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EFFECTS OF BLACK SOLDIER FLY (*Hermetia illucens*) LARVAE FRASS APPLICATION RATES ON EXCHANGEABLE POTASSIUM AND SELECTED CHEMICAL PROPERTIES OF A *TYPIC PALEUDULT*

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ABSTRACT. *Black soldier fly larvae (BSFL; Hermetia illucens) frass can supply nutrients, but its effects on exchangeable potassium in strongly acidic Malaysian Typic Paleudults remain insufficiently resolved. This laboratory study evaluated six frass rates (0, 1, 2, 3, 4 and 5 t ha^{-1}) over 30, 60 and 90 days in a factorial completely randomised design with three independent replicates per combination, giving 54 destructive experimental units. Application rate and incubation period did not significantly affect soil pH, organic matter or cation exchange capacity. Both factors significantly affected electrical conductivity and exchangeable potassium, with no significant interaction. At 90 days, 5 t ha^{-1} produced 74.67 mg kg^{-1} exchangeable potassium compared with 33.67 mg kg^{-1} in the untreated control, a 2.22-fold difference. Thus, the short-term potassium response was not accompanied by detectable improvements in pH, organic matter or cation exchange capacity. BSFL frass acted mainly as a short-term potassium-containing amendment under the tested conditions. Field studies are required before an agronomic or economic optimum is recommended.*

INTRODUCTION

Typic Paleudults are highly weathered acidic soils formed under prolonged leaching in humid tropical environments. They commonly have low organic matter, low cation exchange capacity and limited retention of exchangeable base cations. These properties increase the risk of nutrient loss and constrain crop production unless soil fertility is carefully managed (Paramananthan, 2000; Ng et al., 2022; Paramisparam et al., 2024).

Organic amendments can supply nutrients and carbon and may create additional exchange sites as organic materials decompose and stabilise. Their effects, however, depend on amendment composition, application rate, soil properties and duration of interaction. Lime can correct acidity but does not provide the broader carbon and nutrient functions of organic inputs, whereas nutrient-rich organic amendments may increase soluble salts without providing sufficient acid-neutralising capacity (Haynes and Naidu, 1998; Li et al., 2023).

Black soldier fly larvae (BSFL; *Hermetia illucens*) frass is produced during insect-based bioconversion of organic residues and contains larval excreta, unconsumed substrate, shed exoskeletons and microbial biomass. Depending on feedstock and processing, the material may contain organic carbon, nitrogen, phosphorus, potassium and other base cations. Its nutrient composition varies with feedstock and processing conditions (Klammsteiner et al., 2020; Gärttling and Schulz, 2022; Phooi et al., 2026).

Previous frass studies have examined crop performance and soil acidity under contrasting soil conditions. Beesigamukama et al. (2020) evaluated maize growth and nutrient use at frass rates of 2.5–7.5 t ha^{-1} on an Acric Ferralsol with initial pH 5.9 and exchangeable K of 2.07 cmolc kg^{-1}. David et al. (2024) reported no significant improvement in soil pH buffering capacity following the addition of 5.4–9.0 g frass per 350 g of a Malaysian *Typic Paleudult*. The exchangeable K response to low frass application rates in strongly acidic soils with low initial K remains insufficiently understood. This study evaluated six frass application rates and three incubation periods for soil pH, electrical conductivity, organic matter, cation exchange capacity and exchangeable potassium. It was hypothesised that increasing frass application would increase each of these five properties through nutrient and organic matter inputs during the 90-day incubation.

MATERIALS AND METHODS

Soil and amendment materials

Soil was collected at one point representing one pedon in an uncultivated forest area at Universiti Teknologi MARA Pahang Branch, Jengka Campus, at a depth of 0–15 cm. The soil was classified as a Segamat Series *Typic Paleudult* (Soil Survey Staff, 2014). The collected material was air-dried, gently crushed, passed through a 2-mm sieve and thoroughly homogenised into one bulk sample before distribution among containers. Commercial BSFL frass was supplied by Biovae, Malaysia, as one batch produced using soya and coconut pulp residue as larval feedstock. Frass was used as received, without further drying. Selected initial properties were determined in triplicate by laboratory analysis (Table 1).

Table 1. Selected initial properties of the *Typic Paleudult* and Black Soldier Fly Larvae frass

Property	Unit	Soil	Frass
pH (water)	-	4.61 ± 0.22	6.5 ± 0.35
Electrical conductivity	µS cm^{-1}	35.1 ± 4.7	nd
Bulk density	g cm^{-3}	1.33 ± 0.14	nd
Moisture content	%	nd	15.8 ± 1.20
Carbon-to-nitrogen ratio	-	27:1	32.7:1
Total carbon	%	2.16 ± 0.22	55.6 ± 3.40
Organic matter	%	nd	95.8 ± 3.40
Total nitrogen	%	0.08 ± 0.01	1.7 ± 0.02
Total phosphorus	mg kg^{-1}	22.25 ± 1.04	nd
Phosphorus as P_2O_5	%	nd	1.0 ± 0.15
Total potassium	mg kg^{-1}	101.27 ± 2.51	nd
Potassium as K_2O	%	nd	5.2 ± 0.26
Cation exchange capacity	cmolc kg^{-1}	4.67 ±0.11	nd
Exchangeable potassium	cmolc kg^{-1}	0.06 ±0.08	nd
Exchangeable acidity	cmolc kg^{-1}	1.15 ± 0.04	nd
Exchangeable aluminium	cmolc kg^{-1}	1.02 ± 0.11	nd
Texture	-	Sandy loam	nd

Note. Values are means ± SD (n = 3), except C:N ratios and texture. C:N ratios were calculated from mean carbon and nitrogen concentrations. Frass P and K are expressed as P_2O_5 and K_2O. nd = not determined.

Experimental design and incubation

The experiment was arranged as a 6 × 3 factorial in a completely randomised design. The factors were six frass application rates (0, 1, 2, 3, 4 and 5 t ha^{-1}) and three incubation periods (30, 60 and 90 days). Each treatment-period combination had three independent replicates. Separate sets of 18 containers were prepared for each destructive sampling period, giving 54 experimental units. Each container received 200 g of air-dried soil and the assigned as-received quantity of frass (Table 2). Soil moisture was maintained at approximately 60% of water-holding capacity with distilled water. Incubation was conducted at ambient laboratory temperature of approximately 25–30 °C.

Rate conversion used the measured field bulk density of 1.33 g cm^{-3}. A hectare of soil to 0.15 m depth contained approximately 1,995,000 kg soil, rounded to 2,000,000 kg ha^{-1}. Consequently, 5 t ha^{-1} corresponded to 2.5 g as-received frass kg^{-1} air-dried soil and 0.50 g frass per 200 g soil. The other treatment quantities were proportional to this highest tested rate. At 15.8% frass moisture, 0.50 g as received corresponds to 0.421 g dry matter, giving 4.21 t dry frass ha^{-1} at the highest nominal rate. At each sampling time, the relevant containers were harvested and samples were air-dried at ambient laboratory temperature for approximately 2–3 days to reduce moisture before gentle crushing and analysis.

Table 2. Black Soldier Fly Larvae frass treatments used at each incubation period

Code	Field rate (t ha^{-1})	Frass per 200 g soil (g)	Description
T1	0	0.00	Untreated control
T2	1	0.10	20% of highest tested rate
T3	2	0.20	40% of highest tested rate
T4	3	0.30	60% of highest tested rate
T5	4	0.40	80% of highest tested rate
T6	5	0.50	Highest tested rate

Note. T1–T6 denote 0, 1, 2, 3, 4 and 5 t ha^{-1}, respectively, throughout the tables and figures. Rates and amendment masses refer to frass as received. Each rate was replicated three times at 30, 60 and 90 days, giving 54 independent containers.

Laboratory analyses

Soil and frass pH, and soil electrical conductivity, were determined in a 1:2.5 sample-to-distilled-water suspension. A 10-g sample was mixed with 25 mL distilled water, shaken for 15 min at 180 rpm and allowed to equilibrate overnight. pH was measured with a SevenEasy pH meter and electrical conductivity with a SevenEasy Conductivity meter (Mettler-Toledo GmbH, Greifensee, Switzerland) (Peech, 1965).

Organic matter and total carbon were determined by loss on ignition. Samples were oven-dried at 60 °C for 24 h, ashed at 300 °C for 1 h and subsequently at 550 °C for 8 h (Chefetz et al., 1996). Cation exchange capacity was determined by saturation with 1 M ammonium acetate at pH 7, ethanol washing, displacement with potassium sulphate, steam distillation and titration (Cottenie, 1980). Total nitrogen was determined by Kjeldahl digestion, distillation and titration (Bremner, 1965).

Total phosphorus and potassium were extracted using aqua regia. Potassium was quantified by atomic absorption spectrometry using an AAnalyst 800 instrument (PerkinElmer, Norwalk, Connecticut, United States), while phosphorus was measured colorimetrically at 882 nm using a Lambda 25 ultraviolet-visible spectrophotometer (PerkinElmer, United States) after colour development (Bernas, 1968; Murphy and Riley, 1962). Exchangeable potassium was extracted from 5 g soil with 50 mL of 1 M ammonium acetate at pH 7, shaken at 150 rpm for 30 min, filtered and quantified using the same atomic absorption spectrometer (Helmke and Sparks, 1996).

Statistical analysis

Data were analysed as a 6 × 3 factorial experiment using two-way analysis of variance in Statistical Analysis System version 9.4. The model tested the main effects of frass application rate and incubation period and their interaction. Normality and homogeneity of variance were assessed before interpretation. Where a significant effect was detected, means were separated using Tukey's honestly significant difference test at $p \leq 0.05$. Incubation results are presented as means ± standard error of three independent containers per treatment-period combination.

RESULTS AND DISCUSSION

Effects of application rate and incubation period

Application rate and incubation period significantly affected electrical conductivity and exchangeable potassium (Table 3). Neither factor significantly affected soil pH, organic matter or cation exchange capacity, and none of the application rate × incubation period interactions were significant. The measurable short-term response was therefore concentrated in soluble-ion concentration and exchangeable potassium rather than in the more stable soil properties.

Table 3. Two-way analysis of variance for selected soil chemical properties

Parameter	Source of variation	F-value	p-value	Significance
Soil pH	Application rate	2.08	0.0908	ns
	Incubation period	0.83	0.4439	ns
	Rate × period	0.04	1.0000	ns
Electrical conductivity	Application rate	91.27	<0.0001	*
	Incubation period	5.00	0.0121	*
	Rate × period	1.45	0.2001	ns
Exchangeable potassium	Application rate	57.47	<0.0001	*
	Incubation period	29.15	<0.0001	*
	Rate × period	1.32	0.2584	ns
Organic matter	Application rate	0.30	0.9079	ns
	Incubation period	0.01	0.9935	ns
	Rate × period	0.00	1.0000	ns
Cation exchange capacity	Application rate	1.63	0.1767	ns
	Incubation period	0.95	0.3981	ns
	Rate × period	0.03	1.0000	ns

*Note. * = significant at $p < 0.05$; ns = not significant.*

Table 4. Soil pH, organic matter and cation exchange capacity after incubation

Period (days)	Treatment	Soil pH	Organic matter (%)	CEC (cmolc kg^{-1})
30	T1	4.66 ± 0.24	3.70 ± 0.19	4.43 ± 0.28
30	T2	4.76 ± 0.29	3.76 ± 0.27	4.77 ± 0.42
30	T3	4.87 ± 0.27	3.81 ± 0.24	4.87 ± 0.27
30	T4	4.98 ± 0.34	3.86 ± 0.34	5.00 ± 0.51
30	T5	5.08 ± 0.27	3.91 ± 0.23	5.12 ± 0.37
30	T6	5.18 ± 0.36	3.96 ± 0.37	5.25 ± 0.51
60	T1	4.68 ± 0.26	3.69 ± 0.24	4.72 ± 0.25
60	T2	4.84 ± 0.31	3.75 ± 0.30	4.88 ± 0.39
60	T3	4.98 ± 0.29	3.80 ± 0.22	5.03 ± 0.56
60	T4	5.12 ± 0.37	3.85 ± 0.39	5.20 ± 0.35
60	T5	5.27 ± 0.30	3.90 ± 0.30	5.40 ± 0.51
60	T6	5.40 ± 0.36	3.95 ± 0.39	5.60 ± 0.68
90	T1	4.70 ± 0.25	3.68 ± 0.20	4.73 ± 0.28
90	T2	4.91 ± 0.34	3.74 ± 0.25	4.94 ± 0.42
90	T3	5.08 ± 0.29	3.79 ± 0.33	5.15 ± 0.55
90	T4	5.26 ± 0.37	3.84 ± 0.27	5.35 ± 0.40
90	T5	5.42 ± 0.34	3.89 ± 0.41	5.60 ± 0.73
90	T6	5.57 ± 0.37	3.94 ± 0.36	5.85 ± 0.53

Note. Values are means ± SE (n = 3). Treatment codes are defined in Table 2.

Soil pH

Soil pH means ranged from 4.66 to 5.57, with no significant effect of application rate or incubation period (Tables 3 and 4). At 90 days, soil pH was 5.57 ± 0.37 at the highest rate and 4.70 ± 0.25 in the control. Frass application therefore produced no significant pH improvement during the incubation.

The release of base cations during organic matter decomposition may be offset by acidifying processes such as nitrification. David et al. (2024) also reported no significant improvement in soil pH buffering capacity following the addition of 5.4–9.0 g frass to 350 g of a Typic Paleudult, despite frass pH values of 7.46–7.98. Although assessed by acid titration, their findings similarly indicate a limited short-term response of soil acidity to frass application.

Electrical conductivity

All frass-amended treatments had significantly higher electrical conductivity than the untreated control at each sampling period (Figure 1). Across periods, amended treatment means ranged from 181.33 to 237.33 µS cm^{-1}, compared with 79.33–89.67 µS cm^{-1} in the controls. At 90 days, the highest

rate produced 220.33 ± 3.18 µS cm⁻¹ compared with 89.67 ± 5.36 µS cm⁻¹ in the control. Differences among the five amended rates were not significant within individual sampling periods.

Electrical conductivity reflects the combined concentration of soluble ions. Ortiz Escobar and Hue (2008) reported increased EC after applying 10 t ha⁻¹ of organic manures to tropical Andisol, Ultisol and Oxisol soils. Klammsteiner et al. (2020) measured EC values of 77.3–81.5 µS cm⁻¹ in frass-amended soil and 95.5 µS cm⁻¹ in a mineral-N control using 1:2.5 water extracts from a near-neutral to alkaline soil. These contrasting responses indicate that soil conditions, amendment composition and fertiliser inputs influence the EC response.

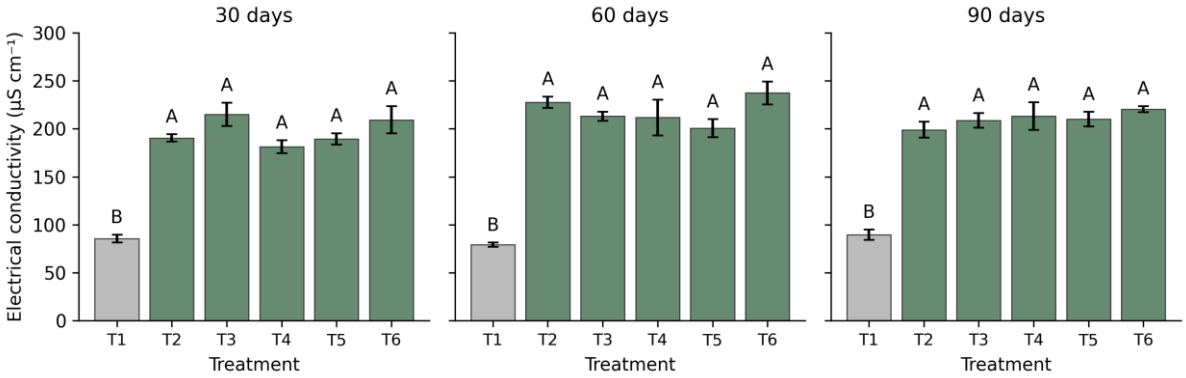

Figure 1**.** Electrical conductivity of air-dried soil extracts (1:2.5 soil:water) after BSFL frass application. Bars show means ± SE (n = 3). Within each period, means sharing an uppercase letter are not significantly different (Tukey HSD, $p \leq 0.05$). Treatment codes are defined in Table 2.

Exchangeable potassium

Exchangeable potassium generally increased as the frass rate increased (Figure 2). The 5 t ha⁻¹ treatment recorded the highest mean at each sampling period, while the untreated control recorded the lowest. After 90 days, the highest rate reached 74.67 ± 1.45 mg kg⁻¹ compared with 33.67 ± 1.45 mg kg⁻¹ in the control, a 2.22-fold difference and a control-adjusted increase of 41.00 mg kg⁻¹. Adjacent application rates were not always significantly different according to Tukey's test.

The increase in exchangeable K is consistent with the frass K content of 5.2% K_2O, equivalent to 4.32% elemental K. Beesigamukama et al. (2020) reported 0.17% total K in brewery-residue frass and an initial soil exchangeable K concentration of 2.07 cmolc kg⁻¹. The present soil contained 0.06 cmolc kg⁻¹ exchangeable K before incubation. Differences in feedstock, analytical basis and initial soil fertility may contribute to variation in nutrient responses among studies. The observed increase may reflect K release from frass and retention on soil exchange sites (Paramisparam et al., 2024).

The highest tested rate produced the greatest exchangeable K concentration, with no clear plateau across the application range. Agronomic and economic optima require evaluation under field conditions.

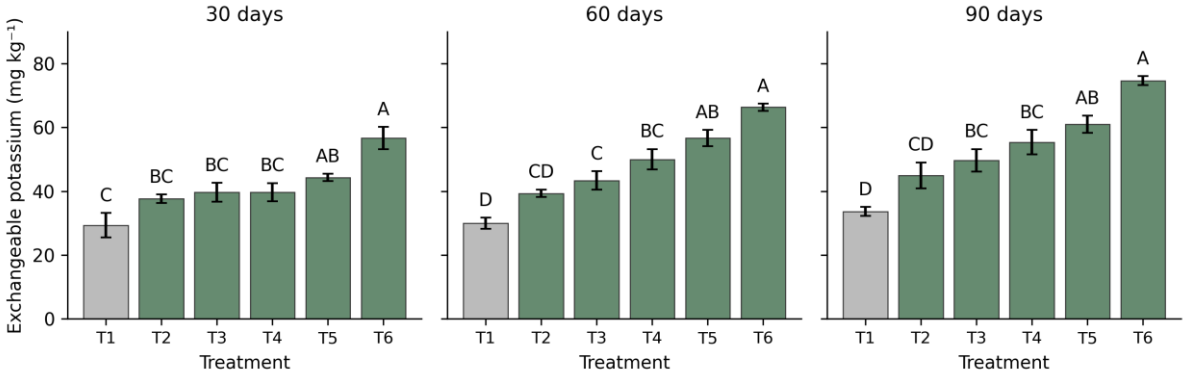

Figure 2**.** Exchangeable potassium after 30, 60 and 90 days of incubation with BSFL frass. Bars show means ± SE (n = 3). Within each period, means sharing at least one uppercase letter are not significantly different (Tukey HSD, $p \leq 0.05$). Treatment codes are defined in Table 2.

Organic matter and cation exchange capacity

Frass application did not significantly change soil organic matter or cation exchange capacity during the 90-day incubation (Tables 3 and 4). Organic matter means ranged from 3.68% to 3.96%. At 90 days, values were 3.94 ± 0.36% at the highest rate and 3.68 ± 0.20% in the control. Klammsteiner et al. (2020) similarly reported no significant difference in volatile solids, with 35.4–38.4 g kg^{-1} in frass-amended soils and 37.3 g kg^{-1} in a mineral-fertilised control. Although the analytical measures differed, both studies recorded no significant increase in soil organic material. The small quantity of frass applied and mineralisation during incubation may have limited organic matter accumulation.

Cation exchange capacity ranged from 4.43 to 5.85 cmolc kg^{-1}. At 90 days, the highest rate averaged 5.85 ± 0.53 cmolc kg^{-1} compared with 4.73 ± 0.28 cmolc kg^{-1} in the control, with no significant rate effect. David et al. (2024) reported initial soil and frass CEC values of 11.67 and 20.23–21.00 cmol kg^{-1}, respectively, demonstrating variation in the exchange capacity of materials used in frass studies. The absence of a significant CEC response in the present study may reflect the small amendment input and limited change in soil organic matter during incubation.

Overall amendment performance

Black Soldier Fly Larvae frass increased electrical conductivity and exchangeable potassium without significantly altering soil pH, organic matter or cation exchange capacity. Under the conditions tested, the amendment functioned primarily as a potassium-containing organic nutrient source.

Field experiments are needed to evaluate crop growth, potassium uptake, leaching losses, residual fertility and economic performance. Comparisons with established liming materials should include post-treatment exchangeable acidity and aluminium measurements.

CONCLUSION

Black Soldier Fly Larvae frass did not significantly alter soil pH, organic matter or cation exchange capacity during 90 days of laboratory incubation. Frass increased electrical conductivity and exchangeable potassium, with the highest tested rate of 5 t ha^{-1} producing 74.67 mg kg^{-1} exchangeable potassium at 90 days compared with 33.67 mg kg^{-1} in the control. These findings indicate a short-term potassium benefit without significant improvement in the other measured soil properties. Field evaluation of crop response, nutrient losses and economic returns is required before an application rate can be recommended.

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