# PHOSPHORUS AND POTASSIUM AVAILABILITY IN SOIL AMELIORATED BY DIFFERENT QUALITY ORGANIC MATERIALS ENRICHED WITH HUMIC SUBSTANCES

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## ABSTRACT

The residues of palm oil production and understorey biomass have potential to be used as ameliorants to release soil accumulated P from prolonged intensive inorganic fertilization and increase potassium (K) availability. However, low-quality OM that is widely available in the field has high C:N ratio and contains recalcitrant materials, making it difficult to decompose and reduce nutrient availability. Humic substances (HS) which are believed to increase nutrient availability were chosen as additional material to enhance the amelioration benefits of OM. Two complete randomized design laboratory incubation (60 days, at room temperature, and 60±10% field capacity) with three factors: Soil (P accumulated/ oil palm soil, forest soil); OM (without OM, ferns, empty fruit bunches/ EFB, fronds); HS (without HS, with HS), and with the addition of inorganic fertilizer as basic fertilizer was done to observe the effect of those combination on soil respiration and soil readily available P and K. The results showed that soil respiration rate were higher in soil with OM and HS addition compared to un-ameliorated soil. The general trend of soil respiration from rapid to slow was in order of ferns, EFB, and fronds. A combination of OM and HS causes the release of insoluble P in oil palm soil. Immobilization occurs in the initial incubation period, but after day 7, readily available P increased, indicating that OM and HS affect positively on available P. Meanwhile, readily available K increased immediately after OM and HS addition and did not show any immobilization process. OM with HS treatment shows lower available K compared to OM without HS addition, however, the values is still much higher than control, means K mineralization from added OM still occur.

Keywords: accumulated P, empty fruit bunches, fern, frond, incubation experiment

## INTRODUCTION

Macro nutrients (e.g. N, P, K) are essential for the growth and enhancement of oil palms, but their availability in the soil is often low. To meet the nutritional needs of oil palms, inorganic fertilizers are generally given intensively. The fertilization budget in oil palm plantation may take up to 24% of production cost or range from 40-60% of the total maintenance costs (Budiargo *et al.,* 2015). However, according to Ginting (2020) the level of fertilization efficiency in oil palm plantations is usually low.

Prolonged use of inorganic Phosphorus (P) fertilizer leads to accumulation of P residues in soil which are unavailable for plant uptake, especially in the disk zone where fertilizers applied. According to Archana *et al.,* (2017) the utilization of P fertilizer by plants is generally low due to soil adsorption and fixation reactions which cause large accumulations of P in soil over many years. According to Hartono *et al.,* (2015) and Muindi (2019) Insoluble P in soil caused by chemical fixation and adsorption where soluble phosphorus forms insoluble compounds with $Fe^{3+}$ and $Al^{3+}$ in acidic soil and insoluble compounds with $Ca^{2+}$ in alkaline soil.

The use of inorganic fertilizer has been proven to increase oil palm growth and yield by providing readily available nutrient. However, land management that relying solely on inorganic fertilizer for a long time can lead to significant environmental problem and soil health degradation that often results in lower yields over the long term. Amelioration of OM is less desirable in cultivation activities because of the assumption that OM need to be applied in very large quantities to fulfill plant nutrients requirements. To mitigate these issues, integrated nutrient management, which combine inorganic fertilizers with organic matter amelioration can be applied to increase nutrients availability including by releasing accumulated P in the soil in order to sustain yields while improving soil health and reducing environmental impact.

Amelioration can be done by utilizing palm oil processing waste (e.g., empty fruit bunches/ EFB, and fronds) and understorey biomass (e.g., fern) that can easily be found in plantation areas especially plantation that equipped with palm oil processing facilities, one of which is PTPN III Cikasungka. Application of EFB as mulch or incorporated into the soil increased soil organic matter and nutrients (Anyaoha *et al*., 2018; Moradi *et al*., 2012). EFB contains macro- and micro-nutrients, in which potassium (K) has the highest proportion compared to others and causes an increase in exchangeable K (Ginting, 2020; Moradi *et al.,* 2012). The research of palm fronds effect as ameliorant to soil nutrient availability is still quite rare compared to other palm oil wastes such as EFB and palm oil mill effluent (POME), even though fronds also contain nutrients that have the potential to be released into the soil. Ferns, especially N. *biserrata* that are often used as a cover crop under palm oil plants are easily decompose substrate which released available nutrients for plants (Yahya *et al.,* 2022). The potassium (K) content in palm oil processing waste and fern is quite high, which has the potential to

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increase soil available K through its decomposition and mineralization processes.

Crop residues that are returned to the soil shows enormous potential in nutrient cycling and plays a valuable role in improving soil fertility and increasing crop productivity. However, the effects of OM amelioration on soil fertility is influenced by various factors, including soil characteristics and the quantity and quality (C:N rasio, recalcitrant content, and particle size) of OM added (Liang *et al*. 2017). The benefit of applying OM is generally found in good quality OM, but often plant residues are stems, roots and other parts that contain recalcitrant material and a high C:N ratio making it difficult to decompose, this will reduce nutrient availability through the immobilization process. Amelioration of OM has been shown to increase the availability of soil P and K but requires to be applied in a large quantity. So, it is necessary to find alternative materials that are efficient, available in large quantities, easy to apply and environmentally friendly to increase the availability of P and K for plants from accumulated residues. Humic substances are one of the potential ingredients. Amelioration with humic substances is known to increase soil organic C content, total N, micronutrients, and soil P and K availability. Applying humic substances to soils containing high concentrations of aluminum and iron oxides can reduce P absorption (Hartono *et al*., 2013; Hanudin *et al*., 2014). Thus, in this study, different quality organic materials were enriched with humic substances (HS) and inorganic fertilizer to observe wheter this combination can increase the benefit of OM amelioration. The objective of this research is to determine the effect of adding organic matter with different qualities (ferns, empty fruit bunches, and fronds) with and without humic substances addition on soil respiration and readily available P and K.

## MATERIALS AND METHOD

The research was conducted from November 2022 to May 2023. Soil and OM were taken from PT. Perkebunan Nusantara III, Oil Palm Cikasungka Plantation, Bogor. Incubation experiments and analysis were carried out at the Laboratory of the Department of Soil Science and Land Resources, Faculty of Agriculture, IPB University.

This research uses a complete randomized design with three factors. Factor I: Soil type i.e., forest soil (T0) and oil palm soil (T1); Factor II: Organic matter i.e., without OM (B0), fern (B1), empty fruit bunches/ EFB (B2), frond (B3); Factor III: Humic substances i.e., without HS (H0) and with HS (H1). Combinations of these factors resulting in 16 treatments: (1) T0B0H0, (2) T0B1H0, (3) T0B2H0, (4) T0B3H0, (5) T0B0H1, (6) T0B1H1, (7) T0B2H1, (8) T0B3H1, (9) T1B0H0, (10) T1B1H0, (11) T1B2H0, (12) T1B3H0, (13) T1B0H1, (14) T1B1H1, (15) T1B2H1, (16) T1B3H1. Each treatment was done in triplicate, so there were 48 experimental units in total. The amount of each OM and HS added in treatment to the soil as at a rate of 20 t ha$^{-}$ and 20 kg ha$^{-}$ respectively. In addition, all treatments were enriched with inorganic fertilizer in the form of NPK 13-6-27 (75% of recommended dosage).

### Materials and Tools

The materials used in this study included: P accumulated soil from PTPN III Cikasungka and forest soil from Cigudeg, Bogor, OM (fern, EFB, and frond) from PTPN III Cikasungka, humic materials (commercial: Andersons HumaPro), inorganic fertilizers (NPK 13 -6-27), and chemicals for laboratory analysis. The tools used in this study consisted of incubation jars and laboratory equipment such as titration instruments, spectrophotometers, flame photometers, centrifuges, pH meters, and glassware.

### Method

**Soil and OM sampling, and preliminary analysis**

Soil samples (0-10 cm) purposively taken from two predetermined locations brought to the laboratory. Soil divided into two sub-samples such as 1) fresh soil, passed through 5 mm sieve used for incubation experiments, and 2) air-dried soil used for preliminary analysis. OM was dried at 60ºC for 48 hours then grinded until passes 2 mm sieve. The initial characteristics of soil determined in preliminary analysis such as soil texture, pH, exchangeable-Al, total N, organic C, potential P and K, available P and K. Initial OM characteristics observed in preliminary analysis namely: water content, organic C, total N, total P and K, C:N, C:P, C:K ratio.

**Pre-incubation**

Prior to incubation, 50 g of soil was placed in 200 ml incubation jar for soil respiration experiment and 1000 g of soil was placed in 1500 ml incubation jar for the P and K availability experiment, then incubated without treatment (pre-incubation) at 28-30ºC and 50±10 field capacity for seven days. The purpose of pre-incubation was to anticipate spikes in respiration by microorganisms due to increased soil moisture (Shi and Marschener 2017).

**Laboratory incubation experiment**

Pre-incubated soil was then added with OM and HS according to predetermined treatments to observe soil respiration and the content of readily available-P and K. In addition, all treatments were enriched with inorganic fertilizer in the form of NPK 13-6-27 as basic fertilizer. The incubations were carried out for 60 days at room temperature and the soil moisture was maintained at 60±10% field capacity using Gravimetric (weighing) method. First by calculating the target weight (jar with soil inside added with OM, HS, and basic fertilizer + water at 60% FC) at day 1 of incubation, then periodically weighing each jar and adding distilled water to replace any mass lost through evaporation.

For measuring soil respiration, two bottles each filled with 10 ml distilled water and 10 ml of 0.2 KOH as trap solution placed in each jar. Respired C-$CO_2$ was determined by titrating the 0.2N KOH from each jar with 0.2N HCl using phenolphthalein and methyl orange as indicators (Shahbaz *et al*., 2017). Measurement was taken on day 1, 10, 20, 30, 40, 50, and 60 after incubation started. To correct $CO_2$ contamination from atmosphere during operational process, a blank (empty jar containing only KOH) was analyzed simultaneously, and the value then subtracted from each treatment. On each measurement day, the bottle contains KOH in each jar taken for measurement was replaced with a new one. The cumulative values of the KOH titration during incubation were calculated by adding the respiration rate over time.

Another incubation set was used to measure the content of readily available-P and K. Readily available P and K determined using soil taken from incubation jar on day 0, 3, 7, 14, 28, 45, 60 after incubation started. The measurement of available P was carried out according to Chang and Jackson (1957) which was modified by Eviati and Sulaeman (2009), namely fraction I ($NH_4Cl$-P) or available P. $NH_4Cl$ extracted P solution added with phosphate color reagent and measured with spectrophotometer (λ: 889 nm). Available K determined with the same extract without color reagent using flame photometer.

**Data analysis**

Two-way ANOVA was used to determine the effect of OM and HS addition, and soil type on OM decomposition as well as available P and K. significant factors then further tested with Tukey to test the difference in mean values between treatments. Differences with $P<0.05$ were considered statistically significant.

## RESULT AND DISCUSSION

Initial soil characteristics determined in preliminary analysis are shown in Table 1. Both soils used in this experiment have the same texture (clay). Based on the evaluation criteria of soil analysis results (Eviati and Sulaeman, 2009) soil reaction of oil palm soil is neutral while forest soil is acidic. This is due to soil management practice in oil palm plantation that use lime to reduce soil acidity. Based on Cikasungka plantation fertilization data, in 2023 the dose of lime given was 0.99 kg of dolomite per palm per year. Exchangeable-Al is aluminum in the form of $Al^{3+}$ which if available in large quantity in soil can increase soil acidity by hydrolysis reaction. Forest soil has a higher exchangeable-Al compared to oil palm soil whose value is not measurable (0 $cmol^+ kg^{-1}$). At soil with pH higher than 5.5, $Al^{3+}$ is relatively undetectable, which means that the concentration is very low (Hartono, 2022).

Organic C and potential K content in forest soil is higher than that of oil palm soil. This result represents higher soil organic matter (SOM) in the forest soil. Forest soils usually have higher organic matter than agricultural soil with the values approximately 1-5% organic matter by weight (Osman, 2013). Available K in forest soil is also higher than that of oil palm soil, whereas total N and potential P were lower in the forest soil. This might be due to intensive inorganic fertilizer used in the oil palm plantation. Despite having a very high potential P (162.29 mg $P_2O_5$ 100 $g^{-1}$) compared to the forest soil (23.49 mg $P_2O_5$ 100 $g^{-1}$), readily available P values in both soils are very similar. This result suggested that there was an accumulation of P in unavailable form in oil palm soil from prolonged inorganic fertilization, known as legacy P. Inorganic P from fertilizer applied to soil become unavailable for plants due to it transforms to insoluble form by many reactions, i.e., adsorption onto Fe/Al oxyhydroxide and clay minerals, reaction with Al, Fe, and Ca ions, and complex reactions with soil organic substance (Chen *et al.*, 2017).

Table 1 Initial soil characteristics

| Parameters | Analytical Method | Oil Palm Soil | Forest Soil |
|---|---|---|---|
| Texture | Pipette method | Clay | Clay |
| Sand (%) | | 5.4 | 5.8 |
| Clay (%) | | 81.0 | 56.6 |
| Silt (%) | | 13.5 | 37.6 |
| Soil pH | $H_2O$ (1:5), pH meter | 7.37 ± 0.01 | 5.14 ± 0.01 |
| Exchangeable-Al ($cmol^+ kg^{-1}$) | Extraction of 1N KCl (titration) | nm* | 6.71 ± 0.56 |
| Total N (%) | Kjeldahl | 0.21 ± 0.02 | 0.11 ± 0.01 |
| Organic C (%) | Walkley and Black | 1.75 ± 0.05 | 2.76 ± 0.21 |
| Potential P (mg $P_2O_5$ 100 $g^{-1}$) | HCl 25% | 162.29 ± 4.92 | 23.49 ± 4.66 |
| Potential K (mg $K_2O$ 100 $g^{-1}$) | HCl 25% | 8.12 ± 0.39 | 17.65 ± 0.94 |
| Available P (mg $P_2O_5$ 100 $g^{-1}$) | Modified Chang and Jackson (1 N $NH_4Cl$) | 2.10 ± 0.07 | 2.16 ± 0.35 |
| Available K (mg $K_2O$ 100 $g^{-1}$) | Modified Chang and Jackson (1 N $NH_4Cl$) | 6.48 ± 0.26 | 12.2 ± 0.63 |

Note: Mean values followed by standard deviation (n=3); *) not measurable

Table 2 Initial organic matter and humic substances characteristics

| Parameters | Analytical Method | Fern (B1) | EFB (B2) | Frond (B3) | HS (H1) |
|---|---|---|---|---|---|
| Organic C (%) | *Loss on ignition* (LOI) | 52.12±0.1 | 51.76±0.1 | 55.69±0.01 | 37.63±0.12 |
| Total N (%) | Kjeldahl | 1.91±0.04 | 0.95±0.01 | 0.64±0.02 | 1.47±0.01 |
| Total P (%) | Wet Ashing, ($HNO_3$ and $HClO_4$) | 0.31±0.01 | 0.15±0.00 | 0.04±0.00 | 0.06±0.01 |
| Total K (%) | Wet Ashing, ($HNO_3$ and $HClO_4$) | 1.87±0.26 | 3.17±0.22 | 0.46±0.02 | 0.20±0.01 |
| C:N ratio | | 27.3 | 54.2 | 86.7 | 25.6 |
| C:P ratio | | 168.8 | 339.0 | 1443.8 | 609.1 |
| C:K ratio | | 27.9 | 16.3 | 121.0 | 185.6 |

Note: Mean values followed by standard deviation (n=3)

The initial characteristic of OM and HS (Table 2) shows that organic C content of fern, EFB, and frond is very similar (51.76-55.69%) while HS has lower organic C (37.63%). Total N content followed the order of fern, HS, EFB and frond from high to low respectively. This resulted in the lowest carbon to nitrogen ratio (C:N ratio) of HS followed by fern, EFB, and frond. Total P and K content of fern and EFB were higher than those of frond and HS, which means C:P and C:K ratio of fern and EFB were lower than those of frond and HS. The quality of OM is largely determined by their biochemical composition, such as lignin, starch, cellulose, hemicellulose, and stoichiometry ratios like C:N and C:P ratio (Deepak *et al*., 2024). OM with high C:N ratio (>40) decaying more slowly than those which have low C:N ratio (<40). OM with C:N ratio between 25 – 30 have sufficient N available for microbes to decompose them without needing to use soil N stores. OM with C:N ratio <25 will generally result in more rapid decomposition of OM or crop residues added and tend to release plant-available nutrients, meanwhile OM with much higher C:N ratio contain relatively more C than N, soil microbes need to another source of N to decompose wich resulted in soil nutrient reserves being immobilized (Hoyle, 2013)

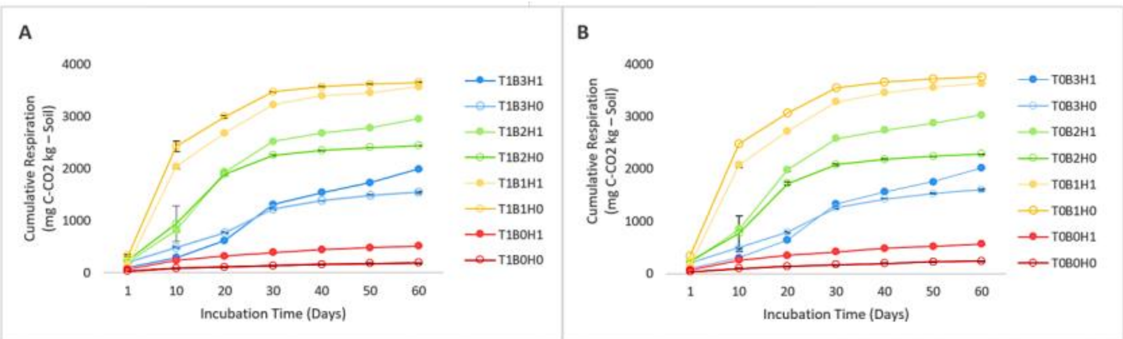
## Soil Respiration

Soil respiration is defined as the $CO_2$ produced from the biological activity of soil organisms. It can be well correlated with soil microbial activity and affected by the quality and quantity of available substrate, nutrient content, moisture and temperature. The effect of amelioration on cumulative $CO_2$ released during incubation experiment is shown in Fig 1. Cumulative release $CO_2$ at the start of incubation (6 hour after treatments added to the pre-incubated soil) significantly ($P$<0.001) affected by OM and HS addition; and interaction between OM and HS; but not significantly different between the two soils. Meanwhile after being incubated for 60 days, soil type and amelioration of OM and HS significantly ($P$<0.05) affected soil respiration rate. The F values from two-way ANOVA showing the effects of OM, HS, and soil type; and the differences of mean values among treatments on the cumulative soil respiration shown in Table 3 and 4 respectively.

At any given time, the cumulative $CO_2$ evolved in both soils were greater for all soil treated with OM with or without HS addition over the unamended soils. In all soils treated with OM with or without HS, cumulative respired C was much higher in the early stage of incubation than later days which consistent with other studies. This indicates that easily decomposable compounds depleted in the first 10 days after ameliorant added to the soils. Crop residues decomposition is the microbially mediated progressive breakdown of organic material into C (biomass or $CO_2$) and other nutrients. The decomposition process which indicated by the soil respiration rate can be divided into two distinct phases, i.e., rapid phase, which decay about 70% of C, and slower phase which decomposes more resistant fraction (Babu *et al.*, 2014).

Soil respiration occurs intensively during early phase due to the presence of nutrient substrates for microbial uptake provided by OM, HS and inorganic fertilizer addition. However, the respiration rate decreased at the later stage due to energy-limited situation when easily available compounds depleted from the decaying residues (Shahbaz *et al.*, 2017). The general trend of soil respiration from rapid to slow was in order of ferns, EFB, and fronds. This order also corresponds to the order of the C:N ratio from low to high, i.e., 27.3, 54.2, 86.7, 54.2 respectively. Amendment of high-quality OM, which usually has lower C:N rasio and more labile compounds to the soil can lead to higher microbial activity due readily available substrate that can be used, compared to low-quality OM that has higher C:N rasio and more recalcitrant compounds.

However, despite having low C:N rasio (25.6), HS addition on soil added with OM was found retarded the soil respiration at the initial stage of incubation, while for control treatment, HS addition increased soil respiration from the start. The decreasing effect caused by the addition of HS on respired $CO_2$ decreased with time. Start from day 20 and 30 days after incubation, HS increased respiration rate of EFB and oil palm frond respectively. However, the combination of ferns and HS caused lower respiration rate compared to ferns without HS treatment until the end of incubation. The decreasing effect of HS decrese over time and predicted that the values of ferns with HS will increas after 60 days. Humic substances seemed to be more effective in increasing soil respiration in soil that ameliorated with lower quality OM.




Note: $T_1$= oil palm soil; $T_0$= forest soil; $B_0$= without OM addition; $B_1$= fern addition; $B_2$= EFB addition; $B_3$= frond addition; $H_0$= without HS; $H_1$= with HS. Error bars are standard deviation in means (n=3).

Figure 1. Cumulative soil respiration affected by OM and HS addition throughout 60 days of Incubation Period (A: oil palm soil; B: forest soil).

The combination of low-quality OM and HS addition which increased soil respiration in these incubation experiment can be explained by positive priming effect. According to Ma *et al.* (2020) one of the priming effect mechanisms is co-metabolism, where SOC mineralization enhanced due to an acceleration of microbial growth and activity due to addition of OM. Microorganism feeding on fresh OM and HS added to the soil could also decomposed similar compound in SOM caused increase in soil respiration rate. Meanwhile, the addition of high-quality OM which also resulted in higher respiration rate compared to control is more likely due to another priming effect mechanism namely microbial stoichiometric decomposition, where OM and HS added to the soil act as a driving force on microbial activity because the C and N inputs match microbial demands.

### Release Patterns of Readily Available Phosphorus (P)

Figure 2A and 2B show readily available P content during 60 days of incubation period in oil palm soil and forest soil, respectively. The treatment of OM, HS, and their interaction significantly affected the available-P in both soil types. The F values from two-way ANOVA showing the effects of OM, HS, and soil type; and the differences of mean values among treatments on the readily available P shown in Table 3 and 4 respectively.

Table 3. F values from two-way ANOVA showing the effects of OM, HS, and soil type on the cumulative soil respiration, readily available P and K on the start and end of incubation

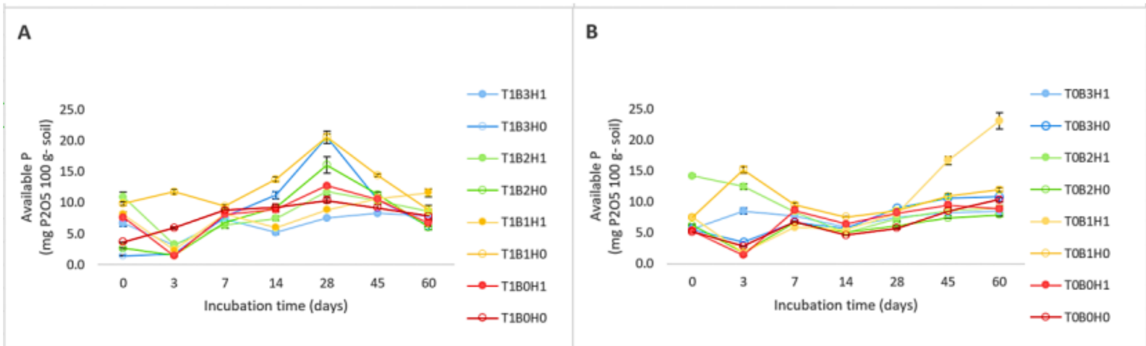
| Source of Diversity | Cumulative soil respiration | | Readily available P | | Readily available K | |
|---|---|---|---|---|---|---|
| | Day 1 | Day 60 | Day 0 | Day 60 | Day 0 | Day 60 |
| Soil Type | 1.28 ns | 4.18* | 67.5** | 404.6* | 268.9** | 0.6 ns |
| OM | 1025.0** | 911.7** | 407.9** | 288.8** | 3463.9** | 2590.5** |
| HS | 720.1** | 2022.2** | 1018.2** | 111.05** | 272.5** | 1586.1** |
| **Interactions** | | | | | | |
| Soil*OM | 0.02 ns | 0.05 ns | 132.4** | 67.25** | 86.23** | 247.6** |
| OM*HS | 314.4** | 416.9** | 396.02** | 123.9** | 257.6** | 311.7** |
| Soil*HS | 0.006 ns | 0.02 ns | 94.8** | 3.5 ns | 129.7** | 1282.9** |
| Soil*OM*HS | 0.05 ns | 0.2 ns | 70.7** | 63.9** | 218.7** | 114.8** |

Note: * = $P < 0.05$; ** = $P < 0.001$; ns = not significant

Table 4. The differences of mean values among treatments on the cumulative soil respiration, and readily available P and K on the start and end of incubation

| Treatment combination | Cumulative soil respiration | | Readily available P | | Readily available K | |
|---|---|---|---|---|---|---|
| | Day 1 | Day 60 | Day 0 | Day 60 | Day 0 | Day 60 |
| T0B0H0 | 33.6h | 240.1 e | 5.1i | 10.4def | 15.8hi | 20.2j |
| T1B0H0 | 32.0h | 193.3de | 3.6h | 7.8bc | 21.4i | 15.9i |
| T0B1H0 | 334.7a | 3749.1 de | 7.5c | 12.0cd | 139.5a | 99.0a |
| T1B1H0 | 331.5a | 3652.1de | 9.8de | 8.8b | 245.2b | 45.5d |
| T0B2H0 | 236.6b | 2281.0de | 6.2i | 7.9g | 87.1cd | 67.7b |
| T1B2H0 | 235.4b | 2438.9d | 2.6fg | 6.0def | 108.7e | 66.5c |
| T0B3H0 | 201.8c | 1601.0 c | 5.5j | 10.9fg | 33.8hi | 24.6e |
| T1B3H0 | 198.6c | 1545.3c | 1.4gh | 6.3b | 22.1fg | 22.1ij |
| T0B0H1 | 73.7g | 562.0 de | 5.3de | 8.9efg | 13.5ghi | 18.9 j |
| T1B0H1 | 68.9fg | 515.1d | 7.6gh | 6.7cd | 22.7i | 17.8h |
| T0B1H1 | 150.5d | 3628.7 c | 7.5d | 23.1c | 129.5c | 81.1g |
| T1B1H1 | 148.9d | 3570.7c | 8.1de | 11.6a | 115.0b | 36.5f |
| T0B2H1 | 198.6c | 3023.7 b | 14.2b | 8.9d | 83.2d | 29.1g |
| T1B2H1 | 197.0c | 2954.0b | 10.8a | 8.5cd | 100.2e | 71.1c |
| T0B3H1 | 102.5ef | 2019.1 a | 5.6ef | 8.4def | 27.7f | 13.1ij |
| T1B3H1 | 97.7e | 1990.1a | 6.6gh | 7.8de | 37.9fgh | 20.7hi |

Note: Mean values (n=3); different letter indicates the significant differences of the mean values among treatments according to Tukey test ($P < 0.05$)




Note: $T_1$= oil palm soil; $T_0$= forest soil; $B_0$= without OM addition; $B_1$= fern addition; $B_2$= EFB addition; $B_3$= frond addition; $H_0$= without HS; $H_1$= with HS. Error bars are standard deviation in means (n=3).

Figure 2. Readily available P affected by OM and HS addition throughout 60 days of incubation period (A: oil palm soil; B: forest soil).

Readily available P content on oil palm soil and forest soil before amelioration are very similar, namely 2.10±0.07 and 2.16 mg $P_2O_5$ 100 $g^{-1}$. However, after the addition of ameliorants (BO and HS), the value of readily available P in oil palm soils is generally higher than in forest soils. It is expected because the value of potential P of oil palm soil is much higher than forest soil due to nutrient accumulation from prolonged inorganic fertilization. Soil potential P content from the original soil might have influenced the amount of P released from OM addition. This result indicates that OM and HS are beneficial in increasing availability of soil P from fixated P. OM addition can increase the soil readily available P through mineralization process of OM added and or released of accumulated P. Organic acids produce through OM decomposition and from the addition of HS can form chelation bonds with Ca, Fe, and Al ions which lead to a decrease in the solubility of Ca, Al, and Fe, and liberated adsorbed P. This could be owing to the organic forms covering sesquioxide, which lowered soil P fixing capability and increased P availability (Kumar *et al.* 2013).

At the start of incubation, OM with or without HS increased readily available P right after addition, except for frond treatment in oil palm soil. That means there were enough substrates and nutrients to meet microbes demands, and induced P mineralization. The highest value in both soils on day 0 was EFB with HS treatment. This result suggested that high C content from EFB increased microbial growth and activities, but the nutrients provided from OM, HS, and inorganic fertilizer added to the soil were still sufficient to meet microbial requirements. However, 3 days after incubation, readily available P content in soil decreased, especially for EFB and frond treatment without HS addition and HS without OM which the values decreased until lower than initial soil P availability, which means immobilization occurs at that time. P immobilization occurs when the nutrient provides by plant residue added to the soil insufficient to meet microbial requirement as it proliferates due to input of C substrate (Damon *et al.* 2014). The only treatment increased available P content at day 3 was fern addition, this due to low C:N ratio and high labile compound contain in fern which easily decomposable.

The values started to increase again from day 7 and reached a peak on day 28 for palm oil and day 60 for forest soil. Carron *et al.* (2015) found that the total soil organic N, P, K, Mg, Ca, and C from decomposed EFB decreased over time with the reached highest values 30 days since the material was added.

In general, soil treated with fern with or without HS addition accounted for the highest P available content, followed by EFB and frond at early stage of incubation. However, at the later stage the order changes to fern, frond, and EFB from high to low respectively. In fact, frond and fern have very similar values on day 28. Higher release of mineral P from soil is treated with fern over other treatments because fern has lowest C:P ratio. P mineralization negatively correlated with C:P ratio, which are accordance with present result. High quality residues release nutrients rapidly, whilst nutrients from low quality residues may be initially immobilized, and then later mineralized, ultimately becoming available for plant uptake (Gomez-Munoz *et al.* 2014).

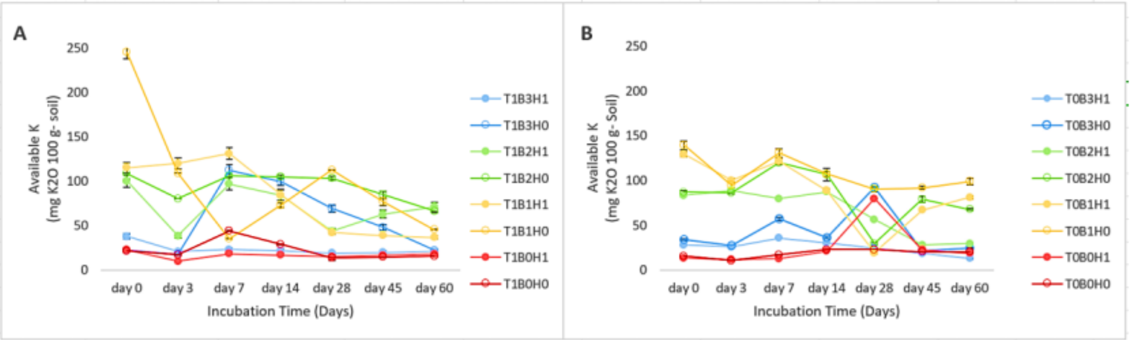
At the end of incubation, available P content of soil treated with OM with HS have higher values than soil treated only with OM. The application of humic substances can induce changes in metabolism, allowing organisms to reproduce on substrates they were previously unable to use. Hanudin *et al.* (2014) reported that HS can decrease P sorption in high Al and Fe oxides soils and increased P availability. Muliana *et al.* (2018) found similar results, the addition of HS and bio-fertilizer can improve the released available P of residue P in the intensive shallots farming soil in Brebes.

**Release Patterns of Readily Available Potassium (K)**

Figure 3A and 3B show readily available K content during 60 days of incubation period in oil palm soil and forest soil, respectively. The treatment of OM, HS, and their interaction significantly affected the available-P in both soil types. The F values from two-way ANOVA showing the effects of OM, HS, and soil type; and the differences of mean values among treatments on the readily available K shown in Table 3 and 4 respectively.

Readily Available K content in control treatment (soil with no OM and HS addition) constantly lower than those with organic ameliorant, which means there was K release from OM added. In general, the order of available K content released throughout 60 days of incubation from high to low was in order of fern, EFB and frond. This order followed the order of OM quality from high to low respectively because more labile compounds can be found on fern compared to other treatments, that contain more recalcitrant compounds.

Readily available K increased immediately after OM addition. The result also showed that K release is higher at initial incubation then gradually decreases over time, especially for fern and EFB treatment. Meanwhile available K content in soil treated with frond was lower compared to other treatments at the start of incubation, increased on day 7 and gradually decreased again until day 60. In general, the combination of OM and HS have lower available K values compared to OM without HS. This is due to C:K ratio of HS that was higher than all OM. However, despite the values fluctuated through incubation period, readily available K of soil treated with OM and HS allways higher than soil without amelioration, which means mineralization always higher than immobilization. K is released from plant residues (OM) rapidly and immobilization of K after OM addition is rarely found (Talgre *et al.*, 2014). Some nutrients in crop residues are present in soluble inorganic form, e.g., $K^+$ and $SO_4^{2-}$ (Sarkar *et al*., 2020).




Note: $T_1$= oil palm soil; $T_0$= forest soil; $B_0$= without OM addition; $B_1$= fern addition; $B_2$= EFB addition; $B_3$= frond addition; $H_0$= without HS; $H_1$= with HS. Error bars are standard deviation in means (n=3).

Fig 2. Readily available K affected by OM and HS addition throughout 60 days of incubation period (A: oil palm soil; B: forest soil).

## CONCLUSION

Organic matter and humic substances addition significantly increased cumulative respiration of $CO_2$ during 60 days of incubation compared to un-ameliorated soil. Cumulative soil respiration from rapid to slow was in order of fern, EFB, and frond which corresponds to the order of the C:N ratio (soil quality). Soil type did not significantly affect decomposition at the the start of incubation, but it was affected by the end of incubation. Humic substances addition retarded respiration at early stage of incubation. But the decreasing effect decreased over time, and at the end of incubation organic matter treatment with humic substances addition found to increase soil respiration.

The addition of organic matter and humic substances and its interactions significantly increased readily available P and K in oil palm and forest soil. The values of readily available P fluctuated throughout incubation period. However, in general, the treatments added were found to have higher readily available P compared to soil before treatments except for day 3. Soil type significantly affected readily available P content with the values higher in oil palm soil indicating that the treatment combination is beneficial to induce the release of accumulated residual P in intensive fertilized oil palm soil. Meanwhile, readily available K increased immediately after organic matter and humic substances addition, with the values decreasing over time. Despite the fluctuated values over incubation period, organic matter and humic substances treated soil always have higher available K than initial soil. The result indicating that the addition of organic matter and humic substances beneficial to increase readily available P and K from several mechanisms i.e., mineralization from added organic matter and humic substances, mineralization from soil organic matter induced from amelioration because of positive priming effect, released of accumulated P by reaction of organic acids produced from decomposition and humic substances with Ca, Mg, Fe and Al, and released of soluble inorganic form of K from organic matter added.

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