7 | 6.9 |
| Total N (%) | 0.8 | 0.18 | 1.47 | 0.68 |
| Total-P (ppm) | 660 | 0.2 | 4,400 | 7,000 |
| Total K (ppm) | 1,190 | 0.07 | 8,300 | 4,000 |
| Organic-C (%) | 2.56 | 0.75 | 24.4 | 7.69 |

Source: *Dea et al. 2025, **Hamzah et al. 2023

## 3. Results and Discussion

3.1. Soil pH

Based on the soil pH analysis after planting mustard greens, the treatment T1P2B2, (agricultural land with Tithonia fertilizer dose of 300g polybag$^{-1}$ and Bicomat 20 t ha$^{-1}$) showed the highest pH value of 7.30 followed by T1P1B1 and T1P1B2. KT2 treatment (Post-mining C soil without treatment) showed the lowest pH of 5.29 and was significantly different from the other treatments. This indicates that the combination of Tithonia and Bicomat organic fertilizers can effectively increase soil pH, especially in agricultural land (Figure 1).

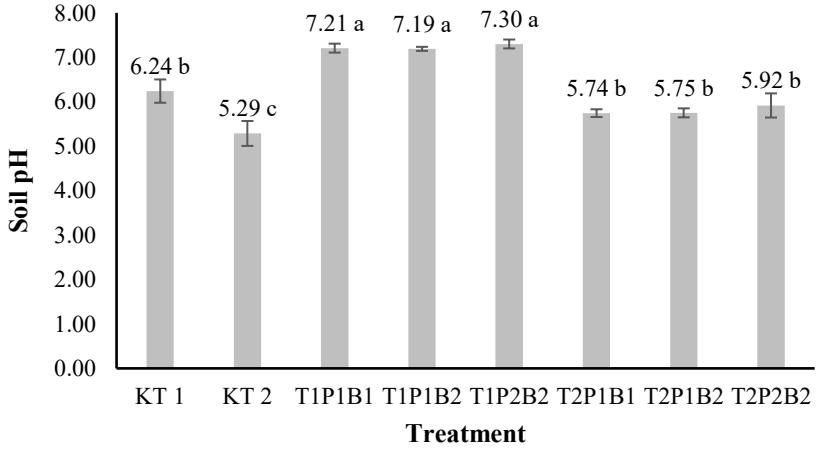


Figure 1. Mean pH in agricultural soil and post-mining C soil after bok choy planting. Bars with the same letter are not significantly different (Tukey HSD, $\alpha = 0.05$).

This increase in pH can be explained by the characteristics of the organic materials used. Tithonia compost has a basic pH (8.7), high nitrogen content (1.47%) and potassium (8,300 ppm), and organic-C of 24.4%, indicating a very good amelioration capacity for acidic soils. Bicomat, with a pH of 6.9 and high P and K content, also contributes to neutralizing soil acidity and improving chemical fertility. The combination of these two materials is very effective on agricultural soils that were initially acidic (pH 5.88), causing the pH to increase to near neutral. The application of biochar improves soil pore structure and, consequently, agricultural productivity, emphasizing its role in nutrient management (An et al., 2022). The effects of humic acids, which are essential components of organic matter, enhance nutrient absorption in plants and buffer soil pH, thereby improving the structure and chemical fertility of soils and crop yields, demonstrating beneficial outcomes in sandy soils (Zhou et al., 2019). The use of biochar as organic material has also been shown to increase soil pH due to the increased concentration of alkali metals ($Ca^{2+}$, $Mg^{2+}$, and $K^{+}$) in biochar (Yunanda et al., 2022).

On the other hand, in post-mining soil C which has a high initial pH (5.66), the response to organic matter treatment is not as strong as agricultural soil. Treatments such as T2P1B1, T2P1B2, and T2P2B2 only increase the pH between 5.74-5.92 and are statistically in the same group as KT 1 (agricultural soil without treatment). This

could be caused by the very low organic-C content of ex-mining soil (0.75%), as well as the soil structure which is likely damaged, so that the storage capacity and reactivity to organic input are limited. The exposure and oxidation of sulfide-bearing minerals during mining activities alongside the intensive leaching of cations such as $K^+$, $Ca^{2+}$ and $Mg^{2+}$ due to absence of vegetative cover is also the reason why the soil pH in post-mining soil is low. Nutrient availability in reclaimed soils from mining is generally low, limiting the response to organic matter applications. In contrast, agricultural soils that receive continuous nutrient input show greater microbial activity and enhanced mineralization of organic compounds, leading to more substantial improvements in soil fertility (Liu et al., 2023; Yang et al., 2020).

3.2. Organic-C

The analysis showed that the levels of soil organic-C after planting mustard greens were significantly different between treatments due to the addition of Tithonia compost and Bicomat (Figure 2). The T1P1B1 treatment produced the highest organic-C of 8.31%, indicating the synergistic effectiveness between the relatively fertile agricultural soil conditions and the addition of organic fertilizers rich in organic matter. Agricultural soil has an initial organic-C content of 2.56%, much higher than post-mining soil (0.75%, Table 2) so that it can respond to the treatment more optimally. The presence of organic matter, such as from biochar, can enhance microbial enzyme activities, which in turn facilitates the transformation of nutrients and impacts overall soil fertility (Liu et al., 2022).

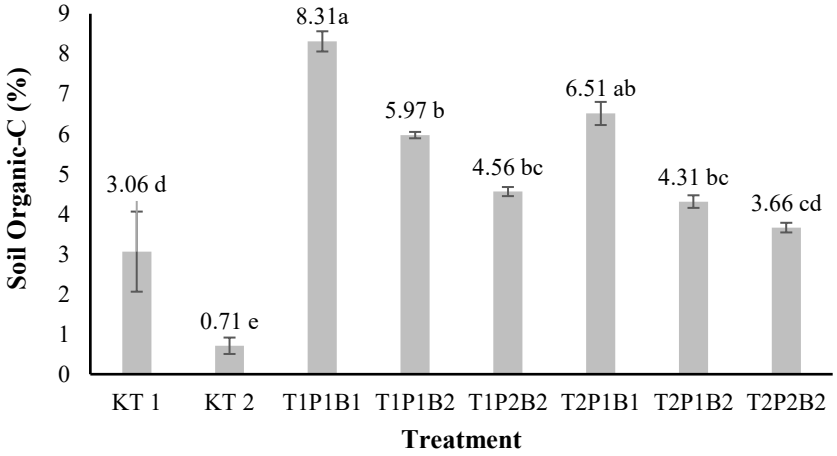


Figure 2. Mean organic-C (%) in agricultural soil and post-mining C soil after bok choy planting. Bars with the same letter are not significantly different (Tukey HSD, $\alpha = 0.05$).

Both organic materials used, Tithonia compost and Bicomat (biochar coated humate), have very high organic content, 24.4% and 7.69% respectively, as well as large macronutrient content. Tithonia is very superior in nitrogen content (1.47%) and potassium (8,300 ppm). While Bicomat is superior in phosphorus content (7,000 ppm). This combination not only enriches soil nutrients but also accelerates the formation of soil organic matter through the activity of microorganisms and the decomposition of fresh and stable materials. The addition of biochar to soil systems improved nitrogen retention and facilitated the transformation of organic matter into stable forms (Gao et al., 2023; Yu et al., 2024). This transformation occurs as microorganisms break down organic materials, leading to increased microbial biomass and activity, which subsequently contributes to the accumulation of SOM. Additionally, Liu et al. (2022) found that the incorporation of organic amendments, including biochar and compost, can significantly enhance SOM accumulation by providing a continuous source of organic inputs that promote microbial action.

Treatments T1P1B2 and T2P1B1 showed high levels of organic-C (5.97% and 6.51%) indicating that increasing the dose of Bicomat or the use of post-mining C soil has not been able to exceed the effectiveness of T1P1B1. Even increasing the dose of Tithonia to 300 g polybag$^{-1}$ (as in treatments T1P2B2 and T2P2B2) did not always increase the levels of organic-C significantly. This can be explained by the possibility of an imbalance in the C/N ratio that inhibits mineralization. When the C/N ratio is elevated, microbes may face a nitrogen deficit, leading to reduced activity and slower decomposition rates, which can inhibit nitrogen mineralization. Research conducted by Yu et al. (2024) demonstrates that C/N ratio imbalances can significantly affect soil organic matter stability and nitrogen availability, notably with the use of maize straw improving nitrogen availability in soils. Yang et al. (2020) reported that nitrogen addition affects microbial diversity but noted the potential for less effective soil carbon-nitrogen interactions if the C/N ratio is unbalanced.

Interestingly, the control treatment in agricultural soil (KT1) showed a slight increase in organic-C content after the planting period. This phenomenon is likely due to root exudates secreted by the bok choy plants and the presence of decaying fin roots remaining in the soil after harvest. Furthermore, regular watering during the experiment may have stimulated microbial activity, that contributed to a temporary increase in microbial biomass carbon, even the absence of external organic amendments. The results of the meta-analysis by Xu et al. (2020) showed that microbial biomass carbon (MBC) increased by 18% under conditions of increased rainfall and decreased by 17% under drought conditions. The drying-wetting cycles increased dissolved organic carbon in the soil by 12.3% (Dong et al., 2021).

Meanwhile, the control treatment, especially KT2 (post-mining C soil without treatment) treatment had the lowest organic-C content (0.71%), indicating extremely low organic matter and nutrients status. This is in line with the characteristics of the initial ex-mining soil which has a pH of 5.66, total-N 0.18% and very low P and K content (0.2 ppm and 0.7 ppm), which causes low microbial activity and slow formation of natural organic matter. Specifically, research indicates that reclaimed mining soils frequently experience compaction and reduced organic matter content, negatively impacting microbial populations and activity (Zheng et al., 2022). For instance, emphasized that mining-affected soils generally display poor nutrient profiles and acidic conditions, resulting in a diminished capacity to support microbial life (Guéablé et al., 2022). Furthermore, studies have highlighted that organic matter accumulation is critical for enhancing microbial diversity and overall soil fertility, which tends to be significantly lacking in mining areas (Li et al., 2024).

### 3.3. Total-N

The analysis showed that there was a significant difference in the total-N content of the soil after planting mustard greens due to the addition of Bicomat and Tithonia fertilizer (Figure 3). The T1P2B2 (1.45%) and T2P2B2 (1.47%) treatments showed the highest total-N values compared to other treatments. This increase indicates that the addition of compost and bioactivator doses simultaneously can significantly increase soil nitrogen availability.

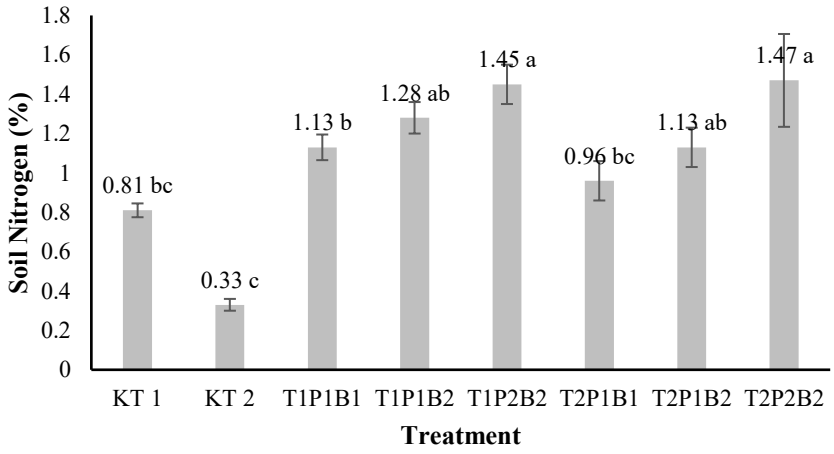


Figure 3. Mean total-N (%) in agricultural soil and post-mining C soil after bok choy planting. Bars with the same letter are not significantly different (Tukey HSD, $\alpha = 0.05$).

Post-mining C soil without treatment (KT2) had very low total-N content (0.18%) and low organic-C content (0.75%), making it unable to provide enough nitrogen for plants without additional treatment. On the contrary, treatment with doses of Tithonia compost and Bicomat showed an increase. Tithonia compost contains high levels of organic N and C content as a source of quickly available N. The combination of biochar and humate in Bicomat helps the mineralization of organic matter and the release of N. Research by Gao et al. (2023) indicates that the application of organic amendments, including compost and biochar, significantly increases soil nutrient levels, thereby improving overall soil productivity and carbon sequestration capacities. The effect of organic matter on nitrogen retention and enhanced nutrient cycling has also been demonstrated, highlighting how organic amendments can improve soil structure and functionality (Tian et al., 2024). Furthermore, the incorporation of organic materials into soils not only elevates nutrient availability but also enhances microbial activity, which is essential for nutrient mineralization and overall soil health (An et al., 2023).

The T1P1B1, T1P1B2, and T2P1B2 treatments showed a significant increase compared to the control treatment but were not as optimal as the highest dose combination. Meanwhile, the control treatments (KT1 and KT2) showed low total-N values, proving that without organic input, both agricultural and post-mining soils have limited ability to provide nitrogen for plants. Additionally, Risch et al. (2019) suggest that increased organic matter in soil

significantly correlates with higher rates of nitrogen mineralization, making it an important factor in soil fertility under varying climatic conditions. Overall, these results support that Tithonia and Bicomat (biochar coated humate) combination are synergistically able to improve soil nitrogen nutrient status, especially on post-mining C soil and have a great potential as a soil fertility restoration strategy.

3.4. Total-P

The analysis of total-P in the soil after mustard green planting showed a significant effect due to the addition of a combination of Tithonia compost and Bicomat (Figure 4). The T1P2B2 treatment showed the highest total-P value (131 mg 100 $g^{-1}$), followed by the T2P1B1 treatment (125 mg 100 $g^{-1}$) and T2P1B2 treatment (117 mg 100 $g^{-1}$), which were applied to post-mining C soil with a lower dose of Tithonia or Bicomat fertilizer. The control treatment KT2 (1 mg 100 $g^{-1}$) and T2P2B2 (19 mg 100 $g^{-1}$), which originated from post-mining C soil without or with less effective treatment, had much lower values.

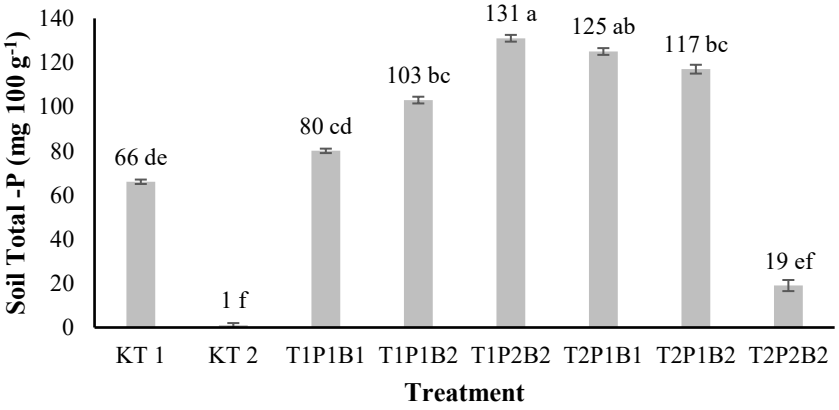


Figure 4. Mean total-P (mg 100 $g^{-1}$) in agricultural soil and post-mining C soil after bok choy planting. Bars with the same letter are not significantly different (Tukey HSD, $\alpha = 0.05$).

The significant differences between treatments indicate that the combination of soil type, organic fertilizer dosage (Tithonia and Bicomat—biochar-coated humate) greatly affects phosphorus availability in the soil. Organic fertilizers have a direct impact on nutrient dynamics in soil ecosystems, ultimately affecting the availability of phosphorus (Ge et al., 2021). Organic fertilizers can enhance soil nutrient availability, including phosphorus, through improved soil aggregation and enhanced microbial activity (Guan et al., 2018, Liu et al., 2023). Furthermore, the interaction between these organic amendments facilitates nutrient cycling processes that lead to the increased availability of essential nutrients like phosphorus (Guan et al., 2018). The initial characteristics of the materials show that Tithonia contains very high phosphorus levels (4,400 ppm), which can enhance soil microbial activity and mobilize bound phosphorus. Meanwhile, Bicomat plays a role in increasing phosphorus availability in soils with low pH or minimal organic matter. Humic substances play a significant role in facilitating the movement and transformation of phosphorus in the soil, thereby enhancing the availability of phosphate for plants (Yang et al., 2021). Biochar can be incorporated into soil aggregates to enhance their structural stability, which helps protect granular phosphorus and supports the long-term preservation of phosphorus in the soil (Debicka et al., 2023).

Agricultural soil (Soil 1) had a higher organic carbon content (2.56%) and total-P (660 ppm) compared to post-mining C soil (Soil 2), which is highly nutrient-deficient (total-P only 0.2 ppm and organic-C 0.75%). Therefore, the response of post-mining C soil to treatments strongly depends on the quality and quantity of ameliorants applied. Studies have demonstrated that the addition of specific ameliorants, such as organic fertilizers or biochar, significantly alters soil properties, promoting both nutrient availability and microbial activity. For instance, Liu et al. (2023) indicated that treating soil with various fertilizers, including phosphorus, increases soil organic matter content and influences the chemical composition and cation exchange capacity, which are key in determining soil health and its response to amendments. In similar research, Guéablé et al. (2022) emphasized that the effectiveness of certain amendments in rehabilitating mining soils largely depends on their chemical nature and the application method, pointing towards the important role played by quality and quantity in achieving desired outcomes in soil restoration.

Although T2P1B1 and T2P1B2 showed a significant increase in total-P, the T2P2B2 treatment (a high-dose combination of Tithonia + Bicomat on Soil 2) was ineffective. This may be due to disproportionate C/N ratio or microbial saturation, which commonly occurs in soils with low organic matter content such as post-mining C soil.

These conditions can limit microbial activity and nutrient mineralization, thus reducing phosphorus availability despite high input levels. Overall, the best treatment for increasing soil total-P was the high-dose combination of Tithonia and Bicomat (T1P2B2). However, on post-mining C soil a more moderate treatment such as T2P1B1 produced better results. The addition of organic matter from agricultural residues may not always reduce phosphorus sorption, but it can interfere with phosphorus fixation and potentially affect its mobility and availability in the soil (Debicka et al., 2023).

3.5. Total-K

The application of a combination of Tithonia compost and Bicomat significantly affected the total K content of the soil after planting mustard greens (Figure 5). The highest total-K value was obtained in the T1P2B2 treatment (83,5 mg 100 $g^{-1}$), an agricultural land given a combination of 300 g Tithonia compost and 20 t $ha^{-1}$ Bicomat. The treatment with the lowest value was in the control post-mining C soil (KT2; 8,7 mg 100 $g^{-1}$).

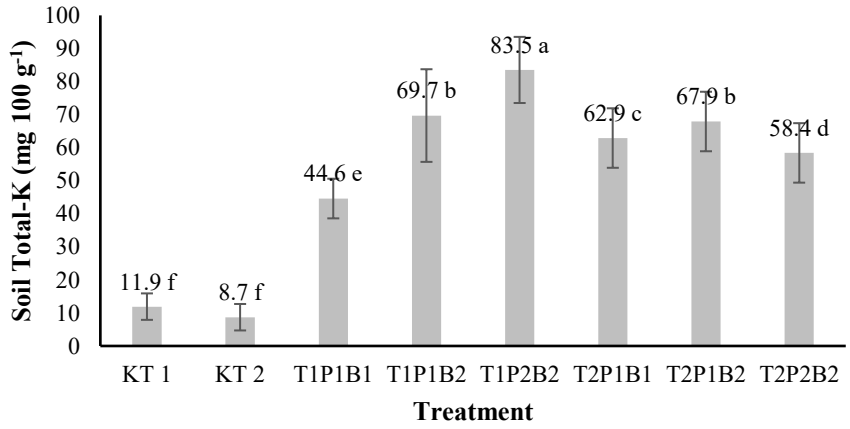


Figure 5. Mean total-K (mg 100 $g^{-1}$) in agricultural soil and post-mining C soil after bok choy planting. Bars with the same letter are not significantly different (Tukey HSD, $\alpha = 0.05$).

In general, the application of Tithonia compost and Bicomat fertilizer increased the total-K content in both types of soil. However, the greatest increase occurred in agricultural soil (Soil 1/KT 1 treatment) compared to post-mining C soil (Soil 2/KT 2 treatment). This indicates that the soil response to treatment depends on the initial soil conditions. Agricultural soil has relatively more fertile initial properties compared to post-mining C soil, indicated by higher organic-C, total N, P, and K content. These different nutrient values will affect nutrient availability, cation exchange capacity and soil structure (related to aggregation). Therefore, the increase in total-K is more optimal in soil that already has better organic matter content. The research results of Sae-Tun (2024) explained that the low content of organic matter (0.2%) and dissolved nutrients limited the improvement response, so that even in applications, increases in biomass and nutrients (including P and K) remained limited. Organic amelioration improves the physical, chemical and biological properties of soil, especially at 0–20cm - to levels approaching natural soil conditions though the improvements in these properties vary according to initial soil conditions, and their effectiveness decreases at depths >20cm (Chen et al., 2023).

Tithonia compost has a very high K content (8,300 ppm) followed by Bicomat (4,000 ppm). The use of higher doses of both (especially the Tithonia dose composition of 300 g $polybag^{-1}$ + Bicomat 20 t $ha^{-1}$) clearly provides an abundant source of potassium, thus having a direct impact on increasing soil total-K. Variations in organic matter input due to different types of ameliorants enabled better degradation and mineralization processes that are vital for restoring post-mining landscapes (Goossens et al., 2022). Turmudi et al. (2019) stated that the application of compost at a dose of 20 t $ha^{-1}$ increased the availability of K and other nutrients significantly enough to stimulate plant growth.

However, in post-mining C soil, even though it was given the same treatment (T2P2B2 treatment), the total-K value achieved was still lower (58,4 mg 100 $g^{-1}$) compared to agricultural soil. This could be caused by damaged soil structure, non-ideal pH, low microorganism activity. The combination of all of them affects the retention and release of nutrients in the soil. Moreover, the organic-C value of the soil is very low and inhibits the soil's ability to store and release nutrients. Post-mining soils generally show low microbial diversity and biomass due to extreme condition such as low pH and contaminants-which impact soil ecosystem function (Wang et al., 2025).

3.6. Synergistic Interaction of Amendments on Soil Chemical Stability

The improvement in the chemical properties of post-mining soil in this study was driven by the synergistic relationship between Bicomat and Tithonia compost. Bicomat, through its humic acid content and biochar pore structure, plays a role in increasing soil pH and cation exchange capacity (CEC), which creates an ideal microenvironment for the nitrogen mineralization process from Tithonia compost. The combustion process with temperatures ranging from 300°C to 700°C makes the resulting biochar product retain most of the carbon (Patel and Panwar, 2023; Ali et al., 2025). The cation exchange capacity (CEC) of biochar decreases with increasing pyrolysis temperature due to the loss of negatively charged functional groups and low pyrolysis temperature (300–450 °C). On the other hand, biochar production with high CEC can absorb $NH_4^+$, among other things, and reduce N solubilization (Seleiman et al., 2020; Alkharabsheh et al., 2021). Humic acid added as an enrichment fills the pores of the biochar and acts as a nutrient binder. This makes the biochar-humic acid (Bicomat) combination a slow-release fertilizer, increasing nutrient utilization efficiency. The mechanisms involved are the porous structure of biochar that absorbs $Na^+$ ions and the humic acid functional groups that release $H^+$ to lower the pH, which collectively increases salt solubilization and nutrient retention (Wang et al., 2025).

The pattern of increase in total N in this study does not always run linearly with the increase in organic-C. This is due to microbial activity that uses C as an energy source (released as $CO_2$), while the remaining nitrogen from Tithonia decomposition is trapped in the micropores of biochar and bound by the carboxyl and hydroxyl functional groups of humic acid. Biochar incorporation significantly increases soil carbon and nitrogen stocks in the short term, but due to the potential for carbon loss due to increased microbial activity, biochar placement methods and residual nitrogen effects must be carefully considered in land management practices (Huang et al., 2022). The decomposition characteristics of *T. diversifolia* biomass are highly favorable for sustained N release, with studies reporting C:N ratios between 12:1 and 16:1, which facilitates rapid mineralization and subsequent N availability to plants. This synergy explains why the T2P2B2 treatment on post-mining soil produced the highest total-N value (1.47%) naturally occurring with the lowest initial chemical properties. Marginal soils that are 'empty' have unsaturated cation exchange sites, making them very responsive to the nutrient trapping provided by the combination.

The relationship between these chemical parameters explains the stability of post-harvest bok choy soil. Despite intensive nutrient uptake by plants, nutrient retention in the treated soil remained significantly maintained. Even in the control soil (KT2), there was a slight increase in N compared to the initial soil levels before the study. This phenomenon is likely triggered by the priming effect of plant root exudates, which stimulate the activity of non-symbiotic nitrogen-fixing microbes in the rhizosphere to convert residual organic N into available forms. Organic carbon compounds in root exudates serve as an energy source for nitrifying bacteria (e.g., *Variovorax* and *Sporocytophaga*) and denitrifying bacteria (e.g., *Dechloromonas*), thereby modulating soil nitrification and denitrification rates and further altering N loss pathways and utilization efficiency (Wang et al., 2021; Guo et al., 2024; Li et al., 2025).

However, this efficiency is much lower than that of the Bicomat-treated soil, which minimizes nutrient leaching in the porous post-mining soil structure. Thus, this post-planting chemical analysis demonstrates that the combination of Bicomat and Tithonia not only provides an immediate nutrient supply but also creates a buffering system that maintains the integrity of the soil's chemical fertility for the sustainability of marginal land. Nutrient leaching can be inhibited by increasing water retention. Furthermore, the inhibitory effect of biochar on organic N mineralization, through physical protection of organic matter, can reduce the amount of nutrients released and thus further leaching (Jien et al., 2018; Kuo et al., 2020).

## 4. Conclusion

The combination of Tithonia fertilizer and Bicomat has been proven to significantly improve the chemical quality of the soil, including pH, organic-C, total-N, total-P, and total-K, especially on agricultural soil compared to post-mining C soil. The T1P2B2 treatment showed the best results in pH, total-N, total-P, total-K parameter on agricultural soil, treatment T1P1B1 showed the best results in organic-C. T2P1B1 treatment showed the best results in pH, total-N, and total-K parameter on post-mining C soil. These findings offer a scalable strategy for restoring soil fertility in degraded post-mining areas and provide a sustainable alternative for enhancing long-term nutrient retention in agricultural systems through organic-based amendments.

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