INNSPUB

International Journal of Agronomy and Agricultural Research (IJAAR)

ISSN: 2223-7054 (Print) 2225-3610 (Online)
http://www.innspub.net
Vol. 26, No. 5, p. 1-13, 2025

RESEARCH PAPER OPEN ACCESS

Growth responses of hybrid corn applied with black soldier fly frass (BSFF)

Edineil T. Dalupang[*1,2]

[1]*Central Graduate School, Isabela State University, Echague, Philippines*

[2]*College of Agriculture, Isabela State University, Echague, Philippines*

Article published on May 06, 2025

Key words: Agricultural waste, BSF frass, Hybrid corn, Organic fertilizer, Black soldier fly

Abstract

This study evaluated the effects of integrating Black Soldier Fly (BSF) frass with inorganic fertilizers on the growth and yield performance of hybrid corn. A field experiment was conducted using six treatments: T1-control, T2- recommended rate of inorganic fertilizer, T3- half rate of inorganic fertilizer, T4- recommended rate plus BSF frass, T5 half rate plus BSF frass, and T6- BSF frass alone. Results showed that T4 consistently recorded the highest values across key parameters, including plant height, ear length and diameter, ear weight, shelling percentage, and grain yield. T2 and T5 also performed significantly well, indicating that partial substitution of synthetic fertilizer with BSF frass can maintain high productivity. Notably, T5 achieved comparable yields to full-rate IOF, offering a cost-effective and environmentally sustainable alternative. While BSF frass alone (T6) significantly improved growth and yield over the control, it was not sufficient to match IOF-inclusive treatments. The computed grain yield ranged from 6.51 tons/ha in the control to 12.82 tons/ha in T2, with T6 showing a 32% yield increase over T1. These findings highlight the agronomic potential of BSF frass as a complementary organic input that enhances nutrient efficiency, supports partial fertilizer replacement, and contributes to sustainable corn production. The use of BSF frass in integrated nutrient management strategies is therefore recommended to improve crop output while reducing chemical input dependency.

* **Corresponding Author:** Edineil T. Dalupang ✉ edineildalupang19@gmail.com

Introduction

Hybrid corn production has become a focal point of global agricultural concerns due to its significant impact on food security, biodiversity, and environmental sustainability. On one hand, hybrid corn varieties are praised for their high yield potential and resistance to pests and diseases, which can help meet the demands of a growing population. However, the widespread adoption of hybrid varieties has raised worries about the loss of traditional maize varieties, which often have unique traits that contribute to genetic diversity. This erosion of genetic resources can leave crops more vulnerable to pests, diseases, and climate change.

Additionally, the reliance on hybrid corn often necessitates the use of chemical fertilizers and pesticides, raising concerns about soil health and water contamination. Critics argue that this model promotes monoculture farming, which can degrade ecosystems and diminish rural livelihoods. As countries grapple with these issues, the need for sustainable practices that balance productivity with ecological and social considerations has become increasingly urgent. Policymakers and agricultural scientists are now advocating for a more integrated approach to corn production that includes the preservation of traditional varieties, organic farming methods, and agro ecological practices to ensure a resilient and sustainable food system for future generations.

In the Philippines, corn is a vital crop that makes a substantial economic contribution and provides a substantial source of income for many farmers. All things considered, corn is significant in the Philippines since it supports the nation's economy, livelihoods, and food security. However, poor soil fertility associated with nutrient depletion, restricted fertilizer use, inadequate insect management, climate change, and socioeconomic and institutional barriers pose challenges to maize's food security and economic contribution.

Adding organic additions to agricultural soils generally conserves natural resources and lessens the need for artificial inorganic fertilizers. After applying organic amendments, soil structure, nutrient composition, and microbiological activity typically improve. This is due to the simple molecules carbohydrates and amino acids included in organic amendments, which support fertility and microbiological activity as well as higher amounts of enzymes released by soil microorganisms.

Organic fertilizers supply the macronutrients required for crop growth and enhance soil microbial activity. Furthermore, secondary nutrients and micronutrients which are essential for the absorption and use of macronutrients are provided by organic fertilizers. To increase and maintain soil fertility, crop yields, and agronomic nutrient use efficiency, a combination of inorganic and organic fertilizer applications has been suggested. Because most organic resources have conflicting uses, like fuel and cattle feed on the farm, most farmers do not apply organic fertilizers, despite their crucial role in restoring natural fertility. Inadequate cultural techniques that result in a suboptimal plant stand and low yield are another limitation that contributes to low production. Low soil fertility is another factor contributing to low plant output. Adding organic amendments to hybrid corn production is one way to increase soil fertility and low yield caused by farming techniques.

Severe soil deterioration is the cause of a sharp drop in corn output. It has been discovered that combining organic and inorganic fertilizers increases soil fertility and raises maize product output and quality. High commercial fertilizer inputs are therefore essential, but they are still costly and out of reach for farmers with limited resources. As a result, BSF frass, which is a by-product of the generation of BSF larvae, can be used as an alternative fertilizer source to help mitigate soil nutrient deficiencies and improve agricultural productivity and food security. The potential of BSF frass to enhance soil fertility, crop output, and plant health has been shown in earlier research.

On the other hand, little is known about how BSF frass fertilizer affects maize growth performance. Even though black soldier fly frass fertilizer (BSFF) is widely acknowledged as a promising and potentially high-quality organic fertilizer, little is known about how it affects maize growth performance, how it works in conjunction with NPK, or how it affects maize production economically.

The research gap in the application of black soldier fly (BSF) frass on hybrid corn production highlights the need for comprehensive studies to better understand its effects on growth, yield, and soil health. While BSF frass is recognized as a nutrient-rich organic fertilizer containing essential macro and micronutrients, there is limited research specifically focused on its application in hybrid corn cultivation. Most existing studies emphasize the general benefits of BSF frass in organic farming; however, detailed investigations into optimal application rates, timing, and methods specific to hybrid corn are lacking. Understanding how BSF frass influences key growth and yield parameters, is crucial for establishing its efficacy as a fertilizer in this context.

Additionally, the interactions between BSF frass and various soil types, as well as its impact on soil microbial communities, remain underexplored. Research is needed to evaluate how BSF frass affects soil fertility and health over time, particularly in relation to nutrient cycling and retention, which are vital for sustaining high yields in hybrid corn. Furthermore, studies examining the long-term effects of BSF frass on crop quality and resistance to pests and diseases could provide valuable insights for farmers looking to improve productivity sustainably.

By addressing these gaps, future research could provide a clearer understanding of the potential of black soldier fly frass as an organic input in hybrid corn production, helping to optimize its use and support sustainable agricultural practices. This knowledge would not only benefit farmers in maximizing their yields but also contribute to broader goals of reducing chemical fertilizer reliance and enhancing environmental sustainability in agriculture.

Sustainable development goals (SDGs) focus on promoting economic growth while ensuring environmental sustainability and social inclusion. One innovative approach to achieving these goals involves utilizing black soldier fly (BSF) larvae as a sustainable protein source for animal feed and organic fertilizer production. The larvae thrive on organic waste, such as agricultural by-products and food scraps, effectively converting them into high-quality protein. When applied to hybrid corn farming, BSF frass— the nutrient-rich residue left after larvae feed—can enhance soil fertility and structure. This organic fertilizer not only improves the growth and yield of hybrid corn but also reduces the reliance on synthetic fertilizers, thereby minimizing environmental pollution. Moreover, by incorporating BSF into the agricultural ecosystem, farmers can reduce waste, increase crop resilience, and contribute to a more sustainable food system. Ultimately, the integration of black soldier fly frass in hybrid corn cultivation represents a viable pathway towards achieving multiple SDGs, including zero hunger (SDG2), responsible consumption and production (SDG 12), and climate action (SDG 13).

Materials and methods

Procurement of seeds and black soldier fly frass

The seeds of yellow hybrid corn (Dekalb 8282S) was purchased from accredited dealer of Dekalb Seed Company and the BSF larvae frass was secured at the Municipal Agriculture Organic Farm of Echague located at Brgy. Babaran, Echague, Isabela.

Soil sampling and analysis

Before the area was prepared, samples of the soil were gathered. A shovel will be used to reach the proper depth, and a zigzag pattern with enough sub-samples will be used. Inert matter was eliminated, the soil was ground up, and it was allowed to air dry. One kilogram of composite soil samples as well as BSF frass were brought to the DA-Bureau of Soils and Water Management Central Office –Quezon City Philippines for analysis. The analysis's findings on the soil's pH and NPK served as the foundation for the fertilizer advice.

Land preparation

Initially, the tractor was used to prepare the area using a disc plow. The weeds were allowed to rot for two weeks. Before planting, the last plowing and harrowing will be done.

Experimental layout and design

Following land preparation, three blocks totaling 364.25 square meters were created, each measuring 5.5 by 23.5 meters and separated by a one-meter alleyway. Six plots, each measuring 3.5 by 4.5 meters and separated by a half-meter alleyway, were further divided into each block. The Randomized Complete Block Design process was used to arrange the treatments.

Experimental treatments

The treatments for the study were the following:

T_1 – Control

T_2 – Recommended Rate of IOF

T_3 – ½ RR IOF

T_4 – RR IOF plus BSF frass

T_5 – ½ RR IOF plus BSF frass

T_6 – BSF frass alone

Construction of furrows and application of fertilizer

Furrows were established after the last harrowing with a distance of 75 cm centimeters apart. The rate of fertilizer base on soil analysis was the fertilizer reference for the study. Ten bags of BSF frass per hectare was mixed together with the basal application of inorganic fertilizer for T_4 and T_5. The inorganic fertilizer for T_2 and T_3, the same as through of the BSF frass for T_6 was done before planting. The fertilizer in all the treatments were applied evenly along the furrows and covered with fine soil to avoid in contact with the seeds.

Planting and replanting

Two seeds per hill were planted with a distance of 25 cm between hills. The seeds were planted using jabber planter and be covered with fine soil to have uniform germination. Replanting of missing hills was done five days after planting. Thinning was done also seven days after planting.

Care and management

Cultivation, side dressing and weeding

Side dressing was done before hilling- up which is 25 days after planting. Hilling-up was done to provide aeration and to control weeds at the same time. Spraying of herbicide was done to remove the weeds between plants.

Crop protection

The occurrence of insect pests was controlled by spraying synthetic chemical insecticide.

Irrigation

The plants were watered as needed.

Harvesting and post-harvest activities

When the corn ear reached the physiological maturity stage when a black layer forms at the grain's attachment point to the cob, the kernels are glazed, and the leaves and husks are dry the crop was harvested. Harvesting of samples was done by plucking the corn ear one by one and placed in plastic bag with tag to avoid intermixing of samples. The harvested corn from each treatment was separately sundried under undisturbed pavement, but the samples were weighed before husk removal and threshing. Samples were threshed by hand to prevent kernel damage. Each sample was promptly labeled to prevent any mixing. The samples were cleaned by winnowing and sundried until 14 % moisture content will be attained. Prior to weighing, the moisture content of the samples was assessed using a moisture meter.

Data gathered

Growth and yield parameters

1. Plant height at 30, 60 and 90 days after planting: The height of the ten randomly selected

representative plants was measured from the base of the plants up to first node of the tassel.

2. Ear weight per plot (Husked): The ears harvested from the 10 sample plants will be weighed as one to obtain the ear weight (husked) per plot.

3. Length and diameter of corn ear: After weighing, the ear length of the sample ear was measured by using foot ruler from end to end and the diameter was measured using the Vernier Caliper.

4. Shelling percentage (Recovery): The shelling percentage was determined after harvest using the formula grain weight divided by ear weight multiply by 100.

5. Grain yield per plot: Grain yield per plot will be collect.

6. Computed seed yield per hectare: The seed yield of the different treatments was computed based on the average yield per plot using the formula:

Yield per Hectare: (Yield per Plot (kg)/ Plot Area (m^2)) × 10,000 m^2

Statistical analysis

The collected data were subjected to statistical analysis using the Analysis of Variance (ANOVA) within a Randomized Complete Block Design (RCBD). Data processing was performed using the Statistical Tool for Agricultural Research (STAR). Treatments that yielded significant results were further analyzed through Tukey's Honestly Significant Difference (HSD) test to identify specific differences between them.

Results and discussion

Plant height

The data presented in Table 1 illustrates the effects of Black Soldier Fly (BSF) frass, applied alone or in combination with inorganic fertilizer, on the plant height of corn at 30, 60, and 90 days after sowing (DAS).

Table 1. Plant height (cm) of Corn Applied with BSF Frass

Treatments	Plant height (cm)		
	30 DAS	60 DAS	90 DAS
T_1 Control	50.00 b	254.37 b	256.57 b
T_2 Recommended rate of IOF	77.50a	281.63 a	283.77 a
T_3 ½ RR IOF	75.47a	276.47 a	278.0 a
T_4 RR IOF plus BSF frass	78.67a	282.50 a	284.03 a
T_5 ½ RR IOF plus BSF frass	77.53a	277.23 a	279.37 a
T_6 BSF frass alone	53.03b	257.77 b	260.77 b

Means with common letter/s are not significantly different with each other using HSD Test

The control treatment (T1), which received no fertilization, consistently showed the lowest plant heights across all growth stages, with 50.00 cm, 254.37 cm, and 256.57 cm at 30, 60, and 90 DAS, respectively. This highlights the necessity of nutrient supplementation for optimal corn growth. Meanwhile, T6 (BSF frass alone) performed slightly better than the control but remained significantly lower than treatments with inorganic fertilizer, indicating that while BSF frass contributes to plant growth, it cannot fully meet the nutrient demands of corn on its own (Mochoge *et al.*, 2020).

The most notable results were observed in T4 (recommended rate of inorganic fertilizer [IOF] plus BSF frass), which produced the tallest plants at each observation period—78.67 cm, 282.50 cm, and 284.03 cm—demonstrating a synergistic effect when BSF frass is combined with IOF. This supports findings by Beesigamukama *et al.* (2020), who reported improved nutrient uptake and plant vigor due to the bioavailable nutrients and beneficial microbial populations present in BSF frass. Additionally, treatments T2 (full IOF) and T5 (half IOF plus BSF frass) yielded comparable plant heights, indicating that integrating BSF frass with a reduced IOF rate can sustain plant growth similar to full fertilization. This has significant implications for reducing reliance on chemical fertilizers, lowering input costs, and promoting sustainable agriculture (Schiavone *et al.*, 2022).

Overall, the integration of BSF frass with inorganic fertilizer (particularly in T4 and T5) resulted in superior plant performance, while BSF frass alone showed limited but positive effects compared to the unfertilized control. These findings align with studies emphasizing the benefits of integrated nutrient management for crop productivity and soil health (Diacono and Montemurro, 2010; Lalander *et al.*, 2015). The study underscores the potential of BSF frass as a complementary organic input that enhances nutrient efficiency and contributes to more sustainable and resilient farming systems.

Corn ear length and ear diameter

Table 2 presents the effects of different fertilizer treatments, including BSF frass, on the length and diameter of hybrid corn ears. The results clearly show that fertilization significantly influenced ear development, with substantial differences among treatments in both length and diameter.

Table 2. Length and diameter of hybrid corn applied with BSF frass

Treatments	Length of corn ear (cm)	Diameter of corn ear (cm)
T_1 Control	13.58 d	4.25 c
T_2 Recommended Rate of IOF	18.81 a	4.83 a
T_3 ½ RR IOF	17.67 b	4.65 ab
T_4 RR IOF plus BSF frass	18.55 a	4.81 a
T_5 ½ RR IOF plus BSF frass	17.48 b	4.67 ab
T_6 BSF Frass alone	15.23 c	4.47 b

Means with common letter/s are not significantly different with each other using HSD Test.

The control treatment (T1), which did not receive any fertilizer, consistently produced the shortest ears (13.58 cm) and the smallest diameter (4.25 cm). This emphasizes the critical role of nutrient availability in supporting reproductive development in corn. In contrast, T2 (Recommended Rate of Inorganic Fertilizer or IOF) and T4 (RR IOF plus BSF Frass) yielded the longest corn ears at 18.81 cm and 18.55 cm, respectively, and also had the greatest ear diameters (4.83 cm and 4.81 cm, respectively). These results demonstrate that combining organic and inorganic fertilizers can be as effective as using the full recommended rate of IOF alone in maximizing ear size. Similar findings were reported by Beesigamukama *et al.* (2020), who highlighted the effectiveness of BSF frass in enhancing nutrient uptake and plant performance when integrated with conventional fertilization.

Interestingly, T5 (½ RR IOF plus BSF frass) and T3 (½ RR IOF) produced intermediate results, with ear lengths of 17.48 cm and 17.67 cm, and diameters of 4.67 cm and 4.65 cm, respectively. This suggests that even with reduced synthetic fertilizer inputs, the use of BSF frass can help maintain favorable growth and yield traits—supporting sustainable fertilizer management practices. The slight improvement of T5 over T3 in terms of ear diameter may be attributed to the contribution of organic matter and micronutrients from BSF frass, which enhance nutrient retention and soil biological activity (Mochoge *et al.*, 2020; Diacono and Montemurro, 2010).

T6 (BSF frass alone) also showed improvements over the unfertilized control, with ear length and diameter reaching 15.23 cm and 4.47 cm, respectively. While significantly lower than treatments involving IOF, these results confirm that BSF frass alone provides some nutritional benefit, albeit insufficient to match the performance of IOF-based treatments. This aligns with observations by Lalander *et al.* (2015) that BSF frass serves best as a supplement rather than a sole nutrient source for high-demand crops like corn.

In summary, the data underscore the synergistic benefits of combining BSF frass with IOF, especially at full or even half rates, to improve corn ear development. These findings reinforce the value of integrated nutrient management approaches, where organic inputs like BSF frass enhance the efficiency of inorganic fertilizers while promoting more sustainable and cost-effective farming practices.

Weight of corn without husk

Table 3 presents the weight of corn ears without husk (kg per 9 m^2) under various fertilizer treatments, revealing the significant impact of nutrient management on corn productivity.

Table 3. Weight of corn ears without husk (kg/9 m^2)

Treatments		Weight of corn ear (kg)
T_1	Control	11.06 b
T_2	Recommended Rate of IOF	18.74 a
T_3	½ RR IOF	16.40 a
T_4	RR IOF plus BSF frass	18.04 a
T_5	½ RR IOF plus BSF frass	16.52 a
T_6	BSF frass alone	12.65 b

Means with common letter/s are not significantly different with each other using HSD Test.

The control treatment (T1) yielded the lowest weight at 11.06 kg, indicating poor performance in the absence of fertilization. Similarly, T6 (BSF frass alone) showed limited effectiveness with a slightly higher weight of 12.65 kg, though still significantly lower than treatments involving inorganic fertilizers. These results highlight that while BSF frass contributes organic matter and nutrients beneficial to soil health and crop growth, it is insufficient as a standalone fertilizer for maximizing yield in high-nutrient-demanding crops like corn (Mochoge *et al.*, 2020; Lalander *et al.*, 2015).

In contrast, all treatments containing inorganic fertilizers—T2 (Recommended Rate of IOF), T3 (½ RR IOF), T4 (RR IOF + BSF frass), and T5 (½ RR IOF + BSF frass)—produced significantly higher weights ranging from 16.40 to 18.74 kg. The highest ear weight was recorded in T2 (18.74 kg), followed closely by T4 (18.04 kg), suggesting that full inorganic fertilization, whether alone or in combination with BSF frass, optimally supports ear development. Interestingly, T5 (16.52 kg) and T3 (16.40 kg), which used only half the recommended rate of IOF, still achieved statistically comparable yields to full-rate treatments. This indicates that supplementing reduced IOF with BSF frass (T5) can maintain productivity, supporting the idea that organic amendments can partially substitute synthetic inputs without compromising yield (Beesigamukama *et al.*, 2020).

These findings reinforce the efficacy of integrated nutrient management (INM) strategies in corn production. INM not only sustains yield but also improves nutrient use efficiency and promotes soil health over time (Diacono and Montemurro, 2010). Moreover, this approach supports economic and environmental sustainability by reducing reliance on costly chemical fertilizers while recycling organic waste materials like BSF frass, which are rich in nutrients and beneficial microorganisms (Schiavone *et al.*, 2022).

In summary, Table 3 underscores the importance of combining BSF frass with inorganic fertilizers to achieve high corn yield. While BSF frass alone provides moderate improvements over no fertilization, its integration with IOF—especially in reduced quantities—offers a practical, sustainable approach to maintaining high productivity with minimized environmental impact.

Shelling percentage

Table 4 shows the shelling percentage (%) of hybrid corn under various fertilization treatments, indicating the efficiency with which kernels are recovered from the cob. Shelling percentage is a critical postharvest parameter, as it reflects not only kernel development but also the effectiveness of nutrient management in promoting grain fill.

The control treatment (T1), which did not receive any form of fertilization, recorded the lowest shelling percentage at 53.35%, significantly below all other treatments. This suggests that nutrient deficiency limited proper grain development, leading to a lower proportion of usable kernels per ear. In contrast, all other treatments, including those with full and half rates of inorganic fertilizer (IOF) and those supplemented with Black Soldier Fly (BSF) frass, had statistically similar and higher shelling percentages, ranging from 61.10% to 63.30%.

Among these, the highest value was observed in T4 (RR IOF + BSF frass) at 63.30%, indicating a potential synergistic effect of integrating organic and inorganic sources. The enhanced performance in T4 could be attributed to the improved nutrient uptake and soil microbial activity promoted by the combination of IOF and BSF frass, leading to more complete kernel development (Beesigamukama *et al.*, 2020; Lalander *et al.*, 2015). This reinforces the value of integrated nutrient management (INM) in improving both yield and postharvest quality.

Table 4. Shelling percentage (%)

Treatments	Shelling percentage (%)
T_1 Control	53.35 b
T_2 Recommended rate of IOF	61.60 a
T_3 ½ RR IOF	61.18 a
T_4 RR IOF plus BSF frass	63.30 a
T_5 ½ RR IOF plus BSF frass	61.35 a
T_6 BSF frass alone	61.10 a

Means with common letter/s are not significantly different with each other using HSD Test.

Interestingly, even T6 (BSF frass alone) achieved a high shelling percentage of 61.10%, not significantly different from the IOF-based treatments. This suggests that while BSF frass alone may not maximize yield components such as biomass or ear weight, it supports good kernel-to-cob ratios—possibly due to improved soil organic matter and beneficial microbes that enhance nutrient cycling (Mochoge *et al.*, 2020; Diacono and Montemurro, 2010).

These results demonstrate that both full and partial fertilization strategies, especially when combined with BSF frass, can enhance postharvest efficiency without compromising quality.

From a sustainability perspective, treatments such as T5 (½ RR IOF + BSF frass) offer promising alternatives for maintaining high shelling efficiency while reducing chemical fertilizer use and leveraging organic waste as a productive input (Schiavone *et al.*, 2022).

Grain yield per net plot

Table 5 presents the grain yield per net plot (kg per 9 m²) of Hybrid corn under various fertilizer treatments, revealing significant differences in productivity depending on the fertilization strategy used. The control treatment (T1), which did not receive any fertilizer, yielded only 5.86 kg, the lowest among all treatments. This confirms the critical role of nutrient inputs in supporting grain filling and final yield. T6 (BSF frass alone) performed moderately better at 7.73 kg, indicating that BSF frass, while insufficient on its own for maximum yield, provides essential nutrients that support improved performance over unfertilized controls. These findings are consistent with previous studies emphasizing the nutrient content and soil-enhancing properties of BSF frass (Mochoge *et al.*, 2020; Lalander *et al.*, 2015).

Table 5. Grain yield per net plot (kg/9 m²)

Treatments	Grain yield per net plot (kg/9 m²)
T_1 Control	5.86 d
T_2 Recommended rate of IOF	11.54 a
T_3 ½ RR IOF	10.04 b
T_4 RR IOF plus BSF frass	11.42 a
T_5 ½ RR IOF plus BSF frass	10.13 b
T_6 BSF frass alone	7.73 c

Means with common letter/s are not significantly different with each other using HSD Test.

The highest yields were recorded in T2 (Recommended Rate of Inorganic Fertilizer, IOF) and T4 (RR IOF + BSF frass) at 11.54 kg and 11.42 kg, respectively, with no significant difference between them. This suggests that the addition of BSF frass to a full dose of IOF does not negatively affect yield but rather offers potential soil health benefits without compromising productivity. These results demonstrate the compatibility and potential synergy of integrating BSF frass with conventional fertilization (Beesigamukama *et al.*, 2020).

Interestingly, T3 (½ RR IOF) and T5 (½ RR IOF + BSF frass) yielded 10.04 kg and 10.13 kg, respectively—values that were statistically similar to each other but lower than full IOF treatments. However, the slight yield increase in T5 over T3 indicates that BSF frass can partially compensate for reduced synthetic fertilizer input, offering a viable strategy for reducing dependence on chemical fertilizers while sustaining acceptable yield levels (Diacono and Montemurro, 2010).

The results clearly illustrate the benefit of integrated nutrient management (INM), particularly the use of BSF frass in combination with reduced rates of IOF, as seen in T5. This approach supports the dual goals of economic sustainability—by lowering input costs—and environmental stewardship—by reducing synthetic fertilizer use and recycling organic waste (Schiavone *et al.*, 2022). While BSF frass alone (T6) cannot match the yields of IOF-based treatments, its ability to improve grain yield over the control suggests it plays an important supplemental role.

Grain yield

Table 6 illustrates the computed yield of hybrid corn (ton/ha) adjusted to 14% moisture content (MC) under different fertilization treatments. The control treatment (T1), which received no fertilization, yielded the lowest at 6.51 tons/ha, setting the baseline for comparison. The application of BSF frass alone (T6) increased yield to 8.59 tons/ha, representing a 32% increase over the unfertilized control. This suggests that BSF frass contributes significantly to yield improvement, likely due to its nutrient content and soil-enhancing properties, although it is not sufficient to match the output achieved with inorganic inputs (Mochoge *et al.*, 2020; Lalander *et al.*, 2015).

The highest yields were observed in T2 (Recommended Rate of Inorganic Fertilizer) and T4 (RR IOF plus BSF frass), with 12.82 and 12.69 tons/ha, respectively. These figures translate to 97% and 95% increases, respectively, compared to the control. The lack of significant difference between T2 and T4 indicates that the combination of IOF and BSF frass performs as well as IOF alone in maximizing yield, while likely offering additional benefits such as improved soil structure and long-term fertility (Beesigamukama *et al.*, 2020; Diacono and Montemurro, 2010).

Treatments with half the recommended rate of IOF (T3) and its combination with BSF frass (T5) produced 11.15 and 11.26 tons/ha, respectively, reflecting yield increases of 71% and 73% over the control. These results underscore that reducing IOF input by half, particularly when supplemented with BSF frass, can still result in high productivity, closely approaching full-rate treatments. The slight yield advantage of T5 over T3 further demonstrates the complementary role of BSF frass in nutrient delivery and soil microbial enhancement, which boosts the efficiency of reduced chemical inputs (Schiavone *et al.*, 2022).

Table 6. Computed yield (ton/ha) adjusted to 14% MC

Treatments	Computed yield (ton/ha)
T_1 Control	6.51
T_2 Recommended rate of IOF	12.82
T_3 ½ RR IOF	11.15
T_4 RR IOF plus BSF frass	12.69
T_5 ½ RR IOF plus BSF frass	11.26
T_6 BSF frass alone	8.59

Means with common letter/s are not significantly different with each other using HSD Test.

The findings strongly advocate for integrated nutrient management (INM), where BSF frass is utilized alongside inorganic fertilizers to achieve near-maximum yields while reducing dependence on costly and environmentally taxing chemical fertilizers. This approach not only supports agricultural productivity but also promotes resource recycling and soil sustainability, key tenets of climate-smart and regenerative farming systems.

Conclusion

The combination of Black Soldier Fly (BSF) frass with the recommended rate of inorganic fertilizer (T4) produced the tallest corn plants across all growth stages, showing the benefit of integrated fertilization on vegetative growth. Treatments with half the inorganic fertilizer (IOF) and BSF frass (T5) performed similarly to the full IOF rate (T2), indicating that organic supplementation can partly replace chemical inputs. Although BSF frass alone (T6) improved plant height over the control, it was less effective than IOF treatments, highlighting its role as a supplemental input. T4 also produced corn ears with lengths and diameters comparable to T2, suggesting a synergistic effect of organic-inorganic integration on reproductive traits. T3 and T5 achieved similar ear quality, supporting reduced IOF use when combined with frass. Ear weight was highest in T2 and T4, while T3 and T5 showed comparable yields, indicating frass can offset lower IOF levels. All fertilized treatments increased shelling percentages over the control, with T4 being the highest. Grain yield peaked in T2 and T4, but T3 and T5 also maintained strong yields. T6 improved yield by 32% over the control, confirming BSF frass as a valuable organic amendment for sustainable and cost-effective corn production.

References

Alattar MA, Alattar FN, Popa R. 2016. Effects of microaerobic fermentation and black soldier fly larvae food scrap processing residues on the growth of corn plants (*Zea mays*). Plant Sci. Today **3**, 57–62.

Anning DK, Ghanney P, Qiu H, Abalori TA, Zhang C, Luo C. 2023. Stimulation of soil organic matter fractions by maize straw return and nitrogen fertilization in the Loess Plateau of Northwest China. Appl. Soil Ecol. **191**, 105061.

Bedoic R, Cosic B, Duic N. 2019. Technical potential and geographic distribution of agricultural residues, co-products and byproducts in the European Union. Sci. Total Environ. **686**, 568–579.

Bohm K, Hatley GA, Robinson BH, Gutierrez-Gines MJ. 2022. Black soldier fly-based bioconversion of biosolids creates high-value products with low heavy metal concentrations. Resour. Conserv. Recycl. **180**, 106149.

Bonviu F. 2014. The European economy: from a linear to a circular economy. Romanian J. Eur. Aff. **14**, 78–91.

Calabrò PS, Fazzino F, Sidari R, Zema DA. 2020. Optimization of orange peel waste ensiling for sustainable anaerobic digestion. Renew. Energy **154**, 849–862.

Camenzind T, Hattenschwiler S, Treseder KK, Lehmann A, Rillig MC. 2018. Nutrient limitation of soil microbial processes in tropical forests. Ecol. Monogr. **88**, 4–21.

Deneve S, Hofman G. 1996. Modelling N mineralization of vegetable crop residues during laboratory incubations. Soil Biol. Biochem. **28**, 1451–1457.

Deneve S, Pannier J, Hofman G. 1996. Temperature effects on C and N-mineralization from vegetable crop residues. Plant Soil **181**, 25–30. https://doi.org/10.1007/BF00011288

Diener S, Zurbrugg C, Tockner K. 2009. Conversion of organic material by black soldier fly larvae: establishing optimal feeding rates. Waste Manage. Res. **27**, 603–610.

Ermolaev E, Lalander C, Vinnerås B. 2019. Greenhouse gas emissions from small-scale fly larvae composting with *Hermetia illucens*. Waste Manag. **96**, 65–74.

Fontaine S, Mariotti A, Abbadie L. 2003. The priming effect of organic matter: a question of microbial competition? Soil Biol. Biochem. **35**, 837–843.

Gao C, El-Sawah AM, Ali DFI, Hamoud YA, Shaghaleh H, Sheteiwy MS. 2020. The integration of bio and organic fertilizers improve plant growth, grain yield, quality and metabolism of hybrid maize (*Zea mays* L.). Agronomy **10**, 319.

Gebremikael MT, Ranasinghe A, Hosseini PS, Laboan B, Sonneveld E, Pipan M. 2020. How do novel and conventional agri-food wastes, co-products and by-products improve soil functions and soil quality? Waste Manage. **113**, 132–144.

Gebremikael MT, Steel H, Bert W, Maenhout P, Sleutel S, De Neve S. 2015. Quantifying the contribution of entire free-living nematode communities to carbon mineralization under contrasting C and N availability. PLoS ONE **10**, e0136244.

Gebremikael MT, Wickeren NV, Hosseini PS, De Neve S. 2022. The impacts of black soldier fly frass on nitrogen availability, microbial activities, C sequestration, and plant growth. Front. Sustain. Food Syst. **6**, 795950.

Gold M, Tomberlin JK, Diener S, Zurbrugg C, Mathys A. 2018. Decomposition of biowaste macronutrients, microbes, and chemicals in black soldier fly larval treatment: a review. Waste Manage. **82**, 302–318.

Gustavsson J, Cederberg C, Sonesson U. 2011. Global food losses and food waste: extent, causes and prevention. International Congress SAVE FOOD! Rome: Food and Agricultural Organization of the United Nations.

Halloran A, Roos N, Eilenberg J, Cerutti A, Bruun S. 2016. Life cycle assessment of edible insects for food protein: a review. Agron. Sustain. Dev. **36**, 57.

Hemati A, Aliasgharzad N, Khakvar R, Khoshmanzar E, Asgari Lajayer B, Van Hullebusch ED. 2021. Role of lignin and thermophilic lignocellulolytic bacteria in the evolution of humification indices and enzymatic activities during compost production. Waste Manag. **119**, 122–134.

Houben D, Daoulas G, Dulaurent AM. 2021. Assessment of the short-term fertilizer potential of mealworm frass using a pot experiment. Front. Sustain. Food Syst. **5**, 714596.

Houben D, Daoulas G, Faucon MP, Dulaurent AM. 2020. Potential use of mealworm frass as a fertilizer: impact on crop growth and soil properties. Sci. Rep. **10**, 4659.

Joergensen RG. 1996. The fumigation-extraction method to estimate soil microbial biomass: calibration of the k(EC) value. Soil Biol. Biochem. **28**, 25–31.

Kaczor M, Bulak P, Proc-Pietrycha K, Kirichenko-Babko M, Bieganowski A. 2022. The variety of applications of *Hermetia illucens* in industrial and agricultural areas—review. Biology **12**, 25.

Kuzyakov Y. 2010. Priming effects: interactions between living and dead organic matter. Soil Biol. Biochem. **42**, 1363–1371.

Laboan B. 2018. Investigating the effects of novel bio fertilizers on soil and plant health. Ghent: Ghent University.

Lalander C, Nordberg A, Vinneras B. 2018. A comparison in product-value potential in four treatment strategies for food waste and faeces—assessing composting, fly larvae composting and anaerobic digestion. Gcb Bioenergy **10**, 84–91.

Liu H, Li S, Qiang R, Lu E, Li C, Zhang J, Gao Q. 2022. Response of soil microbial community structure to phosphate fertilizer reduction and combinations of microbial fertilizer. Front. Environ. Sci. **10**, 899727.

Lopes IG, Yong JW, Lalander C. 2022. Frass derived from black soldier fly larvae treatment of biodegradable wastes: A critical review and future perspectives. Waste Manag. **142**, 65–76.

Madibana MJ, Mwanza M, Lewis BR, Fouche CH, Toefy R, Mlambo V. 2020. Black soldier fly larvae meal as a fishmeal substitute in juvenile dusky kob diets: Effect on feed utilization, growth performance, and blood parameters. Sustainability **12**, 9460.

Mertenat A, Diener S, Zurbrugg C. 2019. Black soldier fly biowaste treatment—assessment of global warming potential. Waste Manag. **84**, 173–181.

Moller K, Müller T. 2012. Effects of anaerobic digestion on digestate nutrient availability and crop growth: A review. Eng. Life Sci. **12**, 242–257.

Mwaniki Z, Shoveller AK, Huber LA, Kiarie EG. 2020. Complete replacement of soybean meal with defatted black soldier fly larvae meal in Shaver White hens feeding program (28–43 wks of age): Impact on egg production, egg quality, organ weight, and apparent retention of components. Poult. Sci. **99**, 959–965.

Nagarajkumar M, Bhaskaran R, Velazhahan R. 2004. Involvement of secondary metabolites and extracellular lytic enzymes produced by *Pseudomonas fluorescens* in inhibition of *Rhizoctonia solani*, the rice sheath blight pathogen. Microbiol. Res. **159**, 73–81.

Pang W, Hou D, Chen J, Nowar EE, Li Z, Hu R, Tomberlin JK, Yu Z, Li Q, Wang S. 2020. Reducing greenhouse gas emissions and enhancing carbon and nitrogen conversion in food wastes by the black soldier fly. J. Environ. Manag. **260**, 110066.

Poveda J, Jimenez-Gomez A, Saati-Santamaria Z, Usategui-Martin R, Rivas R, Garcia-Fraile P. 2019. Mealworm frass as a potential biofertilizer and abiotic stress tolerance-inductor in plants. Appl. Soil Ecol. **142**, 110–122.

Poveda J. 2021. Insect frass in the development of sustainable agriculture: A review. Agronomy Sustain. Dev. **41**, 5.

Prasad M. 2009. A literature review on the availability of nitrogen from compost in relation to the nitrate regulations SI 378 of 2006. Wexford, Ireland: Environmental Protection Agency.

Quilliam RS, Nuku-Adeku C, Maquart P, Little D, Newton R, Murray F. 2020. Integrating insect frass biofertilisers into sustainable peri-urban agro-food systems. J. Insects Food Feed **6**, 315–322.

Rodriguezkabana R, Godoy G, Morganjones G, Shelby RA. 1983. The determination of soil chitinase activity: Conditions for assay and ecological studies. Plant Soil **75**, 95–106.

Rosmiati M, Nurjanah KA, Suantika G, Putra RE. 2017. Application of compost produced by bioconversion of coffee husk by black soldier fly larvae (*Hermetia illucens*) as solid fertilizer to lettuce (*Lactuca sativa* var. *crispa*): Impact to growth. Proc. Int. Conf. Green Tech. **8**, 38–44.

Rossner H. 1991. Bestimmung der Chitinase-Aktivität. In: Bodenbiologische Arbeitsmethoden. In: Schinner F, Ohlinger R, Kandeler E (eds). Berlin: Springer, pp. 66–70.

Rout GR. 2006. Effect of auxins on adventitious root development from single node cuttings of *Camellia sinensis* (L.) Kuntze and associated biochemical changes. Plant Growth Regul. **48**, 111–117.

Ruiz B, Flotats X. 2014. Citrus essential oils and their influence on the anaerobic digestion process: An overview. Waste Manage. **34**, 2063–2079.

Rummel PS, Beule L, Hemkemeyer M, Schwalb SA, Wichern F. 2021. Black soldier fly diet impacts soil greenhouse gas emissions from frass applied as fertilizer. Front. Sustain. Food Syst. **5**, 709993.

Sarajuoghi M, Ardakani MR, Nurmohammadi G, Kashani A, Rejali F, Mafakheri S. 2012. Response of yield and yield components of maize (*Zea mays* L.) to different biofertilizers and chemical fertilizers. Am.-Eurasian J. Agric. Environ. Sci. **12**, 315–320.

Setti L, Francia E, Pulvirenti A, Gigliano S, Zaccardelli M, Pane C. 2019. Use of black soldier fly (*Hermetia illucens* (L.), Diptera: Stratiomyidae) larvae processing residue in peat-based growing media. Waste Manage. **95**, 278–288.

Sharp RG. 2013. A review of the applications of chitin and its derivatives in agriculture to modify plant-microbial interactions and improve crop yields. Agronomy **3**, 757–793.

Shi J, Zhou H, Xu M, Zhang Q, Li J, Wang J. 2023. Fertilization highly increased the water use efficiency of spring maize in dryland of northern China: A meta-analysis. Agronomy **13**, 1331.

Siddiqui SA, Ristow B, Rahayu T, Putra NS, Yuwono NW, Nisa K, Mategeko B, Smetana S, Saki M, Nawaz A. 2022. Black soldier fly larvae (BSFL) and their affinity for organic waste processing. Waste Manag. **140**, 1–13.

Sleutel S, De Neve S, Roibas MRP, Hofman G. 2005. The influence of model type and incubation time on the estimation of stable organic carbon in organic materials. Eur. J. Soil Sci. **56**, 505–514.

Smetana S, Spykman R, Heinz V. 2021. Environmental aspects of insect mass production. J. Insects Food Feed **7**, 553–571.

Tan JKN, Lee JTE, Chiam ZY, Song S, Arora S, Tong YW. 2021. Applications of food waste-derived black soldier fly larval frass as incorporated compost, side-dress fertilizer and frass-tea drench for soilless cultivation of leafy vegetables in biochar-based growing media. Waste Manage. **130**, 155–166.

Team RC. 2019. R: A Language and Environment for Statistical Computing, 3.5.3 Edn. Vienna: R Foundation for Statistical Computing.

Van Huis A. 2020. Insects as food and feed, a new emerging agricultural sector: A review. J. Insects Food Feed **6**, 27–44.

Vance ED, Brookes PC, Jenkinson DS. 1987. Microbial biomass measurements in forest soils – the use of the chloroform fumigation incubation method in strongly acid soils. Soil Biol. Biochem. **19**, 697–702.

Watson C, Preißing T, Wichern F. 2021a. Plant nitrogen uptake from insect frass is affected by the nitrification rate as revealed by urease and nitrification inhibitors. Front. Sustain. Food Syst. **5**, 721840.