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Application of Frass BSF to Nutrient Uptake and Soybeans (*Glycine max* L.) Production

Gusmawartati Gusmawartati *, Nelvia Nelvia, Aulia Herdayani Ridwan

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ABSTRACT

Soybeans (Glycine max L.) are a highly nutritious crop and serve as the primary raw material for various food products. One approach to increasing soybean productivity involves applying organic matter to marginal soils, such as Inceptisol. The study aimed to determine the effect of black soldier fly (BSF) frass application on improving the growth, yield, and NPK nutrient uptake of soybean plants in Inceptisol soil, as well as to identify the optimal BSF frass application rate that yields the best growth, yield, and NPK nutrient uptake. The study employed a Completely Randomized Design (CRD) with four treatment levels of BSF frass application rates: 0, 5, 7.5, and 10 metric tons of BSF frass per hectare. Data were analyzed using analysis of variance (ANOVA) followed by Duncan's New Multiple Range Test (DNMRT) at the 5% significance level. The observed parameters were plant height, number of pods, percentage of filled pods, seed weight per plant, effective root nodules, and NPK nutrient uptake by soybean plants. The results showed that the application of BSF frass fertilizer increased plant height, the number of pods, the percentage of filled pods, seed weight per plant, effective root nodules, and NPK nutrient uptake by soybean plants. The highest soybean yield was achieved with a BSF frass application rate of 5 t/ha, resulting in a seed weight per plant of 13.11 g—equivalent to 1.64 t/ha—and nutrient uptake of N, P, and K increased by 42.52%, 25%, and 2.90%, respectively.

Keywords: food crops, kasgot, marginal land, nutrient, organic matter

INTRODUCTION

One approach to agricultural land development involves utilizing potential land, such as Inceptisols. Inceptisols have a soil profile depth of 1–2 meters; the soil color tends to be black or gray to dark brown; the soil structure is crumbly with a loose texture; it has a pH ranging from 5.0 to 7.0; nutrient content is low to moderate; and organic matter content is less than 5% (Widodo and Kusuma, 2018). Inceptisols are one of the soil orders widely distributed in Indonesia, covering approximately 20.75 million hectares or 37.5% of Indonesia's land area (Muyyasir *et al.* 2012). According to data from the Indonesian Central Statistics Agency (2015), the area of Inceptisols land in Riau Province is 2.6 ha. Fiantis (2016) states that Inceptisols are relatively young soils and are divided into six suborders: Aquept, Gelept, Cryept, Ustept, Xerept, and Udept. Based on established criteria, Udept Inceptisols soils have low organic matter content. One approach to enhancing the productivity of Udept Inceptisols soils is the application of organic matter.

Organic matter plays a crucial role in improving the physical, chemical, and biological properties of soil. The effects of applying organic matter on soil physical properties include improving soil structure to become crumbly and increasing water-holding capacity (Pan *et al.* 2025). The application of organic matter also influences soil chemical properties, such as aiding in nutrient supply and acting as a pH buffer. Organic matter also plays a role in improving the biological properties of soil by serving as a source of energy and nutrients for soil microorganisms. Soil microorganisms will grow and thrive, thereby increasing their population and diversity. Good physical, chemical, and biological soil properties will maximize plant growth. One type of organic material that can be utilized is black soldier fly (BSF) frass fertilizer.

BSF fertilizer is a byproduct of black soldier fly (BSF) farming and contains a large amount of nutrients that can be utilized by plants. Beesigamukama *et al.* (2022) state that frass fertilizer from all insect species has adequate concentrations and levels of macro- and micronutrients. Agustin *et al.* (2023) note that BSF frass is often referred to as a solid organic fertilizer that can be used to optimize plant growth due to its diverse nutrient content. Elissen *et al.* (2023) added that based on its average composition, BSF frass shows similarities to cattle manure (C/N ratio, N content), pig slurry (P content), poultry manure (dry matter and K content), and compost (dry matter content). According to PT. Bio Cycle Indo (2025), BSF frass contains 56.4% organic carbon; 43.5% moisture; 3.65% total nitrogen; a C/N ratio of 15.5; pH (H_2O) 6.27; total P_2O_5 1.96%;

Agrotechnology Study Program, Faculty of Agriculture, University of Riau, Riau 28292, Indonesia
* Corresponding Author:
Email: gusmawartati@lecturer.unri.ac.id

total K_2O 1.52%; total Mg 0.38%; total Ca 0.32%; and total B 41.1 mg/kg. Beesigamukama *et al.* (2020) stated that the application of BSF frass at a dose of 7.5 t ha^{-1} resulted in the highest accumulation of nitrogen, phosphorus, and potassium in corn compared to other dose treatments. The nitrogen accumulated in corn after the application of 7.5 t ha^{-1} of BSF frass was 17 kg N ha^{-1}, phosphorus accumulated at 15 kg P ha^{-1}, while potassium accumulated at 44 kg K ha^{-1}.

Soybeans (*Glycine max* L.) were selected as the test crop because they have high nutritional value and serve as the primary raw material in various food and industrial products. Soybeans are a major source of plant-based protein; 100 g of soybeans contain approximately 36.5 g of protein, 11–18 g of fat, 30–53 g of carbohydrates, and about 3–9 g of fiber. Soybeans also contain 277 mg of calcium, 704 mg of phosphorus, 15–16 mg of iron, 1,797 mg of potassium, and 280 mg of magnesium, as well as various vitamins, such as vitamin E, vitamin K, and B-complex vitamins (Andra Farm 2025). According to the Indonesian Central Statistics Agency (2024), the national average soybean productivity in 2023 was 1.456 t.ha^{-1}, an increase of 5.58% from 2022, but still far below the potential yield of soybean crops (2.77 t.ha^{-1} for the Grobogan variety).

Soybean productivity can be increased through agricultural intensification and extensification. The application of BSF frass fertilizer is one of the efforts to increase soybean productivity on marginal lands such as Inceptisols. The objective of this study was to determine the effect of BSF frass application on improving the growth, yield, and NPK nutrient uptake of soybean plants in Inceptisols soil, as well as to determine the optimal dose of BSF frass capable of enhancing growth, yield, and NPK nutrient uptake.

METHODS

Materials

The study was conducted at the Experimental Farm and Soil Science Laboratory of the Faculty of Agriculture, University of Riau, Pekanbaru, over a period of 6 months from September 2024 to March 2025. The materials used during the study included Grobogan soybean seeds, Udept Inceptisols soil, BSF frass fertilizer (PT. Bio Cycle Indo), urea fertilizer, TSP fertilizer, KCl fertilizer, and chemical reagents used for soil analysis and plant nutrient uptake. The equipment used in the study included a scale, polybags, a hoe, a bucket, a measuring tape, and laboratory equipment used for soil chemical analysis and plant nutrient uptake.

Research Methodology

The study was designed using a Completely Randomized Design (CRD) with four treatment levels of BSF frass fertilizer application rates: 0, 5, 7.5, and 10 tons of BSF frass per hectare (ha^{-1}), or 0, 25, 37.5, and 50 grams of BSF frass per polybag. Each treatment was replicated five times, resulting in 20 experimental units. One experimental unit consisted of five plants, with one plant used for observing effective root nodules and nutrient uptake. Data were analyzed using analysis of variance (ANOVA); if the calculated F-value was greater than the critical F-value, further testing was conducted using Duncan's New Multiple Range Test (DNMRT) at the 5% significance level.

Implementation

Udept Inceptisols soil was collected at the University of Riau Campground. The soil was then sieved using a 25-mesh sieve; 10 kg of the sieved soil was weighed and placed into 40 cm × 50 cm polybags to serve as the growing medium. Once the growing medium was prepared, the study area was cleared of weeds, plant debris, and trash in the surrounding area. The growing medium was arranged with a spacing of 30 cm between polybags for each treatment and replicate, and each treatment was labeled according to the randomization scheme. Next, BSF frass was weighed according to the treatment dose, then mixed into the growing medium and stirred until homogeneous. Soybean planting was carried out one week after the application of BSF frass using the hole-planting method. Soybean seeds were planted at a depth of approximately 3 cm, with two seeds per planting hole. Subsequently, soybean crop maintenance was carried out, including watering, thinning and transplanting, weeding, and application of inorganic fertilizers according to recommendations (Lagiman *et al.* 2022): Urea (dose 75 kg/ha or 0.375 g per polybag), TSP (dose 100 kg. ha^{-1} or 0.5 g per polybag), and KCl (at a rate of 100 kg.ha^{-1} or 0.5 g per polybag) at 14 DAS (days after sowing), except that urea is applied twice (at 14 DAS and 28 DAS), as well as pest control using the pesticide Sidametrin.

The parameters observed were plant height, number of pods, percentage of pods containing seeds, seed weight per plant, effective root nodules, and NPK nutrient uptake using the wet ashing method with H_2SO_4 and H_2O_2 (Eviati *et al.* 2023) in soybean plants, as well as additional analyses of the initial soil, soil after incubation (following the application of BSF frass), and final soil (before entering the generative phase).

RESULTS AND DISCUSSION

Chemical Properties of Soil and BSF Manure

The results of the chemical analysis of the initial soil, incubated soil, and final soil are shown in Table 1. Table 1 shows that Inceptisols soils have chemical properties that are less favorable for soybean growth, with pH, organic carbon, and cation exchange capacity (CEC) ranging from low to very low. This is consistent with the findings of Widodo & Kusuma (2018), who stated that Inceptisols soils have a pH range of 5.0 to

Table 1 Results of the chemical analysis of soil properties following the application of BSF frass (initial soil, after incubation, and at the end of the study)

Chemical properties of soil	Original land	BSF frass dosage (t/ha)	One-week incubation period	Soil post-treatment
pH	6.48^{sa}	0	6.48^{sa}	7.08^{n}
		5	6.63^{n}	7.12^{n}
		7.5	6.79^{n}	7.27^{n}
		10	7.32^{n}	7.38^{n}
C-Organik (%)	0.18^{vl}	0	0.18^{vl}	0.35^{vl}
		5	0.20^{vl}	0.37^{vl}
		7.5	0.36^{vl}	0.60^{vl}
		10	0.50^{vl}	0.62^{vl}
KTK (me/100 g)	12.65^{l}	0	12.65^{l}	18.47^{m}
		5	14.55^{l}	19.60^{m}
		7.5	14.47^{l}	20.54^{m}
		10	21.58^{l}	21.59^{m}
N-Total (%)	0.11^{l}	0	0.11^{l}	0.06^{vl}
		5	0.18^{l}	0.11^{l}
		7.5	0.27^{m}	0.18^{l}
		10	0.32^{m}	0.21^{m}
P_2O_5 HCl 25% (mg/100 g)	23^{m}	0	23^{m}	19.82^{l}
		5	23.74^{m}	17.43^{m}
		7.5	26.37^{m}	14.03^{m}
		10	30.00^{m}	16.27^{h}
P_2O_5 Olsen (mg/100 g)	12.39^{m}	0	12.39^{m}	9.02^{l}
		5	14.01^{m}	12.65^{m}
		7.5	15.25^{m}	14.03^{m}
		10	17.65^{m}	16.27^{h}
K_2O HCl 25% (mg/100 g)	35.50^{m}	0	35.50^{m}	11.32^{l}
		5	35.54^{m}	11.99^{l}
		7.5	36.94^{m}	14.28^{l}
		10	38.11^{m}	12.80^{l}

Source: Soil and Fertilizer Instrument Standard Testing Center (2023). Notes: sa (slightly acidic), n (neutral), vl (very low), l (low), m (moderate), h (high).

7.0, low to moderate nutrient content, and organic matter content of less than 5%. Table 1 also shows that after one week of incubation, all soil chemical properties improved, thereby enhancing soil fertility—particularly pH, which determines nutrient availability in the soil—shifting from slightly acidic to neutral. The optimal pH range for soybean growth is 6.0–6.5, as under these condition nutrients are available in sufficient quantities and are easily absorbed by plant roots. According to Lagiman *et al.* (2022), soybean plants can grow optimally at a pH range of 6.00–6.68; thus, based on the results of the soil pH analysis, the growing medium used is suitable for soybean plant growth.

A final soil analysis was conducted before the plant entered the generative phase. Table 1 shows that nearly all soil chemical properties decreased compared to the results of the soil analysis after incubation. The decrease in total N, total P, available P, total K, and CEC was caused by the active nutrient uptake by the soybean plants, particularly during the vegetative phase up until just before entering the generative phase for growth and pod formation.

Table 2 shows that the chemical properties of BSF frass fertilizer meet the quality standards for solid organic fertilizers (Soil and Fertilizer Standards and Instrument Testing Center, 2023). Based on these data, BSF frass fertilizer can be used as an organic fertilizer to enhance plant growth and yield. This aligns with the findings of Susilo *et al.* (2024), who noted that BSF frass contains relatively high and balanced NPK levels, making it a potential compound fertilizer for improving nutrient availability to plants. Additionally, frass can raise soil pH, which supports nutrient uptake by roots. The chitin and bioactive compounds within it play a role in stimulating soil microorganism activity, enhancing biological fertility, and exhibiting antimicrobial properties that can suppress the presence of soil pathogens.

NPK Nutrient Uptake

Figure 1 shows that the application of BSF frass at a dose of 5 t ha^{-1} increased N uptake by the plant canopy by 45.52% compared to the control (without BSF frass); at higher doses (7.5 t ha^{-1} and 10 t ha^{-1}), the increases were even higher, rising by 385% and 467%, respectively, compared to the control. BSF frass contains beneficial microorganisms such as nitrogen-fixing and nitrifying bacteria that play a role in increasing nitrogen availability to plants. Nitrogen-fixing and nitrifying bacteria are crucial because nitrogen availability is limited in most ecosystems. Through the process of nitrate assimilation into the plant root system, these bacteria contribute to enhancing soil resilience against environmental stresses such as flooding, drought, and land degradation (Susilo *et al.* 2024). Jones *et al.* (1991) stated that nitrogen (N) levels in soybean plants ranging from 3.10–4.00% fall into the low category, while levels of 4.01–5.50% are considered sufficient. Figure 2 also shows that the N content in the canopy of 42-day-old soybean plants falls into the low category. This is caused by N immobilization due to the high organic C content and C/N ratio of the BSF frass fertilizer (Table 2). This is consistent with the findings of Liu *et al.* (2025), who state that when organic carbon content increases due to the addition of carbon-rich organic matter, microorganisms utilize large amounts of soil nitrogen as an energy source, causing inorganic nitrogen (nitrate and ammonium) to become bound to microbial biomass and thus unavailable for direct uptake by plants. In cultivated plants, nitrogen is used for protein synthesis and is an essential component of chlorophyll, which functions to convert light energy into chemical energy during photosynthesis. Adequate nitrogen availability is indicated by increased photosynthetic activity, leading to optimal vegetative plant growth.

Figure 1 shows that the application of BSF frass at a dose of 5 t ha^{-1} increased P nutrient uptake by the plant canopy by 25% compared to the control (without BSF frass); at higher doses (7.5 t ha^{-1} and 10 t ha^{-1}), the increase was even greater, at 245.83% and 158.3%, respectively, compared to the control. Soybeans require relatively large amounts of P during growth. Phosphorus levels in soybeans of 0.16–0.25% are considered low, and adequate within the range of 0.26–0.50% (Jones *et al.* 1991). Figure 2 also shows that P nutrient levels in the canopy of 42-day-old

Table 2 Results of the chemical analysis of BSF frass fertilizer

Chemical Properties	Scores	Criteria
Total N (%)	4.56	Complies with SNI 7763:2018 standards for solid organic fertilizer
Total P_2O_5 (%)	3.04	Complies with SNI 7763:2018 standards for solid organic fertilizer
Total K_2O (%)	1.99	Complies with SNI 7763:2018 standards for solid organic fertilizer
Total Mg (%)	0.62	Complies with SNI 7763:2018 standards for solid organic fertilizer
Total Ca (%)	0.73	Complies with SNI 7763:2018 standards for solid organic fertilizer
Organic C (%)	56.2	Complies with SNI 7763:2018 standards for solid organic fertilizer
C/N Ratio	12.1	Complies with SNI 7763:2018 standards for solid organic fertilizer
pH (H_2O)	6.69	Complies with SNI 7763:2018 standards for solid organic fertilizer

Source: Central Plantation Services Laboratory (2023); Soil and Fertilizer Instrument Standard Testing Center (2023)

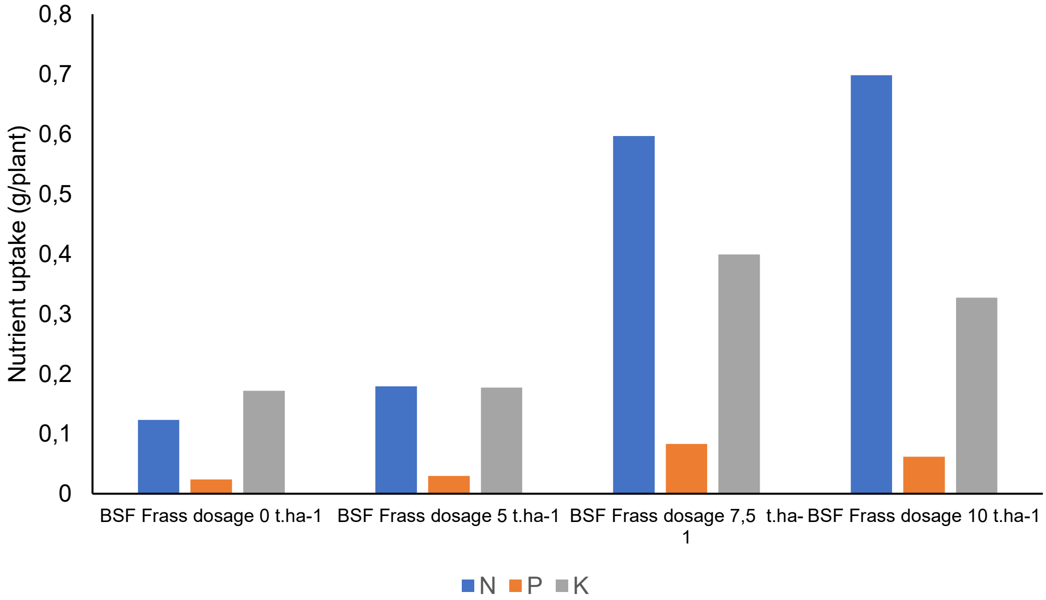

Figure 1 Uptake of N, P, and K nutrients by the canopy of 42-day-old soybean plants after application of BSF frass.

soybean plants were sufficient, except in treatments with 5 t ha⁻¹ of BSF frass and without BSF frass application. The peak period of P uptake occurs from pod formation until approximately 10 days before seed development begins. Grain crops grown on P-deficient soils result in reduced seed filling (Bachtiar 2016).

Figure 1 shows that the application of BSF frass at a dose of 5 t ha^{-1} increased K uptake by the plant canopy by 2.90% compared to the control (without BSF frass); at higher doses (7.5 t ha^{-1} and 10 t ha^{-1}), the increase was even greater, at 131.97% and 90.11%, respectively, compared to without BSF frass application. Jones *et al.* (1991) noted that when K content in soybean plants ranges from 1.26–1.70%, it falls into the low category, while levels between 1.71–2.50% are considered sufficient. Figure 2 also indicates that K levels in the aboveground biomass of 42-day-old soybean plants fall into the low category. This may be due to low final soil potassium levels (Table 1) and high Mg content in the BSF frass fertilizer, thereby triggering K deficiency in the plants. In soils with low potassium levels, excess Mg can inhibit K uptake by plants. K, Ca, and Mg are positively charged cations that exhibit antagonistic interactions with one another. An excess of any one of these three cations will inhibit the availability and uptake of the others (Nguyen *et al.* 2017). This indicates that while Mg is important for plant physiological processes such as photosynthesis and enzyme activation, the balance between Mg and K remains critical. Potassium plays a vital role in plants because it influences metabolic, physiological, and nutritional processes and is required in large quantities to achieve high yields.

The Effect of BSF Frass Application on Soybean Plant Growth and Yield

Table 3 shows that the application of BSF frass significantly increased plant height, the number of pods, the percentage of filled pods, seed weight per plant, and effective root nodules compared to the control treatment without BSF frass application.

Table 3 shows that the application of BSF frass at a dose of 5 t·ha^{-1} increased soybean plant height and met the standards described by the Directorate of Seed Production, General Directorate of Agricultural Crops, Ministry of Agriculture, 2023. The increase in plant height is believed to be closely related to increased uptake of N, P, and K nutrients—particularly N, as shown in Figure 1. Nitrogen is a key component of chlorophyll and proteins, thus playing a direct role in

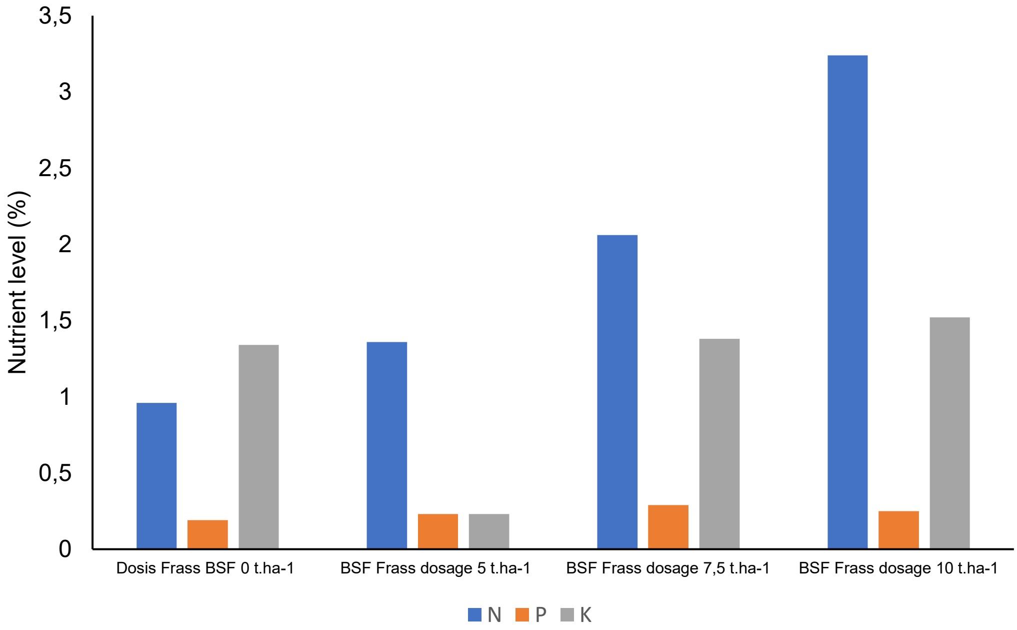

Figure 2 N, P, and K nutrient levels in the foliage of 42-day-old soybean plants after application of BSF frass.

Table 3 Soybean plant growth and yield following BSF frass application

Parameters	BSF Frass Dosage			
	0 t.ha^{-1}	5 t.ha^{-1}	7.5 t.ha^{-1}	10 t.ha^{-1}
Plant Height (cm)	39.34^{b}	54.74^{a}	57.94^{a}	61.18^{a}
Number of Pods (units)	11.60^{b}	24.80^{a}	34.20^{a}	30.40^{a}
Percentage of Mature Pods (%)	75.34^{b}	99.00^{a}	100.00^{a}	99.40^{a}
Seed Weight per Plant (g)	5.23^{b}	9.95^{ab}	13.11^{a}	11.38^{a}
Effective Root Nodules (units)	0.60^{b}	3.40^{ab}	7.60^{a}	6.80^{a}

Note: Numbers in the same row followed by the same lowercase letter are not significantly different according to the DNMRT test at the 5% level.

plant cell division and elongation. The application of BSF frass increases pH, organic carbon content, and cation exchange capacity (CEC), thereby making nutrient availability and uptake more efficient. This is supported by the results of a study by Silin (2026), which found that the application of BSF frass can improve soil fertility by increasing soil pH to 6.87–7.51, organic matter to 3.16–6.43%, total nitrogen by 0.16–0.32%, available phosphorus by 37.27–111.14 ppm, and available potassium by 478.66–1044.70 ppm. The study's results also showed an increase in corn plant height at harvest (136.33 cm). Based on the results of the soil chemical properties analysis (Table 1), the application of BSF frass was able to raise the soil pH—which was initially slightly acidic—to neutral. Soil pH affects plant height because it influences nutrient availability, soil microorganism activity, and root growth. At an ideal soil pH—ranging from 6.0 to 7.0—nutrients are available in a form that is easily absorbed by plant roots. However, if the pH is too low (acidic), some essential nutrients become unavailable or are even bound to toxic elements that can poison the roots and inhibit plant growth. Based on the growth requirements for soybeans as outlined by Lagiman *et al.* (2022), soybeans grow optimally at a pH of 6.00–6.68. The pH of the growing medium after the application of BSF frass fertilizer ranged from 6.63 to 7.32, which is still considered suitable for soybean growth. Therefore, these conditions support the achievement of optimal plant height.

Table 3 also shows that the application of BSF frass at doses ranging from 5 $t.ha^{-1}$ to 10 $t.ha^{-1}$ did not significantly increase the number of pods per plant or the percentage of filled pods; however, these values were significantly different from those without BSF frass application. BSF frass contains macro- and micronutrients that plants need, releasing them gradually and sustainably. In addition, organic fertilizers can improve soil structure and fertility, as well as stimulate the activity of soil microorganisms that are beneficial for root growth and the formation of flowers and pods. Susilo *et al.* (2024) state that BSF frass contains essential nutrients such as N, P, K, and micronutrients required by soybean plants during both the vegetative and generative growth phases, including flower and pod formation. BSF frass also helps improve soil structure by enhancing aeration and water-holding capacity (Rismayani *et al.*, 2024). Good soil structure allows plants to more efficiently absorb the nutrients needed for pod formation. Beesigamukama *et al.* (2022) also state that frass fertilizer contains adequate levels of macro- and micronutrients. Nitrogen (N) aids in chlorophyll formation for photosynthesis, which is essential for the energy required to form fruits and pods. As plants grow taller, more leaves are produced, thereby increasing photosynthetic capacity and generating more photosynthates for flower and pod formation. Phosphorus plays a role in flower formation and seed development. According to research by Nakagawa & Papa (2025), the application of phosphate fertilizer to soybean plants increased the number of pods from 12 to 25 per plant and the number of seeds from 23 to 48 per plant compared to plants without phosphate fertilizer.

Table 3 also shows that the application of BSF frass at a dose of 5 t.ha-1 increased seed weight per plant by 90.24% compared to the treatment without BSF frass, while at higher doses (7.5 t/ha and 10 t/ha), the increases were 150.66% and 117.59%, respectively, compared to the control. This increase in seed weight per plant is due to the fact that, as an organic fertilizer, BSF frass provides essential macro- and micronutrients such as N, P, and K (Table 2), as well as other supporting elements that stimulate plant growth and seed formation. Seed weight is the final outcome of the entire plant growth process and is therefore strongly influenced by the number of pods, the percentage of filled pods, and the plant's ability to absorb nutrients. The higher the uptake of N, P, and K, the more optimally photosynthesis, assimilate translocation, and seed filling occur, resulting in increased seed weight. According to a study by Alam *et al.* (2024), the application of liquid fertilizer containing nitrogen, phosphorus, potassium, sulfur, and boron (NPKSB) increased seed weight by 2.7 $t{\cdot}ha^{-1}$, a 42% increase compared to treatments without NPKSB application. In their study, Primadiyono *et al.* (2020) applied organic fertilizer (petroganic) and demonstrated that the application of organic fertilizer was able to increase seed weight per soybean plant to 8,522 g, which is higher than the yield without organic fertilizer, which produced only about 5,403 g. BSF frass contains macronutrients, particularly P and K, which play a very important role in seed formation. P plays a role in root development and flowering, while K supports seed filling and improves crop quality. By improving soil conditions and increasing nutrient availability, the use of frass can support optimal soybean plant growth, accelerate seed filling, and ultimately increase the resulting seed weight. Nevertheless, the seed weight per plant falls into the low category, equivalent to 1.64 t/ha, when compared to the potential of the Grobogan variety (2.7 to 3.4 t/ha) used in this study. One of the causes is nutrient deficiency, particularly phosphorus and potassium, during seed filling, which prevents the seeds from developing to their full potential. This correlates with the nutrient content results (Figure 2), which indicate that P and K levels in the soybean plants were deficient, resulting in low seed weight.

Table 3 also shows that the application of BSF frass fertilizer at a dose of 5 $t.ha^{-1}$ increased the number of effective root nodules in plants by an insignificant amount compared to the untreated control; whereas at higher doses (7.5 $t.ha^{-1}$ and 10 $t.ha^{-1}$), the increase was significant compared to the untreated control. Root nodules form through a symbiotic relationship between plant roots and nitrogen-fixing bacteria, such as

Rhizobium. An increase in the number of effective root nodules is also thought to contribute to increased nitrogen uptake by the plants. The more effective root nodules there are, the greater the plant's ability to perform biological nitrogen fixation, thereby supporting vegetative growth, pod formation, and ultimately increasing seed yield. As an organic fertilizer, BSF frass contains organic matter and microorganisms, thereby creating fertile and optimal soil conditions for the growth of nitrogen-fixing bacteria. According to Susilo *et al.* (2024), BSF frass contains chitin to stimulate the soil microbiome and produce antimicrobial peptides that can help protect roots from pathogens. This can improve overall soil fertility, allowing root nodules to develop more healthily. Wikandari (2023) also demonstrated that the addition of organic matter in the form of BSF frass can influence the soil nematode community by increasing the abundance of bacterivorous and fungivorous nematodes during the vegetative and generative stages of plant growth. A healthy nematode community can support root nodule growth by maintaining the balance of microorganisms around the roots.

CONCLUSION

Based on the research conducted, it can be concluded that the application of BSF frass fertilizer can improve the growth, yield, and NPK nutrient uptake of soybean plants. The highest soybean yield was achieved with an application rate of 5 $t.ha^{-1}$ of BSF frass, resulting in a seed weight per plant of 13.11 g, equivalent to 1.64 $t.ha^{-1}$, while N, P, and K nutrient uptake increased by 42.52%, 25%, and 2.90%, respectively, compared to the control without BSF frass application.

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